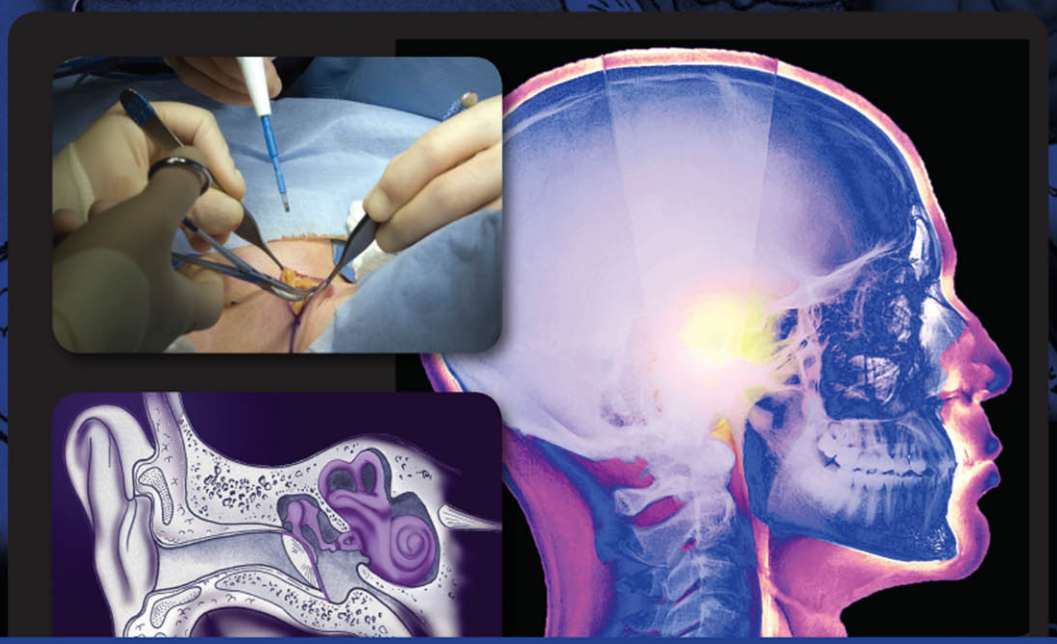
CURRENT Diagnosis & Treatment



OTOLARYNGOLOGY Head and Neck Surgery

third edition

ANIL K. LALWANI

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CURRENT
Diagnosis & Treatment in Otolaryngology—Head & Neck Surgery

THIRD EDITION

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Mc Graw Hill Medical

New York Chicago San Francisco Lisbon London Madrid Mexico City
Milan New Delhi San Juan Seoul Singapore Sydney Toronto

ISBN: 978-0-07-162768-9

MHID: 0-07-162768-5

The material in this eBook also appears in the print version of this title: ISBN: 978-0-07-162439-8,
MHID: 0-07-162439-2.

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Dedication

To my parents, Madan and Gulab, for giving me life;
To my in-laws, Rikhab and Ratan, for adding to my life;
To my wife, Renu, who is my life, And, to my children,
Nikita and Sahil, who show me how to enjoy life.

This book is specially dedicated to all of the extraordinarily gifted and generous teachers in Otolaryngology—Head and Neck Surgery who provide inspirational leadership and serve as role models for the next generation. I would like to express my great appreciation for my own mentors and their spouses for their incredible impact on our lives: Roger and Marianna Boles, Robert and Janet Schindler, Robert and Laurie Jackler, and Noel and Baukje Cohen.

Finally, I am deeply indebted to George and Lori Hall, Susan and Bernie Mendik, Susan Spencer, and Marica and Jan Vilcek for their support and commitment to excellence in Otolaryngology.

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Preface

Otolaryngology-Head & Neck Surgery is a unique subspecialty in medicine that deals with medical and surgical management of disorders affecting the ear, nose, throat, and the neck; the care of the senses including smell, taste, balance and hearing fall under its domain. As a specialty, it interfaces with other medical and surgical subspecialties including allergy and immunology, endocrinology, gastroenterology, hematology, neurology, neurosurgery, oncology, ophthalmology, pediatrics, plastic and reconstructive surgery, pulmonology, radiation oncology, rehabilitation medicine, rheumatology, thoracic surgery, among others. Further, the specialty encompasses the care of the young and the old, man and woman, as well as benign and malignant diseases.

Symptoms and diseases affecting the ear, nose, throat, and neck are common and commonly lead to patients seeking medical care. These include sinusitis, upper respiratory tract infections, hoarseness, balance disturbance, hearing loss, dysphagia, snoring, tonsillitis, ear infections, thyroid disorders, head and neck cancer and ear wax. In this updated third edition of Current Diagnosis & Treatment in Otolaryngology-Head & Neck Surgery, these and many other diseases are covered in crisp and concise manner. Striking just the right balance between comprehensiveness and convenience, it emphasizes the practical features of clinical diagnosis and patient management while providing a comprehensive discussion of pathophysiology and relevant basic and clinical science. With its consistent formatting chapter by chapter, this text makes it simple to locate the practical information you need on diagnosis, testing, disease processes, and up-to-date treatment and management strategies. The book will be of interest to both otolaryngologists as well as all of the medical and surgical specialties and related disciplines that treat patients with head and neck disorders.

OUTSTANDING FEATURES

- Comprehensive review of basic sciences relevant to otolaryngology
- Concise, complete, and accessible clinical information that is up-to-date
- Discussion of both medical and surgical management of otolaryngologic disorders
- Thorough radiology chapter with more than 150 images
- Inclusion of the usual and the unusual diseases of the head and neck
- More than 400 figures to better illustrate and communicate essential points
- Organization by anatomic region to facilitate quick identification of relevant material

INTENDED AUDIENCE

With its comprehensive review of the sciences and the clinical practice of otolaryngology-head & neck surgery, this second edition will be invaluable for medical students, housestaff, physicians of all specialties, nurses, physician assistants and ancillary health care personnel. The book has been designed to meet the clinician's need for an immediate refresher in the clinic as well as to serve as an accessible text for thorough review of the specialty for the boards. The concise presentation is ideally suited for rapid acquisition of information by the busy practitioner.

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Anatomy

1

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The anatomy of the head and neck is rich in complexity as it is populated with motor and sensory organs, cranial nerves, major arterial and venous structures in a compact three dimensional space. This chapter provides a broad and concise overview to familiarize the novice and yet detailed enough to serve as a reference for the more knowledgeable clinician.

FACE

Muscles

The muscles of facial expression develop from the second branchial arch and lie within the skin of the scalp, face, and neck (Figure 1–1).

A. Occipitofrontalis Muscle

The occipitofrontalis muscle, which lies in the scalp, extends from the superior nuchal line in the back to the skin of the eyebrows in the front. It allows for the movement of the scalp against the periosteum of the skull and also serves to raise the eyebrows.

B. Orbicularis Oculi Muscle

The orbicularis oculi muscle lies in the eyelids and also encircles the eyes. It helps to close the eye in the gentle movements of blinking or in more forceful movements, such as squinting. These movements help express tears and move them across the conjunctival sac to keep the cornea moist.

C. Orbicularis Oris Muscle

The orbicularis oris muscle encircles the opening of the mouth and helps to bring the lips together to keep the mouth closed.

D. Buccinator Muscle

The buccinator muscle arises from the pterygomandibular raphe in the back and courses forward in the cheek to blend into the orbicularis oris muscle in the lips. It helps to compress the cheek against the teeth and thus empties food from the vestibule of the mouth during chewing. In addition, it is used while playing musical instruments and performing other actions that require the controlled expression of air from the mouth.

E. Platysma Muscle

The platysma muscle extends from the skin over the mandible through the superficial fascia of the neck into the skin of the upper chest, helping to tighten this skin and also to depress the angles of the mouth. Although lying primarily in the neck, it is grouped with the muscles of facial expression.

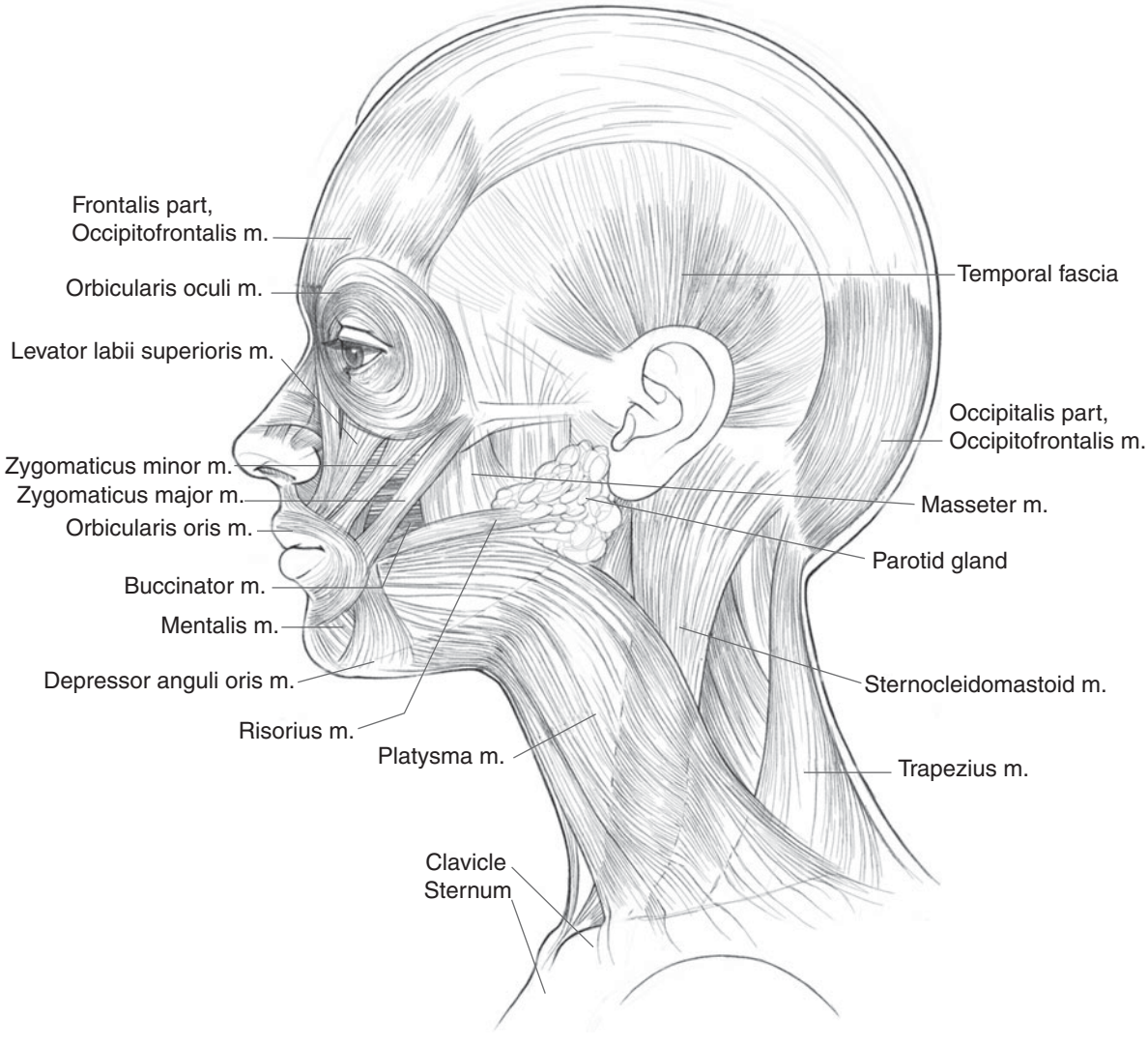
Arteries

The blood supply of the face is through branches of the facial artery (Figure 1–2). After arising from the external carotid artery in the neck, the facial artery passes deep to the submandibular gland and crosses the mandible in front of the attachment of the masseter muscle. It takes a tortuous course across the face and travels up to the medial angle of the eye, where it anastomoses with branches of the ophthalmic artery. It gives labial branches to the lips, of which the superior labial artery enters the nostril to supply the vestibule of the nose.

The occipital, posterior auricular, and superficial temporal arteries supply blood to the scalp. They all arise from the external carotid artery. The superficial temporal artery gives a branch, the transverse facial artery, which courses through the face parallel to the parotid duct.

Veins

The superficial temporal and maxillary veins join within the substance of the parotid gland to form the retromandibular vein (Figure 1–3). The facial vein joins the anterior division of the retromandibular vein to drain into the internal jugular vein. Additional details about the venous drainage pattern of the scalp and face are provided in the discussion of the veins of the neck. The facial vein communicates with both the pterygoid venous plexus and the veins in the orbit. Each of these has connections to the cavernous sinus, thus allowing infections to spread from the face into the cranium.



▲ **Figure 1–1.** Muscles of the face.

Innervation

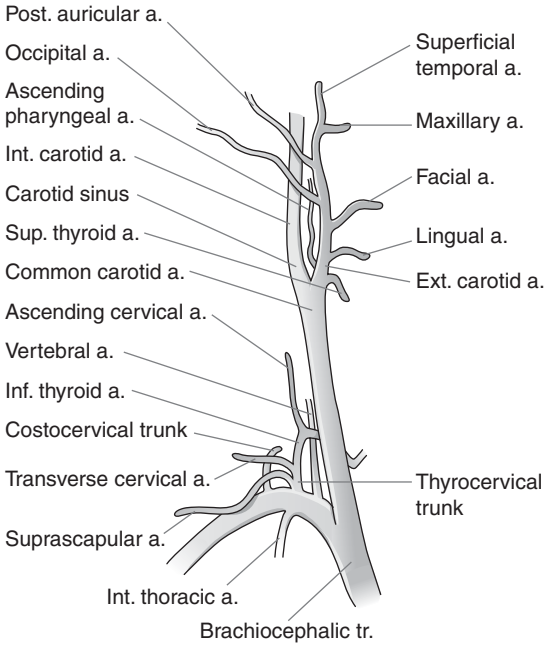
A. Sensory Innervation

The sensory innervation of the face is through terminal branches of the trigeminal nerve (V) (Figure 1–4). Two imaginary lines that split the eyelids and the lips help to approximately demarcate the sensory distribution of the three divisions of the trigeminal nerve.

In addition to the skin of the face, branches of the trigeminal nerve (V) are also responsible for carrying sensation from deeper structures of the head, including the eye, the paranasal sinuses, the nose, and the mouth. The details of this distribution are discussed with the orbit and the pterygopalatine and infratemporal fossae.

1. Ophthalmic division of the trigeminal nerve—The ophthalmic division of the trigeminal nerve (V1) carries sensation from the upper eyelid, the skin of the forehead, and the skin of the nose. Its cutaneous branches, from lateral to medial, are the lacrimal, supraorbital, supratrochlear, and nasal nerves.

2. Maxillary division of the trigeminal nerve—The maxillary division of the trigeminal nerve (V2) carries sensation from the lower eyelid, the upper lip, and the face up to the



▲ **Figure 1–2.** Arteries of the neck and face. (Reproduced, with permission, from White JS. USMLS Road Map: Gross Anatomy, 2nd edition, McGraw-Hill, 2003.)

zygomatic prominence of the cheek. Its cutaneous branches are the infraorbital, zygomaticofacial, and zygomaticotemporal nerves.

3. Mandibular division of the trigeminal nerve—The mandibular division of the trigeminal nerve (V3) carries sensation from the lower lip, the lower part of the face, the auricle, and the scalp in front of and above the auricle. Its cutaneous branches are the mental, buccal, and auriculotemporal nerves.

B. Motor Innervation

The muscles of facial expression are innervated by branches of the facial nerve (VII). After emerging from the stylomastoid foramen, the facial nerve lies within the substance of the parotid gland. Here, it gives off its five terminal branches: (1) The temporal branch courses up to the scalp to innervate the occipitofrontalis and orbicularis oculi muscles. (2) The zygomatic branch courses across the cheek to innervate the orbicularis oculi muscle. (3) The buccal branch travels with the parotid duct and innervates the buccinator and orbicularis oris muscles, and also muscles that act on the nose and upper lip. (4) The mandibular branch innervates the orbicularis oris muscle and other muscles that act on the lower lip. (5) The cervical branch courses down to the neck and innervates the platysma muscle.

NOSE & SINUSES

THE NASAL CAVITY

The nose is bounded from above by the cribriform plate of the ethmoid bone and from below by the hard palate. It extends back to the choanae, which allow it to communicate with the nasopharynx. The nasal septum is formed by the perpendicular plate of the ethmoid and the vomer bones. The lateral wall of the nose has three bony projections, the conchae, which increase the surface area of the nasal mucosa and help to create turbulence in the air flowing through the nose. This allows the nose to humidify and clean the inhaled air and also to change the air to body temperature. The spaces between the conchae and the lateral wall of the nose are called the meatuses. The middle meatus typically has a bulge in its lateral nasal wall, the bulla ethmoidalis, which is created by the presence of ethmoidal air cells. This bulge is bounded from below by a groove, the hiatus semilunaris. The mucous membrane of the nasal cavity is primarily ciliated columnar epithelium and is specialized for olfaction in the roof of the nose and on the upper surface of the superior concha.

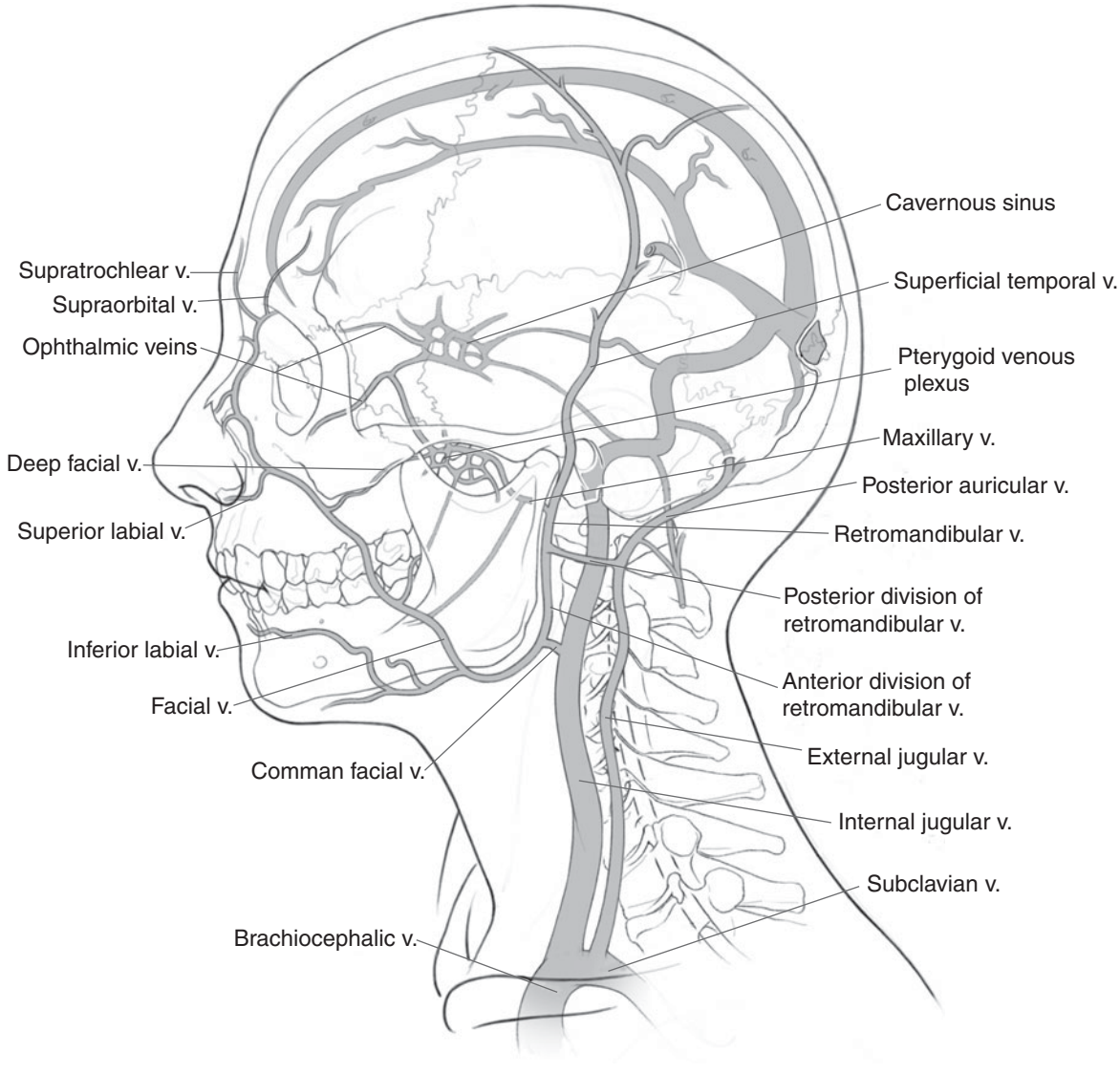
THE PARANASAL SINUSES

Several bones that surround the nose are hollow, and the spaces contained within, the paranasal sinuses, are named for the skull bones in which they lie. They are lined by a mucous membrane that is continuous with the nasal mucosa through openings with which the paranasal sinuses communicate with the nose. The presence of the sinuses decreases the weight of the skull and provides resonant chambers for voice. The secretions of the sinuses are carried into the nose through ciliary action.

The frontal sinus drains into the anterior part of the hiatus semilunaris via the infundibulum. The maxillary sinus also drains into the hiatus semilunaris, as do the anterior and middle ethmoidal sinuses. The posterior ethmoidal sinuses drain into the superior meatus. The sphenoid sinus drains into the space above the superior concha called the sphenoethmoidal recess. The inferior end of the nasolacrimal duct opens in the inferior meatus, allowing tears from the conjunctival sac to be carried into the nose. The maxillary sinus lies between the orbit above and the mouth below. The roots of the upper premolar and molar teeth project into the maxillary sinus, often separated from the contents of the sinus only by the mucous membrane that lines the sinus cavity.

▶ Sensory Innervation

The olfactory nerves (I) pass through the cribriform plate of the ethmoid bone into the olfactory bulb lying in the anterior cranial fossa, carrying the sensations of smell from the olfactory mucosa in the roof of the nose (Figure 1–5).



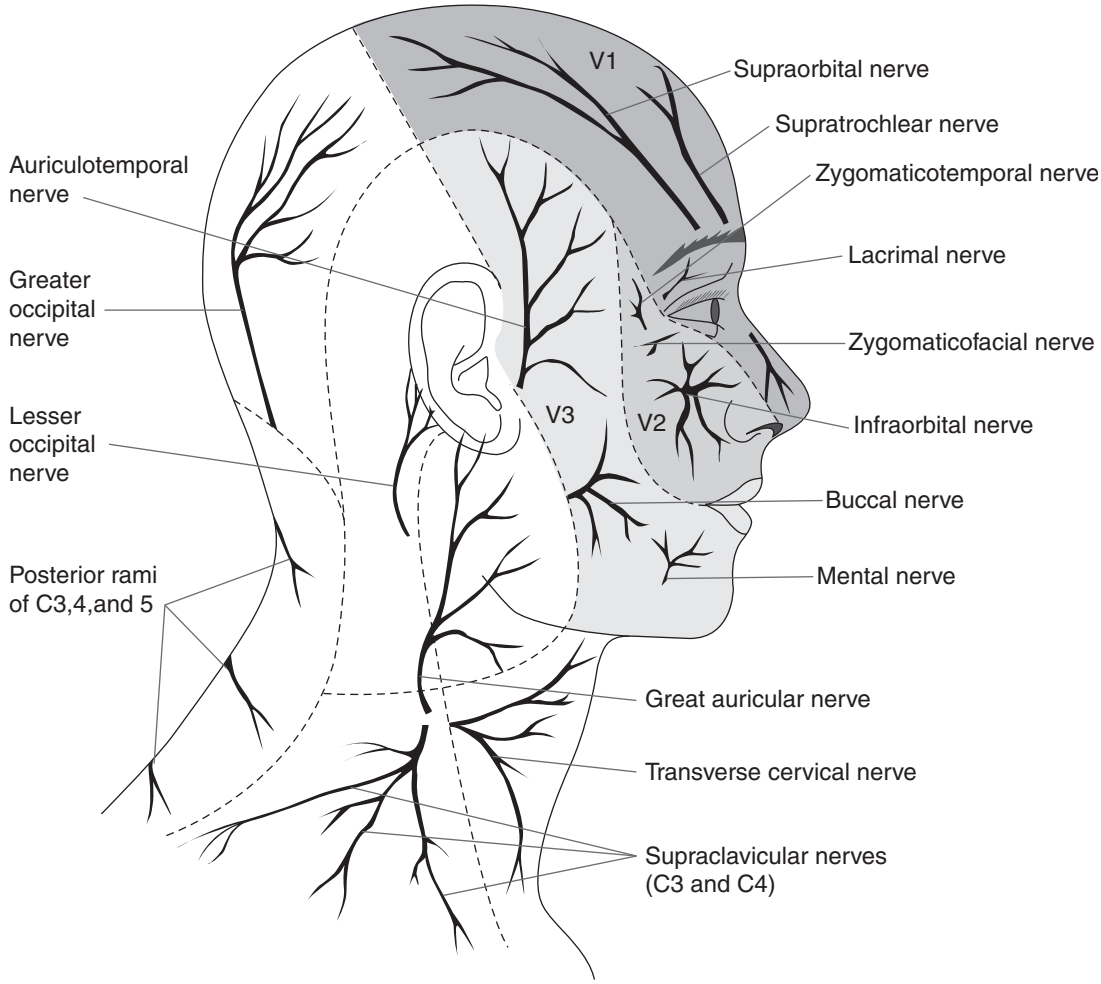
▲ **Figure 1–3.** Veins of the face.

General sensory fibers to the nose are provided by the ophthalmic (V1) and maxillary (V2) divisions of the trigeminal nerve. Specifically, the sensory innervation of the mucosa lining the anterior part of the nasal cavity, as well as that surrounding the olfactory mucosa in the roof of the nose, is by the ethmoidal branches of the ophthalmic division of the trigeminal nerve. Sensation from the lateral wall of the nose is carried by the lateral nasal branches of the maxillary division of the trigeminal nerve. Sensation from the nasal septum is carried by the nasopalatine branch of the maxillary division of the trigeminal nerve.

The sensory innervation of the lining of the frontal sinus is by the supraorbital branch of the ophthalmic division of the trigeminal nerve (V1). Sensory innervation of the sphenoid and ethmoid sinuses is by the ethmoidal branches of the ophthalmic division of the trigeminal nerve. Sensory innervation of the maxillary sinus is by the infraorbital branch of the maxillary division of the trigeminal nerve (V2).

Arteries

The rich blood supply of the nasal cavity is primarily from the sphenopalatine branch of the maxillary artery that enters the nose from the pterygopalatine fossa (Figure 1–6). The superior labial branch of the facial artery supplies the



▲ **Figure 1–4.** Sensory innervation of the head.

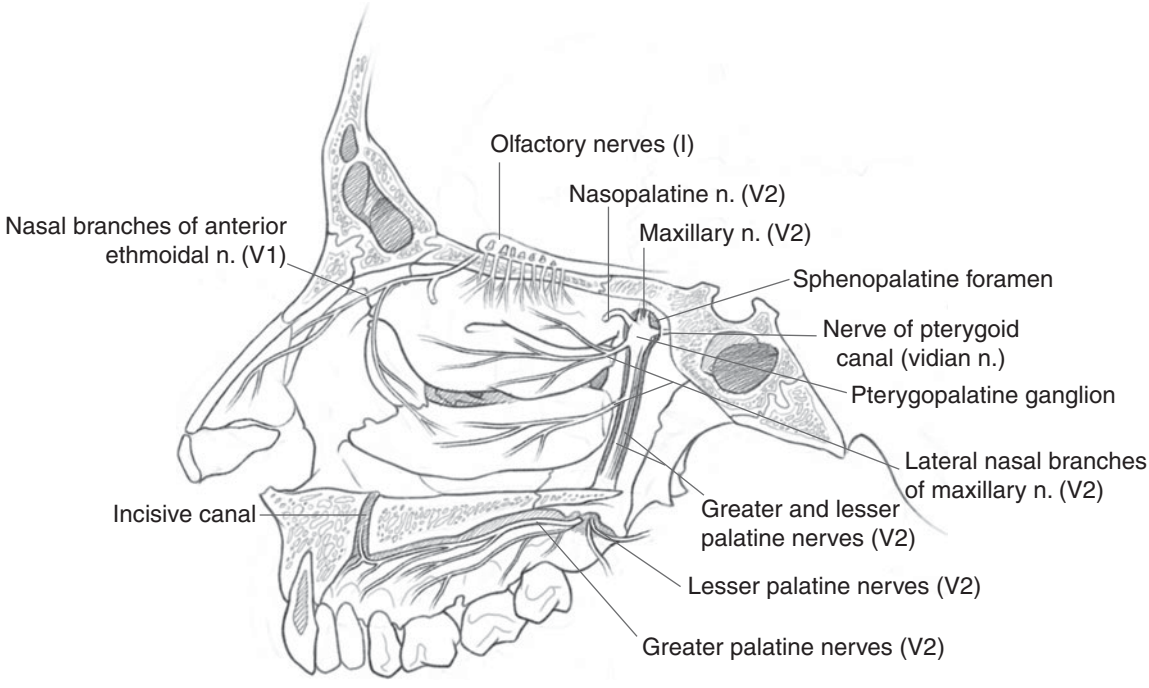
vestibule of the nose. In addition, the ophthalmic branch of the internal carotid artery supplies the roof of the nose. All of these vessels anastomose with each other.

SALIVARY GLANDS

PAROTID GLAND

The parotid gland is wedged into the space between the mandible in front and the temporal bone above and behind. It lies in front of the external auditory meatus. It extends as deep as the pharyngeal wall and is enclosed within a sheath formed by the investing fascia of the neck, which is attached to the zygomatic arch above. The parotid duct passes forward over the masseter muscle and can be palpated just in front of the clenched muscle, about half an inch below the zygomatic arch. It passes into the oral cavity by piercing the buccinator muscle and opens in the buccal mucosa opposite the upper second molar tooth.

Several important structures lie within the capsule of the parotid gland (Figure 1–7). The facial nerve (VII) enters the gland after emerging from the stylomastoid foramen and gives off its terminal branches within the substance of the gland. The external carotid artery ascends up the neck, into the gland, and gives off its two terminal branches—the maxillary and superficial temporal arteries—within the gland. The superficial temporal and maxillary veins come together in the substance of the gland to form the retromandibular vein, which divides into its anterior and posterior divisions as it emerges from the gland.



▲ **Figure 1–5.** Nerves of the nasal cavity.

SUBMANDIBULAR GLAND

The submandibular gland lies in the digastric triangle of the neck, below the mylohyoid muscle. Like the parotid gland, it is enclosed within a sheath formed by the investing fascia of the neck that is attached to the mandible above. A part of the gland extends around the posterior, free edge of the mylohyoid muscle to lie above the muscle in the floor of the mouth. The submandibular duct arises from this deep portion of the gland and extends forward, alongside the tongue, to open at the base of the frenulum of the tongue on the submandibular caruncle.

SUBLINGUAL GLAND

The sublingual gland lies below the tongue in the floor of the mouth. It creates a fold of mucous membrane, the sublingual fold, which lies along the base of the tongue, above the mylohyoid muscle. The gland has multiple ducts that open along the sublingual fold.

Innervation

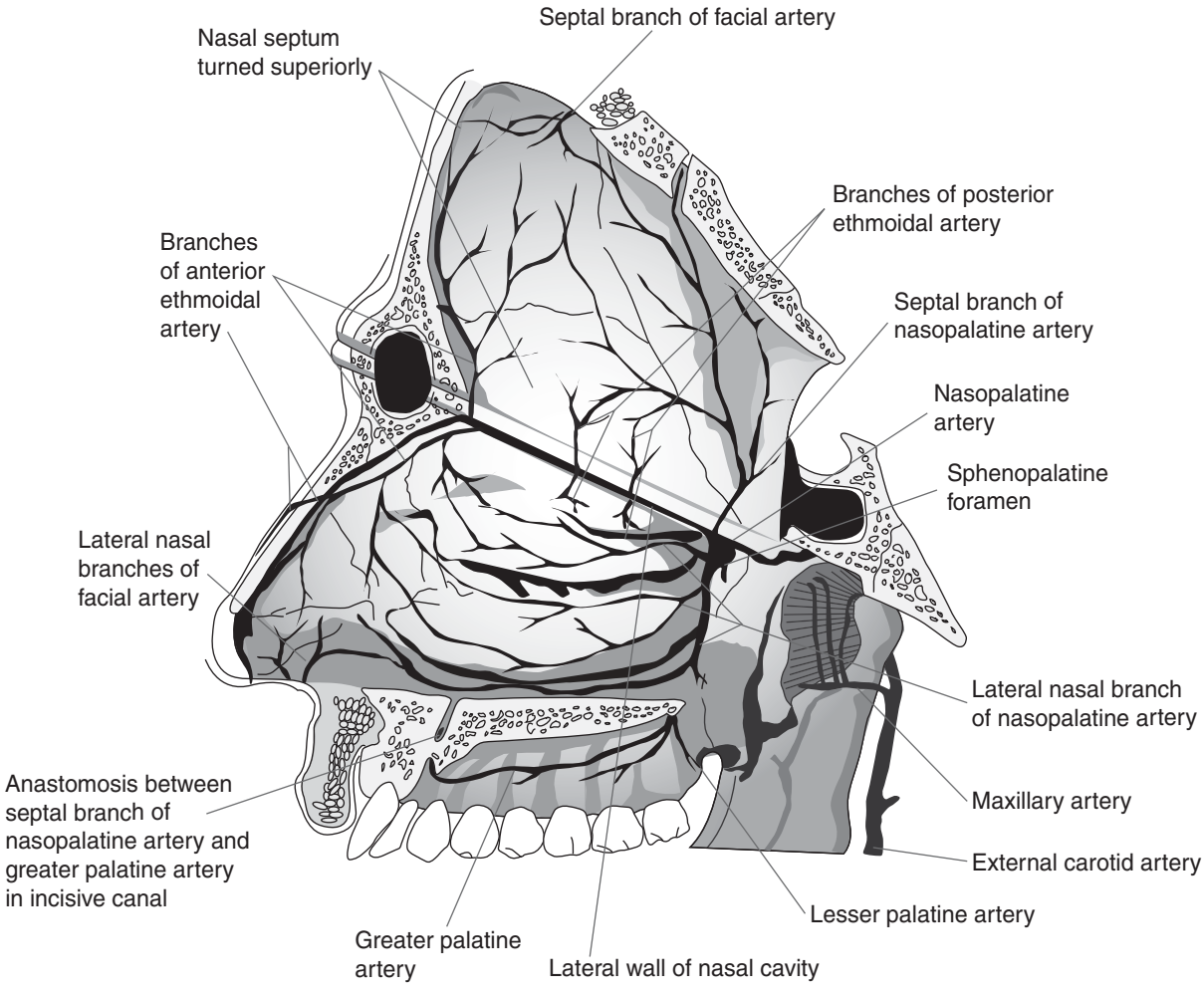
A. Secretomotor Innervation

Although the facial nerve (VII) is responsible for almost all the parasympathetic secretomotor innervation of the head, it is interesting to note that the one gland to which it does not provide secretomotor innervation is the very gland in which it is buried. The secretomotor innervation of the parotid gland is by fibers carried on the glossopharyngeal nerve (IX). The preganglionic parasympathetic fibers originate in the inferior salivary nucleus and join the glossopharyngeal nerve (Figure 1–8). They course through the lesser superficial petrosal nerve and the foramen ovale to synapse at the otic ganglion. The postganglionic fibers now join the auriculotemporal branch of the mandibular division of the trigeminal nerve to reach the parotid gland.

The secretomotor innervation of the submandibular and sublingual glands is by fibers carried on the facial nerve (VII). The preganglionic parasympathetic fibers originate in the superior salivary nucleus and join the facial nerve (Figure 1–9). They course through the chorda tympani nerve and the petrotympanic fissure to join the lingual branch of the mandibular division of the trigeminal nerve (V3) in the infratemporal fossa, and they synapse at the submandibular ganglion. Postganglionic fibers coursing to the submandibular gland usually reach the gland directly from this ganglion. Postganglionic fibers coursing to the sublingual gland reach the gland on branches of the lingual nerve.

B. Sympathetic Innervation

The sympathetic innervation to the salivary glands controls the viscosity of the glandular secretions. The preganglionic neurons originate in the thoracic spinal cord and ascend in the sympathetic trunk to synapse in the superior cervical ganglion in the neck. From here, postganglionic sympathetic



▲ **Figure 1–6.** Arteries of the nasal cavity.

fibers travel as plexuses on the external carotid artery and its branches to reach the salivary glands.

ORAL CAVITY

The mouth is bounded by the palate above, the mylohyoid muscle below, the buccinator muscles in the cheek on each side, and the palatoglossal arches behind. In addition to the oral cavity proper, the mouth includes the vestibule, which is the space between the cheek and the teeth.

PALATE

The hard palate is formed by the palatal process of the maxilla and the horizontal process of the palatine bone, which are covered by a mucous membrane. The soft palate is formed by contributions from a number of muscles.

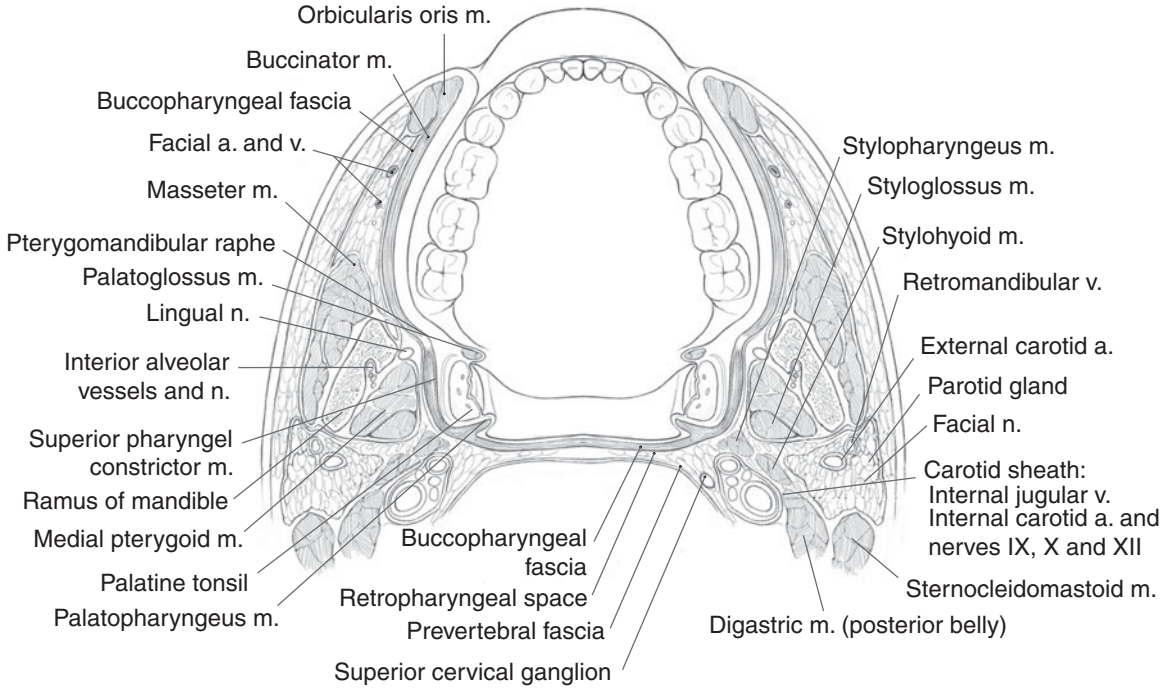
Muscles of the Soft Palate

A. Tensor Veli Palatini Muscle

The tensor veli palatini arises from the scaphoid fossa of the sphenoid bone and descends in the lateral wall of the nose, narrowing to a tendon that turns medially around the pterygoid hamulus. It then fans out to become the palatine aponeurosis and attaches to the muscle of the opposite side. Together, the two muscles tense the soft palate for other muscles to act upon it.

B. Levator Veli Palatini Muscle

The levator veli palatini arises from the petrous part of the temporal bone near the base of the styloid process and from the cartilage of the eustachian tube. It passes between the lowest fibers of the superior pharyngeal constrictor muscle and



▲ **Figure 1–7.** Relationships of the parotid gland. (Cross section at C2)

the highest fibers of the middle pharyngeal constrictor muscle, attaching to the upper surface of the palatine aponeurosis. It helps to elevate the soft palate and, together with the palatopharyngeus and superior pharyngeal constrictor muscles, it closes off the nose from the oropharynx during swallowing.

C. Palatoglossus Muscle

The palatoglossus muscle arises from the lower surface of the palatine aponeurosis and passes down, in front of the palatine tonsil, to attach to the side of the tongue. It pulls the back of the tongue upward and approximates the soft palate to the tongue, closing off the mouth from the pharynx.

D. Palatopharyngeus Muscle

The palatopharyngeus muscle also arises from the lower surface of the palatine aponeurosis and passes down, behind the palatine tonsil, to blend into the longitudinal muscle layer of the pharynx. It helps to pull the pharyngeal wall upward during swallowing, and together with the levator veli palatini and superior pharyngeal constrictor muscles, it closes off the nose from the oropharynx.

E. Musculus Uvulae

The musculus uvulae is a small muscle that helps to elevate the uvula.

Arteries

The blood supply of the palate is from the ascending palatine branches of the facial artery as well as from the palatine branch of the maxillary artery, both of which drop down to the palate from the pterygopalatine fossa by passing through the palatine canal.

TONGUE

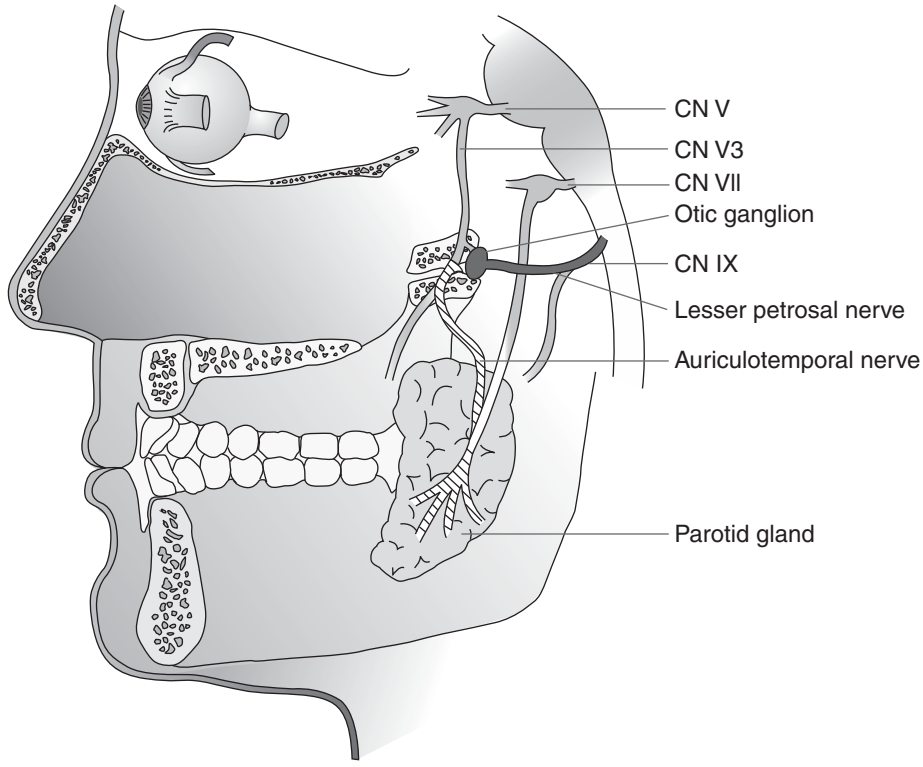
The anterior two-thirds of the tongue develop separately from the posterior third, and the two parts come together at the sulcus terminalis. The surface of the anterior two-thirds of the tongue is covered by filiform, fungiform, and vallate papillae. The posterior third of the tongue contains collections of lymphoid tissue, the lingual tonsils.

Muscles

The mass of the tongue is made up of intrinsic muscles that are directed longitudinally, vertically, and transversely; these intrinsic muscles help to change the shape of the tongue. Several extrinsic muscles help to move the tongue (Figure 1–10).

A. Genioglossus Muscle

The genioglossus arises from the genial tubercle on the inside surface of the front of the mandible and passes upward and



▲ **Figure 1–8.** Schematic of the innervation of the parotid gland by the glossopharyngeal nerve (IX). **Solid black:** Preganglionic parasympathetic nerves leave the brainstem with the glossopharyngeal nerve and run via the lesser superficial petrosal nerve to the otic ganglion. **Hatched segment:** Postganglionic parasympathetic nerves travel with the auriculotemporal branch of the mandibular division of the trigeminal nerve (V3) and then the facial nerve (VII) to reach the parotid gland.

backward into the tongue. It acts to protrude and depress the tongue.

B. Hyoglossus Muscle

The hyoglossus arises from the hyoid bone and passes upward to attach to the side of the posterior part of the tongue. It acts to depress and retract the back of the tongue.

C. Styloglossus Muscle

The styloglossus arises from the styloid process and passes downward and forward through the middle pharyngeal constrictor muscle to attach to the side of the tongue. It acts to elevate and retract the tongue.

D. Palatoglossus Muscle

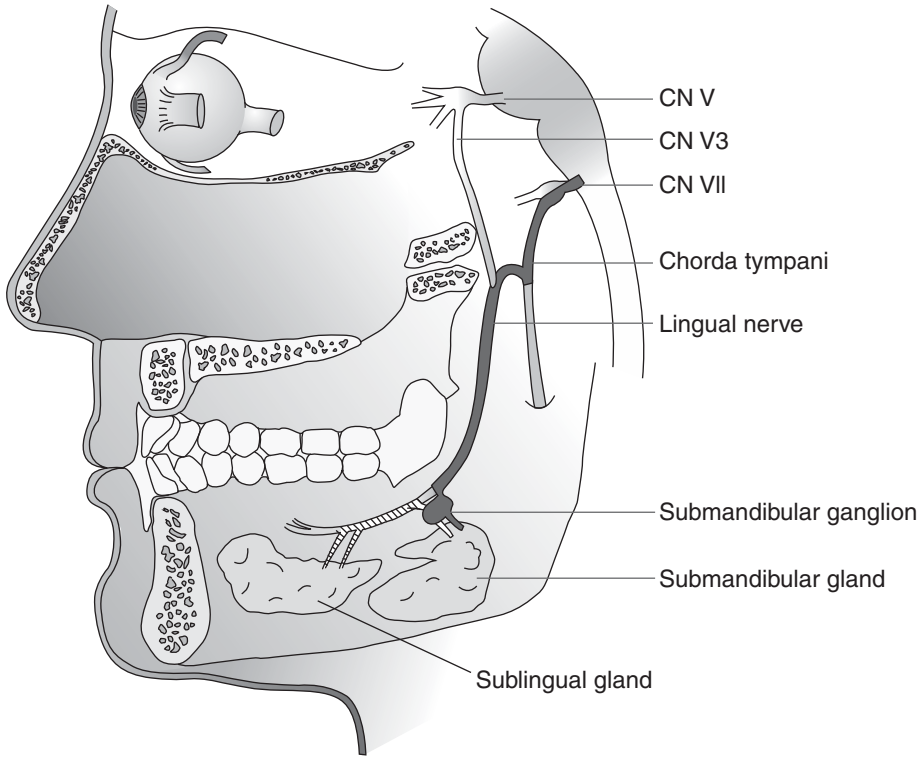
The palatoglossus muscle (described previously) acts on the tongue but is considered a muscle of the palate.

Arteries

The blood supply of the tongue is from the lingual branch of the external carotid artery. The lingual artery reaches the tongue by passing behind the posterior edge of the hyoglossus muscle and turning forward into the substance of the tongue, thus coursing medial to the hyoglossus. In contrast, all the other nerves and vessels of the tongue pass forward lateral to the hyoglossus before entering the tongue.

FLOOR OF THE MOUTH

The floor of the mouth is formed by the mylohyoid muscle upon which lie the geniohyoid muscles (Figure 1–11). The digastric muscle lies immediately below the mylohyoid muscle. Both the geniohyoid and the digastric muscles are discussed with the suprahyoid muscles of the neck. The mylohyoid arises from the similarly named line on the inside surface of the mandible and attaches to the front of the hyoid bone. It is the main support of the structures in the mouth.



▲ **Figure 1–9.** Schematic of the innervation of the submandibular and sublingual glands by the facial nerve (VII). **Solid black:** Preganglionic parasympathetic nerves leave the brainstem with the facial nerve and run via the chorda tympani and the lingual branches of the mandibular division of the trigeminal nerve (V3) to the submandibular ganglion. **Hatched segment:** Postganglionic parasympathetic nerves travel either directly to the submandibular gland or travel back to the lingual nerve to the sublingual gland.

It helps to elevate the hyoid bone during movements of swallowing and speech. Also, with the infrahyoid muscles holding the hyoid bone in place, the mylohyoid and digastric muscles help to depress the mandible and open the mouth.

The deep part of the submandibular gland and the duct that emerges from it lie above the mylohyoid muscle. The sublingual gland also lies above the mylohyoid. The hypoglossal nerve (XII) enters the mouth from the neck by passing lateral to the hyoglossus muscle and above the free posterior edge of the mylohyoid muscle. It continues in the mouth, inferior to the submandibular duct, and enters the substance of the tongue at its side. The lingual branch of the mandibular division of the trigeminal nerve (V3) enters the mouth from the infratemporal fossa by passing medial to the lower third molar. It initially lies above and lateral to the submandibular duct and then spirals under the duct as it comes to lie above and medial to the duct, where it gives off its terminal branches to the tongue and the floor of the mouth. The glossopharyngeal nerve (IX) passes from the pharynx to the mouth, lies lateral to the bed of the palatine tonsil, and courses into the posterior third of the tongue.

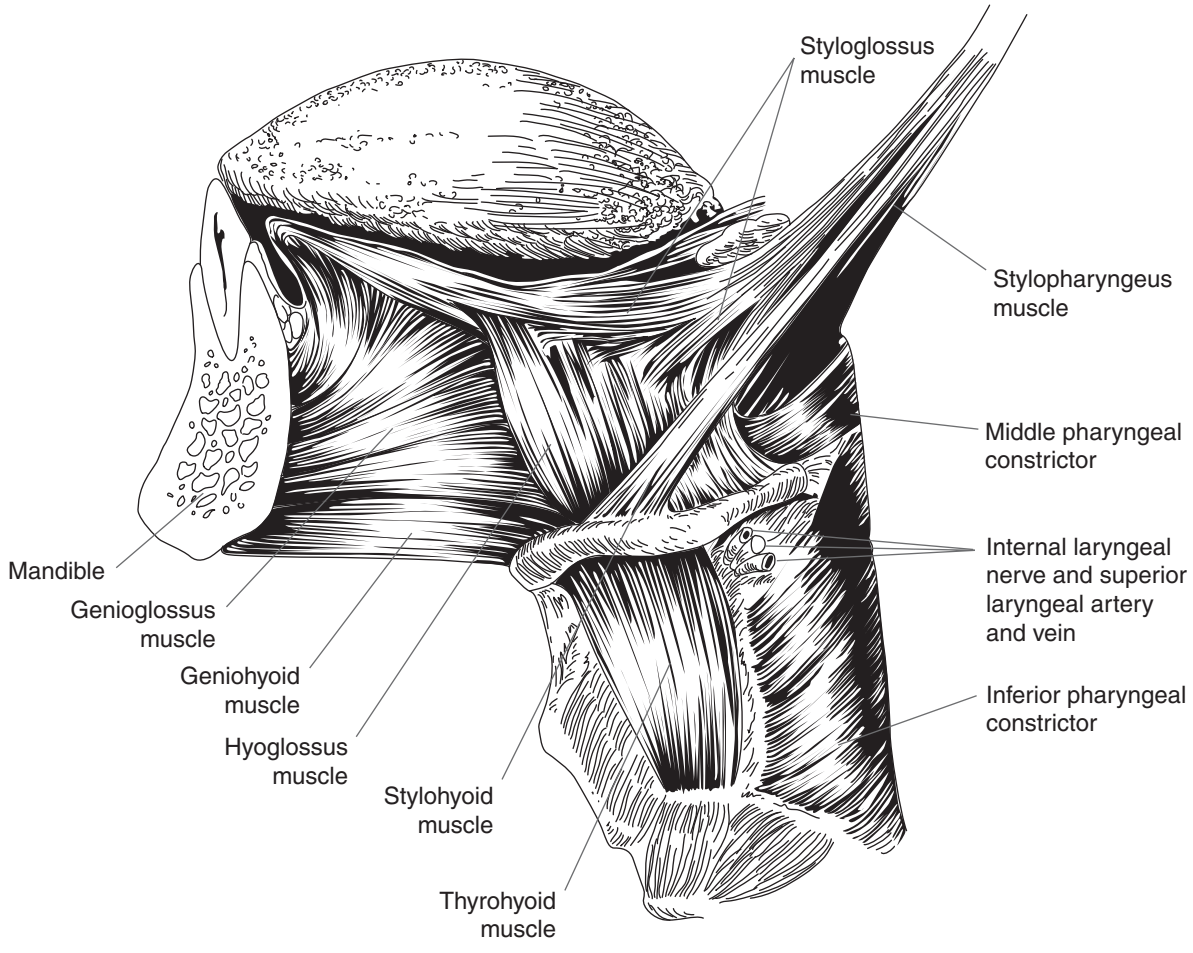
Innervation

A. Sensory Innervation

Sensation from the palate is carried by branches of the maxillary division of the trigeminal nerve (Figure 1–12). From the front of the hard palate, just behind the incisors, sensation is carried by the incisive branch of the nasopalatine nerve. From the rest of the hard palate and the mucosa lining the palatal aspect of the upper alveolar margins, sensation is carried by the greater palatine nerve. From the soft palate, sensation is carried by the lesser palatine nerve.

Sensation from the tongue is carried by nerves predicated upon the development of the tongue. There are general sensory fibers that carry sensations of touch, pressure, and temperature. In addition, there are special sensory fibers that carry the sensation of taste.

General sensation from the anterior two-thirds of the tongue is carried by the lingual branch of the mandibular division of the trigeminal nerve (V3). General sensation from the posterior third of the tongue is carried by the glossopharyngeal nerve (IX). Taste sensation from the



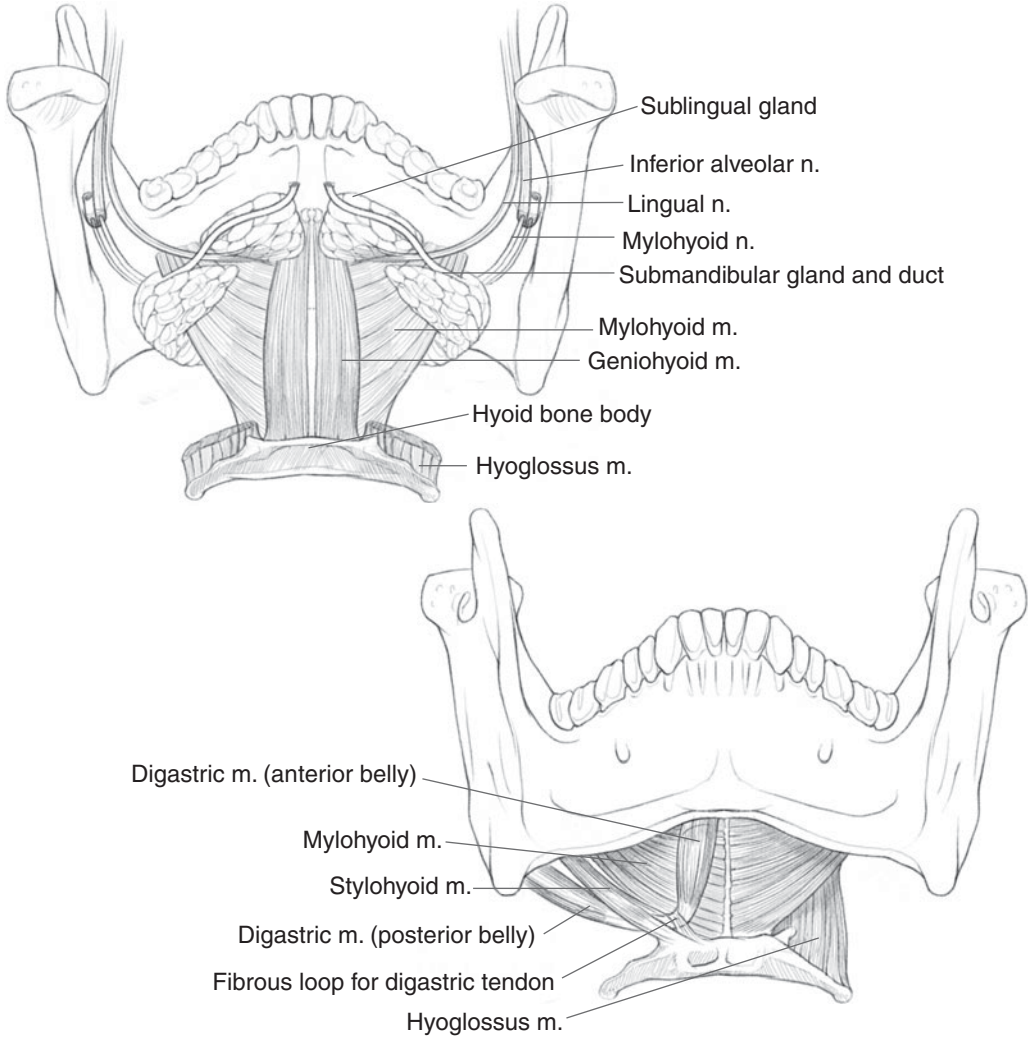
▲ **Figure 1–10.** Muscles of the tongue and pharynx. (Reproduced, with permission, from Lindner HH. Clinical Anatomy, McGraw-Hill, 1989.)

anterior two-thirds of the tongue is carried by the chorda tympani branch of the facial nerve (VII). Taste sensation from the posterior third of the tongue is carried by the glossopharyngeal nerve (IX).

Sensation from the floor of the mouth and the mucosa lining the lingual aspect of the lower alveolar margins is carried by the lingual branch of the mandibular division of the trigeminal nerve (V3). Sensation from the buccal mucosa and the mucosa lining the buccal aspect of the upper and lower alveolar margins is carried by the buccal branch of the mandibular division of the trigeminal nerve (V3). Sensation from the mucosa lining the anterior part of the vestibule, inside the upper lip, and the adjacent mucosa lining the labial aspect of the upper alveolar margins is carried by the infraorbital branch of the maxillary division of the trigeminal nerve (V2). Sensation from the mucosa lining the anterior part of the vestibule, inside the lower lip, and the adjacent mucosa lining the labial aspect of the lower alveolar margins is carried by the mental branch of the inferior alveolar branch of the mandibular division of the trigeminal nerve (V3).

B. Motor Innervation

All the muscles of the palate are innervated by branches of the vagus nerve (X) except the tensor veli palatini, which is innervated by the mandibular division of the trigeminal nerve (V3). All the muscles of the tongue, extrinsic and intrinsic, are innervated by the hypoglossal nerve (XII) except the palatoglossus muscle, which is considered a muscle of the palate and is therefore innervated by the vagus nerve (X). The mylohyoid muscle and anterior belly of the digastric muscle are innervated by the nerve to the mylohyoid muscle, a branch of the mandibular division of



▲ **Figure 1–11.** Floor of the mouth.

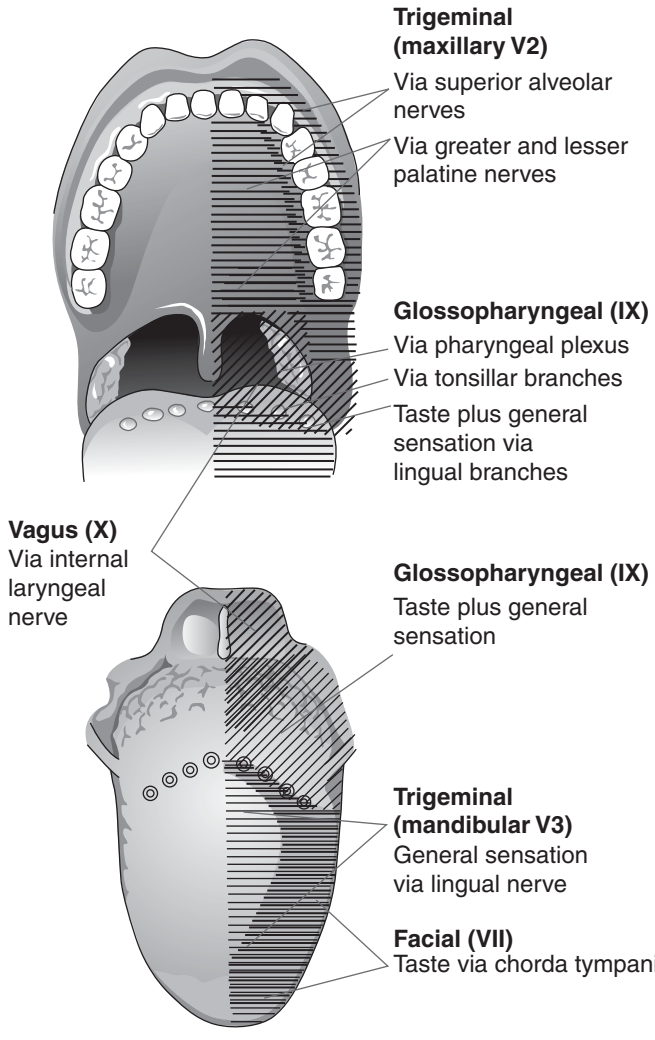
the trigeminal nerve (V3). The posterior belly of the digastric and the stylohyoid muscle are innervated by the facial nerve (VII). The geniohyoid muscle is innervated by fibers from the cervical spinal cord (C1), which are carried to it by the hypoglossal nerve (XII).

PHARYNX

The pharynx is a muscular tube that both lies behind and communicates with the nasal, oral, and laryngeal cavities (Figure 1–13). It lies in front of the prevertebral fascia of the neck and is continuous with the esophagus at the level of the cricoid cartilage. From within, it is made of mucosa, pharyngobasilar fascia, pharyngeal muscles, and buccopharyngeal fascia.

The mucosa is lined by ciliated columnar epithelium in the area behind the nasal cavity and by stratified squamous epithelium in the remaining areas. The pharyngobasilar fascia, a fibrous layer, is attached above to the pharyngeal tubercle on the base of the skull. The muscles of the pharynx consist of the circular fibers of the constrictor muscles that surround the longitudinally running fibers of the stylopharyngeus, salpingopharyngeus, and palatopharyngeus muscles.

The buccopharyngeal fascia is a layer of loose connective tissue that separates the pharynx from the prevertebral fascia and allows for the free movement of the pharynx against



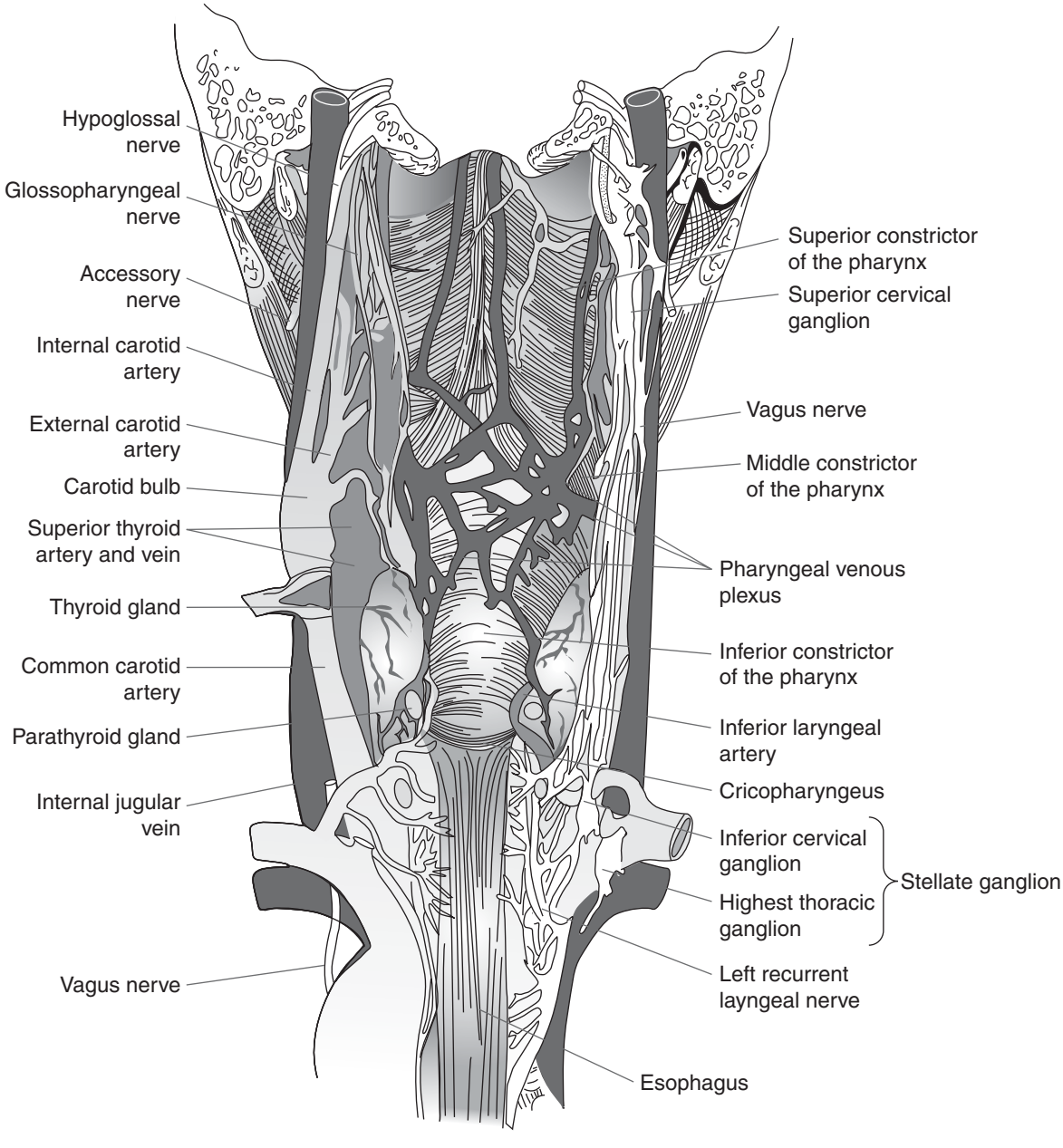
▲ **Figure 1–12.** Sensory innervation of the oral cavity.

vertebral structures. This layer is continuous around the lower border of the mandible with the loose connective tissue layer that separates the buccinator muscle from the skin overlying it.

Muscles

The muscular layer of the pharynx is made of inner longitudinal and outer circular layers (Figure 1–14). The longitudinally running muscles help to shorten the height of the pharynx. As the pharyngobasilar fascia is attached to the skull, this shortening results in an elevation of the pharynx and larynx during swallowing. The salpingopharyngeus, stylopharyngeus, and palatopharyngeus muscles contribute to this layer.

The circularly running muscles help to constrict the pharynx, and their sequential contractions propel food downward into the esophagus. The superior pharyngeal constrictor muscle arises from the pterygomandibular raphe, the middle pharyngeal constrictor muscle from the hyoid bone, and the inferior pharyngeal constrictor muscle from the thyroid and cricoid cartilages. From these narrow anterior origins, the fibers of the constrictor muscles fan out as they travel back around the pharynx and attach to the corresponding muscles of the opposite side at the midline pharyngeal raphe. The pharyngeal raphe is attached along its length to the pharyngobasilar fascia and is thus anchored to the pharyngeal tubercle on the base of the skull. The orientation of the constrictor muscle fibers is such that the

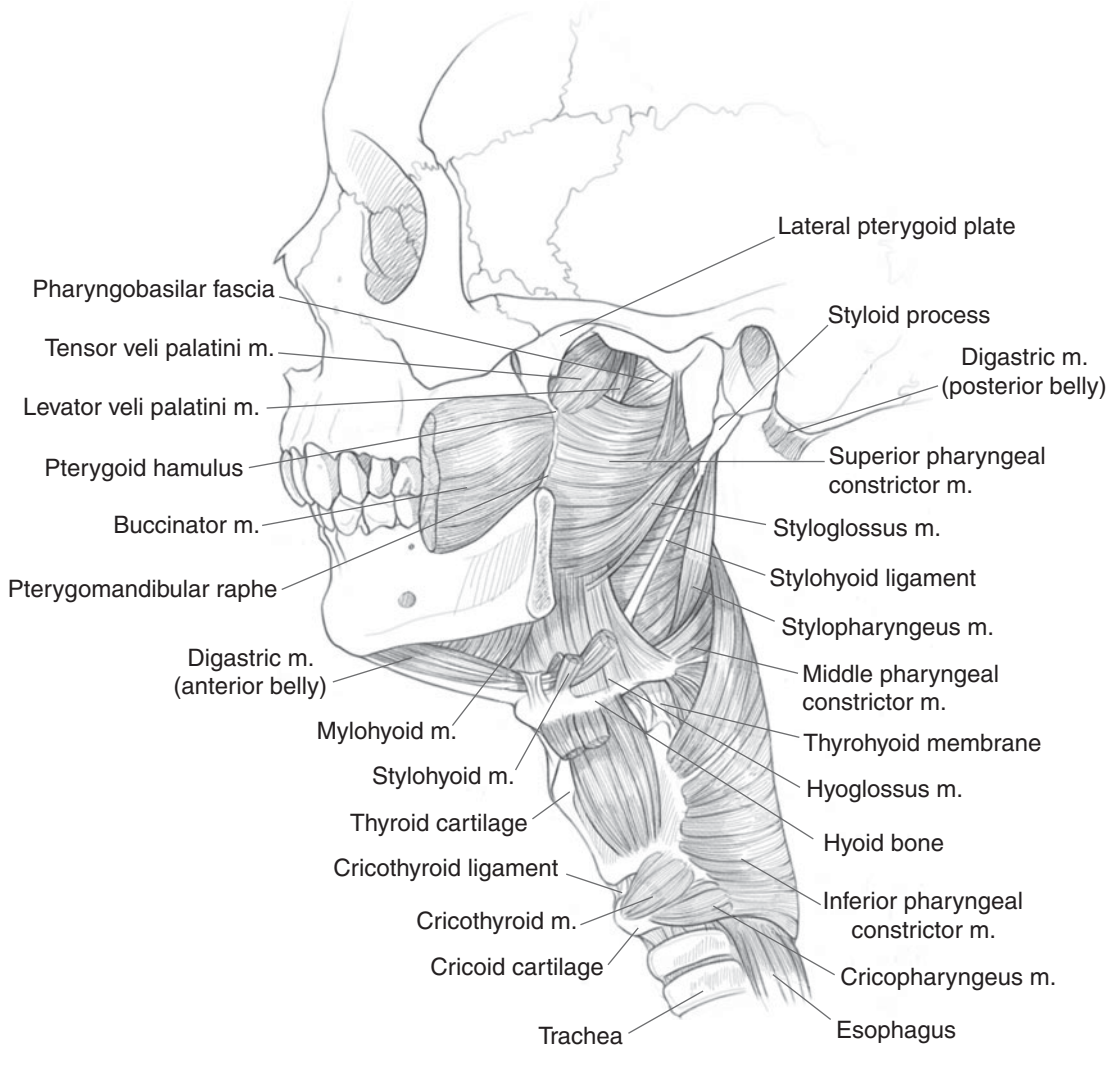


▲ **Figure 1–13.** Exterior of the pharynx. (Reproduced, with permission, from Lindner HH. Clinical Anatomy, McGraw-Hill, 1989.)

inferior fibers of one muscle are overlapped on the outside by the superior fibers of the next muscle down, producing a "funnel-inside-a-funnel" arrangement that directs food down in an appropriate fashion.

The narrow anterior attachments of the constrictor muscles, compared with their broad posterior insertion, create gaps in the circular muscle coat that surrounds the pharynx. Structures from without can pass into the pharynx through these gaps.

The gap between the base of the skull and the upper fibers of the superior inferior constrictor muscle allows the eustachian tube and the levator veli palatini muscle into the nasopharynx.



▲ **Figure 1–14.** Lateral view of the pharynx.

The gap between the lower fibers of the superior pharyngeal constrictor muscle and the upper fibers of the middle pharyngeal constrictor muscle allows the stylopharyngeus muscle and the glossopharyngeal nerve (IX) into the oropharynx.

The gap between the lower fibers of the middle pharyngeal constrictor muscle and the upper fibers of the inferior pharyngeal constrictor muscle allows both the internal laryngeal branch of the vagus nerve (X) and the superior laryngeal branch of the superior thyroid artery into the laryngopharynx and the larynx.

The gap between the lower fibers of the inferior pharyngeal constrictor muscle and the upper fibers of the circular muscle of the esophagus allows both the recurrent laryngeal branch of the vagus nerve (X) and the inferior laryngeal branch of the inferior thyroid artery into the larynx.

Innervation

The innervation of the pharynx is by a group of nerves whose branches form a meshwork of neurons, the pharyngeal plexus, which lies in the wall of the pharynx. The glossopharyngeal nerve (IX), the vagus nerve (X), the maxillary division of the trigeminal nerve (V2), and postganglionic fibers from the sympathetic trunk all contribute to the formation of the pharyngeal plexus.

A. Sensory Innervation

The sensory innervation of the upper part of the nasopharynx is carried by branches of the maxillary division of the trigeminal nerve (V2). The sensory innervation of the lower part of the nasopharynx, the oropharynx, and the laryngopharynx is carried by the glossopharyngeal nerve (IX). The internal laryngeal branch of the vagus nerve (X) carries sensation from the piriform recesses of the laryngopharynx.

B. Motor Innervation

Motor innervation of all the muscles of the pharynx, circular and longitudinal, except the stylopharyngeus, is by the pharyngeal branch of the vagus nerve (X), which carries motor fibers that originated in the cranial component of the accessory nerve (XI). The stylopharyngeus muscle is innervated by the glossopharyngeal nerve (IX).

NASOPHARYNX

The nasopharynx extends from the base of the skull to the level of the soft palate (Figures 1–15 and 1–16). It is continuous with the nasal cavity through the choanae. In its lateral wall, the cartilage of the eustachian tube creates a bulge, the torus tubarius, below which is the opening of the tube. Above and behind this bulge lies a depression called the pharyngeal recess. A collection of lymphoid tissue, the pharyngeal tonsil, lies in the posterior wall and the roof of the nasopharynx. Additional lymphoid tissue, the tubal tonsil, is found around the opening of the eustachian tube. A fold of mucous membrane created by the salpingopharyngeus muscle extends down from the torus tubarius. The nasopharynx is continuous with the oropharynx below.

OROPHARYNX

The oropharynx extends from the soft palate to the epiglottis (Figures 1–15 and 1–16). It is continuous with the mouth through the oropharyngeal isthmus formed by the palatoglossal muscles on each side. The anterior wall of the oropharynx is formed by the posterior third of the tongue. The mucous membrane of the tongue is continuous onto the epiglottis and creates three glossoepiglottic folds—one in the midline and two placed laterally. The space on either side of the median glossoepiglottic fold is the vallecula.

The lateral wall of the oropharynx has two folds of mucous membrane, the palatoglossal and palatopharyngeal, created by the muscles of the same name, which are described with the muscles of the palate. An encapsulated collection of lymphoid tissue, the palatine tonsil, lies in the triangular recess between these two folds. The blood supply of the palatine tonsil is by a branch of the facial artery. Additional lymphoid tissue, the lingual tonsil, is located under the mucous membrane of the posterior third of the tongue. Together, the tonsillar tissues of the nasopharynx and oropharynx form a ring of lymphoid tissue—Waldeyer's ring—that surrounds the entrances into the pharynx from the nose and the mouth. The oropharynx is continuous with the laryngopharynx below.

LARYNGOPHARYNX

The laryngopharynx extends from the epiglottis to the cricoid cartilage (Figures 1–15 and 1–16). It is continuous with the larynx through the laryngeal aditus, which is formed by the epiglottis and the aryepiglottic folds. On either side of these folds and medial to the thyroid cartilage are two pyramidal spaces, the piriform recesses of the laryngopharynx, through which swallowed food passes into the esophagus. The piriform recesses are related to the cricothyroid muscle laterally and the lateral cricoarytenoid muscle medially. The laryngopharynx is continuous with the esophagus below.

NECK

Triangles of the Neck

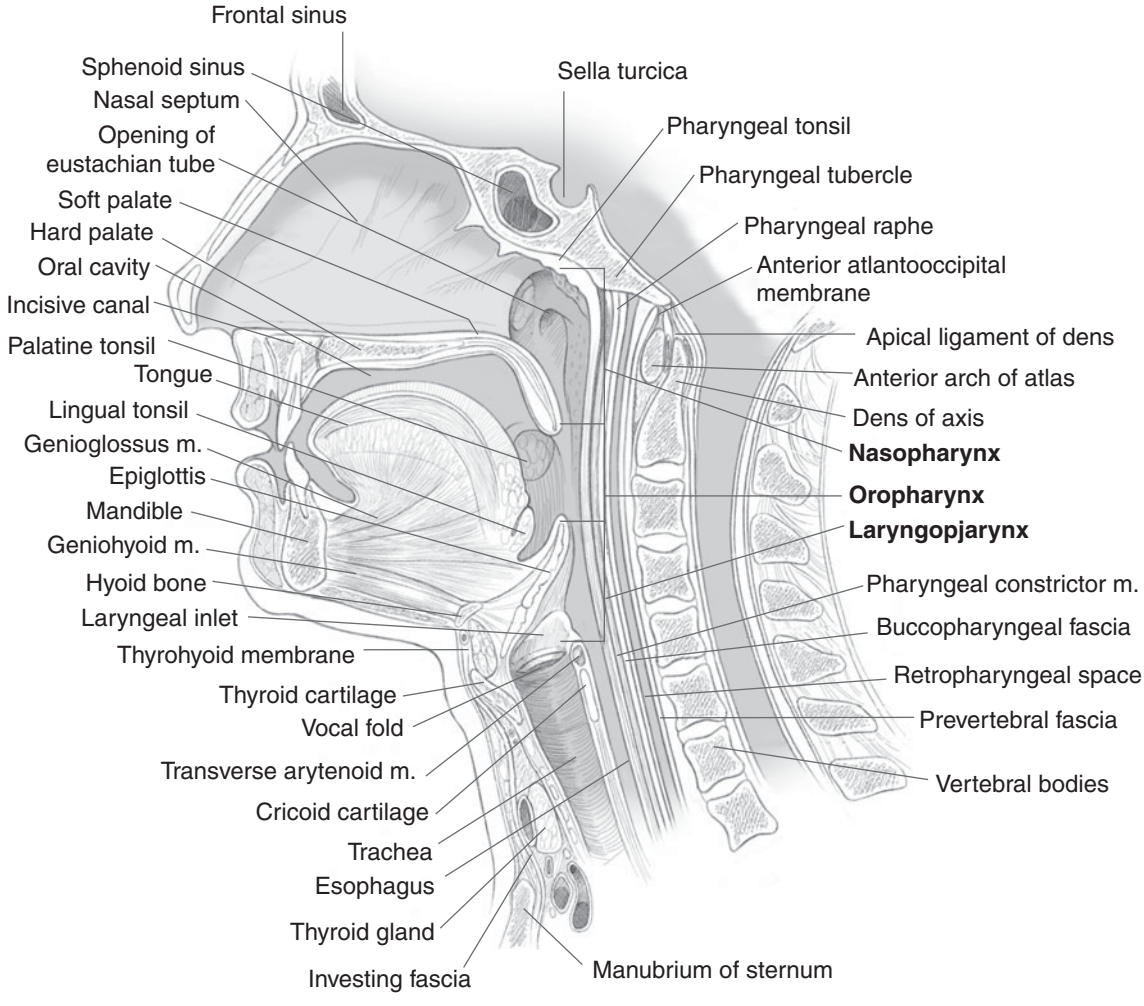
Bounded by the mandible above and the clavicle below, the neck is subdivided by the sternocleidomastoid muscle into an anterior and a posterior triangular region, each of which is further divided into smaller triangles by the omohyoid and digastric muscles (Figure 1–17). The surface markings of these muscles help to visibly define the borders of the triangles of the neck.

A. Posterior Triangle

The posterior triangle is bounded by the sternocleidomastoid muscle in front, the trapezius muscle behind, and the clavicle below. It is divided by the omohyoid muscle into an occipital triangle and a supraclavicular triangle.

1. Occipital triangle—The occipital triangle has a muscular floor formed from above, downward by the semispinalis capitis, splenius capitis, levator scapulae, and scalenus medius muscles. After emerging from behind the sternocleidomastoid muscle, the spinal accessory nerve (XI) courses across the muscular floor of the posterior triangle to pass deep to the trapezius muscle. In addition, the cutaneous nerves of the neck, discussed below, course through the deep fascia of the neck that covers the posterior triangle.

2. Supraclavicular triangle—The supraclavicular triangle lies above the middle of the clavicle. It contains the terminal portion of the subclavian artery, roots, trunks, and divisions of the brachial plexus, branches of the thyrocervical trunk, and cutaneous tributaries of the external jugular vein. The cupola of the pleural cavity extends above the level of the clavicle and is found deep to the contents of the supraclavicular triangle.



▲ **Figure 1–15.** Median section of the pharynx.

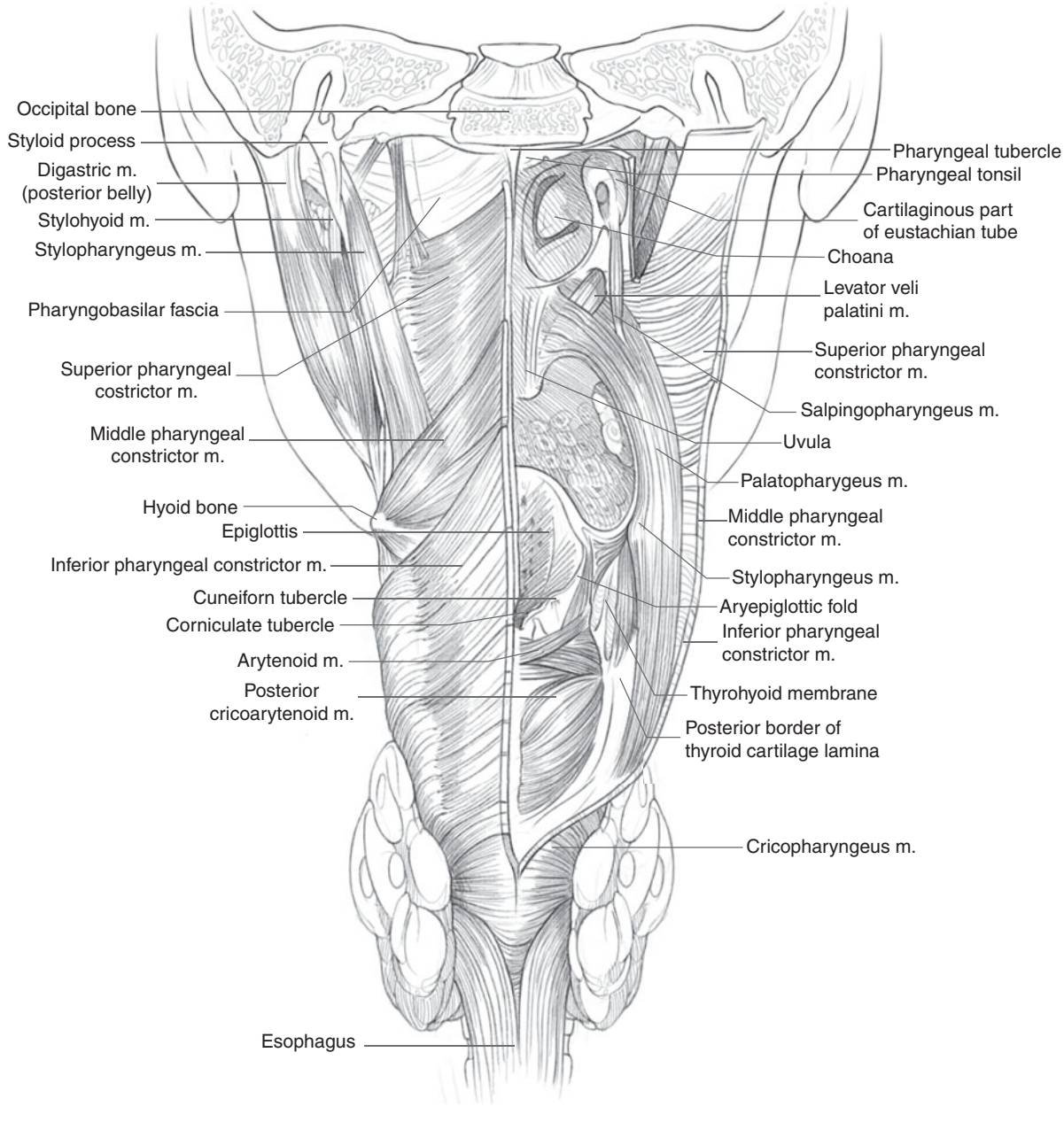
B. Anterior Triangle

The anterior triangle is bounded by the sternocleidomastoid muscle behind, the midline of the neck in front, and the mandible above. It is subdivided into submental, digastric, carotid, and muscular triangles.

1. Submental triangle—The submental triangle is bounded by the anterior belly of the digastric muscle, the midline of the neck, and the hyoid bone. The mylohyoid muscle forms its floor.

2. Digastric triangle—The digastric triangle is bounded by the mandible above and the two bellies of the digastric muscle. In addition, the stylohyoid muscle lies with the posterior belly of the digastric muscle. The mylohyoid and hyoglossus muscles form the floor of this triangle. The submandibular salivary gland is a prominent feature of this area, which is also referred to as the submandibular triangle. The hypoglossal nerve (XII) runs along with the stylohyoid muscle and posterior belly of the digastric muscle, between the hyoglossus muscle and the submandibular gland, on its course into the tongue. The facial vessels course across the triangle, with the facial artery passing deep to the submandibular gland while the facial vein passes superficial to it.

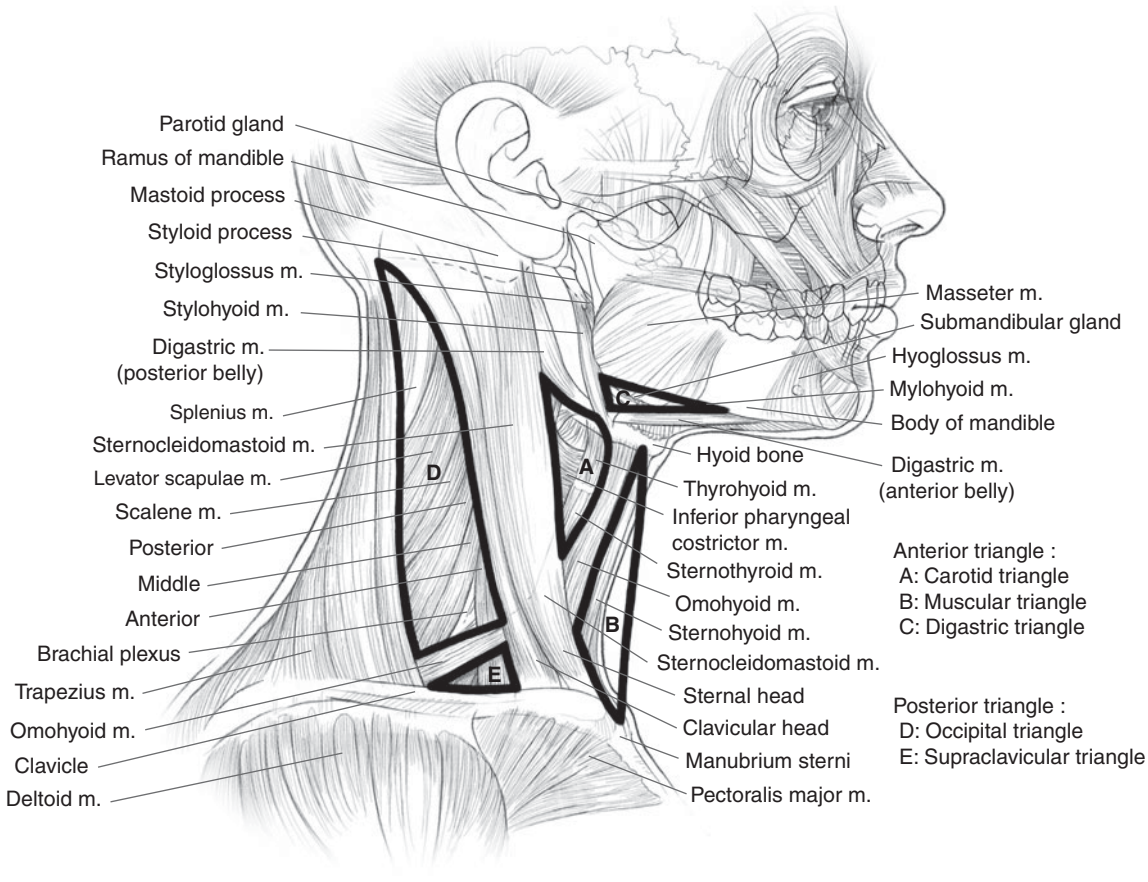
3. Carotid triangle—The carotid triangle is bounded by the sternocleidomastoid muscle behind, the posterior belly of the digastric muscle above, and the omohyoid muscle below. Its floor is formed by the constrictor muscles of the pharynx. It contains the structures of the carotid sheath—namely, the common carotid artery as it divides into its external and



▲ **Figure 1–16.** Posterior view of the pharynx.

internal carotid branches, the internal jugular vein and its tributaries, and the vagus nerve (X) with its branches.

4. Muscular triangle—The muscular triangle is bounded by the omohyoid muscle above, the sternocleidomastoid muscle below, and the midline of the neck in front. It contains the infrahyoid muscles in its floor. Deep to these muscles are the thyroid and parathyroid glands, the larynx, which leads to the trachea, and the esophagus. The hyoid bone forms the superior attachment for the infrahyoid muscles, and the prominent thyroid cartilage and cricoid cartilage are also contained in this region.



▲ **Figure 1–17.** Muscles and triangles of the neck.

Muscles

A. Sternocleidomastoid Muscles

The sternocleidomastoid muscles act together to flex the cervical spine while extending the head at the atlantooccipital joint. Acting independently, each muscle turns the head to face upward and to the contralateral side. By virtue of their attachment to the sternum, the sternocleidomastoids also serve as accessory muscles of respiration.

B. Trapezius Muscles

The trapezius muscles have fibers running in several directions. The uppermost fibers pass downward from the skull to the lateral end of the clavicle and help to elevate the shoulder. The middle fibers pass laterally from the cervical spine to the acromion process of the scapula and help to retract the shoulder. The lowest fibers pass upward from the thoracic spine to the spine of the scapula and help to laterally rotate the scapula, making the glenoid fossa turn upward. This action assists the serratus anterior muscle in rotating the scapula when the arm is abducted overhead.

C. Scalene Muscles

The scalene muscles attach to the cervical spine and pass downward to insert on the first rib. They are contained within the prevertebral layer of deep fascia and help to laterally bend the cervical spine. The roots of the brachial plexus and the subclavian artery pass between the anterior and middle scalene muscles on their course to the axilla. In contrast, the subclavian vein passes anterior to the anterior scalene muscle as it leaves the neck to pass behind the clavicle and reach the axilla. Also, the phrenic nerve lies immediately anterior to the anterior scalene muscle as it runs down the neck into the thorax.

D. Infrahyoid Muscles

The infrahyoid muscles, the omohyoid, sternohyoid, sternothyroid, and thyrohyoid, are named for their attachments. Together, they act to depress the hyoid bone and the thyroid cartilage during movements of swallowing and speech.

E. Suprahyoid Muscles

The suprahyoid muscles, the mylohyoid, stylohyoid, geniohyoid, and digastric, act together to elevate the hyoid bone during movements of swallowing or speech. In addition, with the infrahyoid muscles holding the hyoid bone in place, the suprahyoid muscles help to depress the mandible and open the mouth.

Arteries

The arch of the aorta has three branches: (1) the brachiocephalic artery, (2) the left common carotid artery, and (3) the left subclavian artery. The brachiocephalic artery branches into the right subclavian and right common carotid arteries.

A. Subclavian Artery

The subclavian artery gives off the vertebral artery, the internal thoracic artery, the thyrocervical trunk, and the costocervical trunk (see Figure 1–2).

1. Vertebral artery—The vertebral artery courses up through the transverse foramina of the upper six cervical vertebrae. It enters the vertebral canal, passes through the foramen magnum, and goes on to supply blood to the hindbrain, the midbrain, and the occipital lobe of the forebrain.

2. Internal thoracic artery—The internal thoracic artery leaves the root of the neck and passes into the thorax, where it supplies blood to the anterior chest wall and eventually to the upper part of the anterior abdominal wall through its superior epigastric branch.

3. Thyrocervical trunk—The thyrocervical trunk gives off the following branches: (1) the inferior thyroid artery, which supplies blood to the thyroid gland; (2) the transverse cervical artery, which passes backward across the neck to supply blood to the trapezius and rhomboid muscles; and (3) the suprascapular artery, which courses laterally across the neck toward the suprascapular notch and participates in the elaborate anastomosis of vessels that surround the scapula. The inferior thyroid artery has a branch, the inferior laryngeal artery, which enters the larynx by passing between the lowest fibers of the inferior pharyngeal constrictor muscle and the upper fibers of the circular muscle of the esophagus. The inferior thyroid artery anastomoses with the superior thyroid artery, a branch of the external carotid artery.

4. Costocervical trunk—The costocervical trunk gives off branches that supply blood to the first two intercostal spaces and the postvertebral muscles of the neck.

B. Common Carotid Artery

The common carotid artery courses up into the neck and terminates at the level of the thyroid cartilage by dividing into the internal and external carotid arteries. It has no branches.

1. Internal carotid artery—The internal carotid artery also has no branches in the neck. It travels up to the base of the skull, where it enters the carotid canal and passes through the petrous part of the temporal bone and the cavernous sinus before turning sharply upward and backward at the carotid siphon to pierce the dura mater. It supplies blood to the frontal, parietal, and temporal lobes of the forebrain. Its main branch to the head is the ophthalmic artery, which supplies blood to the orbit and the upper part of the nasal cavity.

2. External carotid artery—The external carotid artery is the main source of blood supply to the head and neck (see Figure 1–2). In the neck, it has a number of branches.

A. Superior thyroid artery—The superior thyroid artery passes downward to supply blood to the upper part of the thyroid gland. It has a branch, the superior laryngeal artery, which pierces the thyrohyoid membrane to pass into the larynx. The superior thyroid artery anastomoses with the inferior thyroid artery, a branch of the thyrocervical trunk of the subclavian artery.

B. Ascending pharyngeal artery—The ascending pharyngeal artery supplies blood to the pharynx.

C. Posterior auricular artery—The posterior auricular artery passes upward, behind the auricle, and supplies blood to the scalp.

D. Occipital artery—The occipital artery passes upward and backward to supply blood to the scalp on the back of the head.

E. Facial artery—The facial artery passes upward and forward, deep to the submandibular salivary gland. It then crosses the mandible, where its pulsations can be palpated just in front of the masseter muscle, to supply blood to the face.

F. Lingual artery—The lingual artery passes upward and forward, behind the posterior edge of the hyoglossus muscle, and into the substance of the tongue, to which it supplies blood.

G. Terminal branches—The external carotid artery then ascends into the substance of the parotid gland, where it gives off two terminal branches.

(1) Superficial temporal artery—The superficial temporal artery crosses the zygomatic arch just in front of the

auricle, where its pulsations can be palpated. It then goes on to supply blood to the scalp.

(2) Maxillary artery—The maxillary artery passes medially into the infratemporal fossa and is responsible for the blood supply to the deep structures of the face and the nose.

Veins

The venous drainage of the head and neck is best understood by comparing it with the arterial distribution described above. Many variations exist in the pattern of venous drainage, but each of the arteries has a vein that corresponds to it (see Figure 1–3).

A. Retromandibular Vein

The veins that correspond to the two terminal branches of the external carotid artery, the superficial temporal and maxillary veins, come together within the substance of the parotid gland to form the retromandibular vein. At the angle of the mandible, the retromandibular vein divides into an anterior and a posterior division.

B. External Jugular Vein

The two veins that correspond to the arteries that pass backward from the external carotid artery, the posterior auricular and occipital veins, join the posterior division of the retromandibular vein and become the external jugular vein. In addition, the suprascapular and transverse cervical veins drain into the external jugular vein.

C. Internal Jugular Vein

The two veins that correspond to the arteries that pass forward from the external carotid artery, the facial and lingual veins, join the anterior division of the retromandibular vein and drain into the internal jugular vein. The internal jugular vein drains blood from the areas to which the internal carotid artery supplies blood. In addition, the superior and middle thyroid veins drain into the internal jugular vein.

D. Inferior Thyroid Veins

The inferior thyroid veins lie in front of the trachea and drain blood from the isthmus of the thyroid gland into the left brachiocephalic vein as it lies behind the manubrium of the sternum.

E. Brachiocephalic Vein

The external jugular vein drains into the subclavian vein, which joins the internal jugular vein at the root of the neck to become the brachiocephalic vein. The two brachiocephalic veins come together to form the superior vena cava.

Lymphatics

The superficial lymph nodes of the head and neck are named for their regional location (Figure 1–18). The occipital, retroauricular, and parotid nodes drain lymph from the scalp, auricle, and middle ear. The submandibular nodes receive lymph from the face, sinuses, mouth, and tongue. The retropharyngeal nodes, although not truly superficially located, receive lymph from deeper structures of the head, including the upper parts of the pharynx. All of these regional nodes drain their lymphatic efferents into the deep cervical nodes, which lie along the internal jugular vein. Two of these deep nodes are commonly referred to as the jugulodigastric and the juguloomohyoid nodes. They lie at locations at which the internal jugular vein is crossed by the digastric and omohyoid muscles, respectively. The jugulodigastric node is concerned with the lymphatic drainage of the palatine tonsil; the juguloomohyoid node is concerned primarily with the lymphatic drainage of the tongue. The deep cervical nodes drain their lymph into either the thoracic duct or the right lymphatic duct. The thoracic duct empties into the junction of the left internal jugular vein and the left subclavian vein. The right lymphatic duct drains into a similar location on the right side of the root of the neck.

Innervation

A. Sensory Innervation

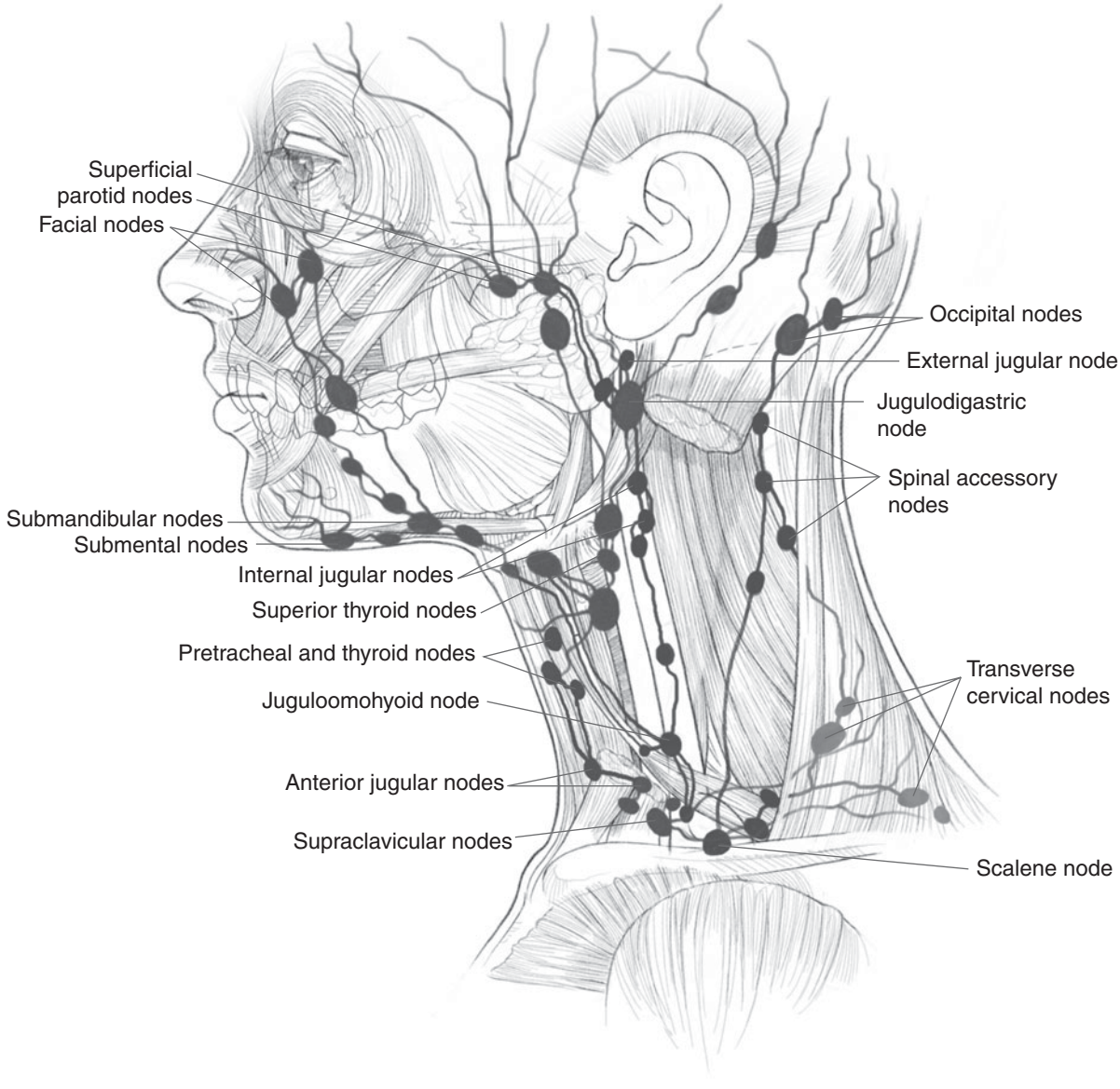
The cutaneous innervation of the anterior skin of the neck is by the ventral rami of cervical spinal nerves that form the cervical plexus (C2–4), whereas the posterior skin of the neck is innervated by the dorsal rami of cervical spinal nerves (C2–5) (see Figure 1–4). The cutaneous branches of the cervical plexus emerge from just behind the sternocleidomastoid muscle, at a point about halfway between its attachments to the sternum and the mastoid process. They are named for the areas of skin from which they carry sensation.

1. Transverse cervical nerve—The transverse cervical nerve turns forward and courses across the neck, with its branches carrying sensation from the anterior neck.

2. Supraclavicular nerves—The supraclavicular nerves course down toward the clavicle and carry sensation from the skin of the lower neck, extending from the clavicle in front to the spine of the scapula behind.

3. Greater auricular nerve—The greater auricular nerve courses up toward the auricle, with its branches carrying sensation from the skin of the upper neck, the skin overlying the parotid gland, and the auricle itself.

4. Lesser occipital nerve—The lesser occipital nerve courses upward to carry sensation from the skin of the scalp that lies just behind the auricle.

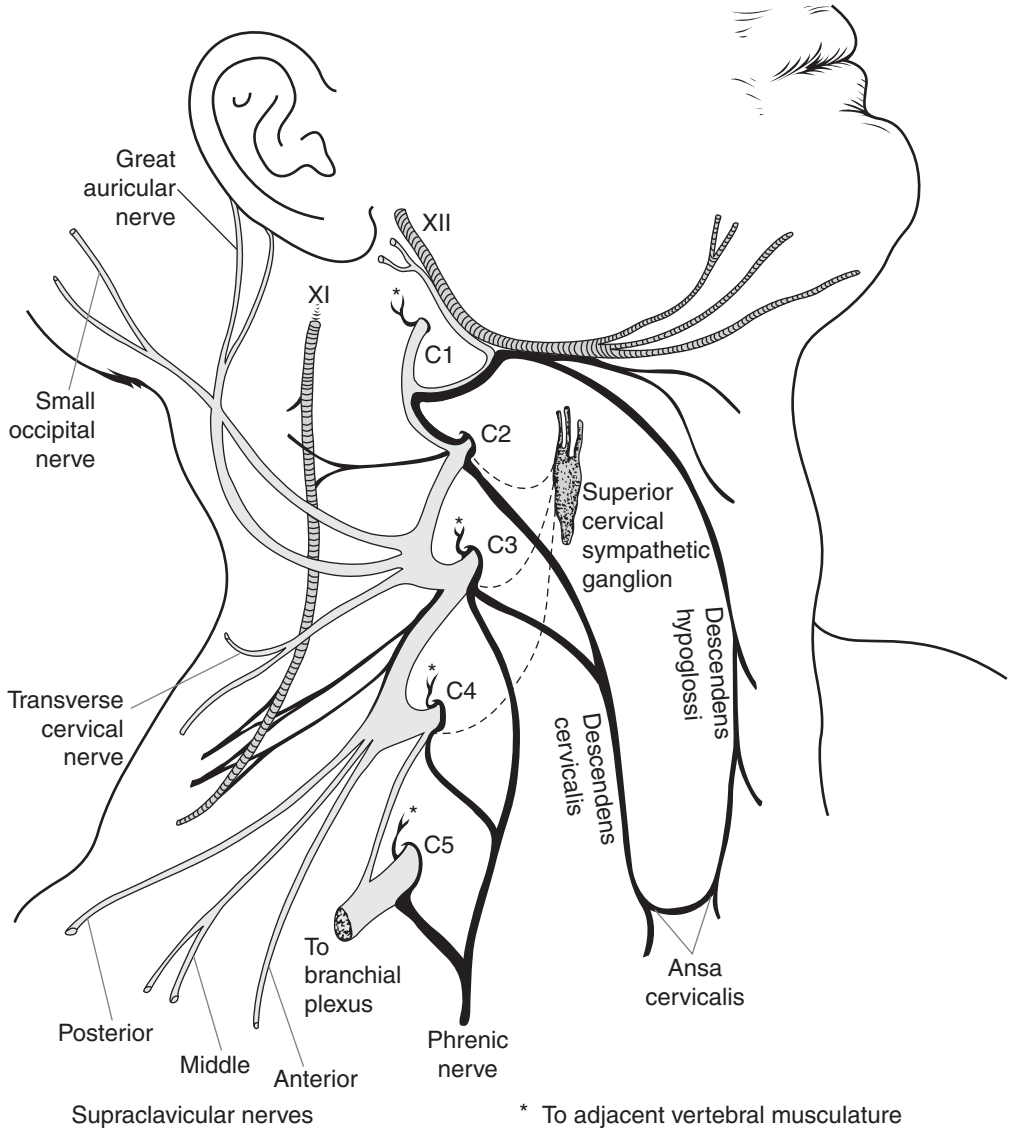


▲ **Figure 1–18.** Head and neck lymphatics.

B. Motor Innervation

The infrahyoid muscles are innervated by branches of the ansa cervicalis, which is formed by the descending cervical nerve and the descending hypoglossal nerve. The descending cervical nerve (C2 and 3) arises from the cervical plexus. The descending hypoglossal nerve contains fibers from the first cervical spinal nerve, some of which initially joined the hypoglossal nerve (XII) before dropping from that nerve to form the ansa cervicalis (Figure 1–19). Other fibers from the first cervical spinal nerve continue on the hypoglossal nerve and later branch off to supply the thyrohyoid muscle.

Of the suprahyoid muscles, the mylohyoid muscle and the anterior belly of the digastric muscle are innervated by the nerve to the mylohyoid muscle, which is a branch of the inferior alveolar nerve from the mandibular division of the trigeminal nerve (V3). The stylohyoid muscle and the posterior belly of the digastric muscle are innervated by the facial nerve (VII). The geniohyoid muscle is innervated by C1 fibers carried by the hypoglossal nerve (XII).



▲ **Figure 1–19.** Cervical plexus. Motor and sensory innervation of the neck. (Reproduced, with permission, from Lindner HH. Clinical Anatomy, McGraw-Hill, 1989.)

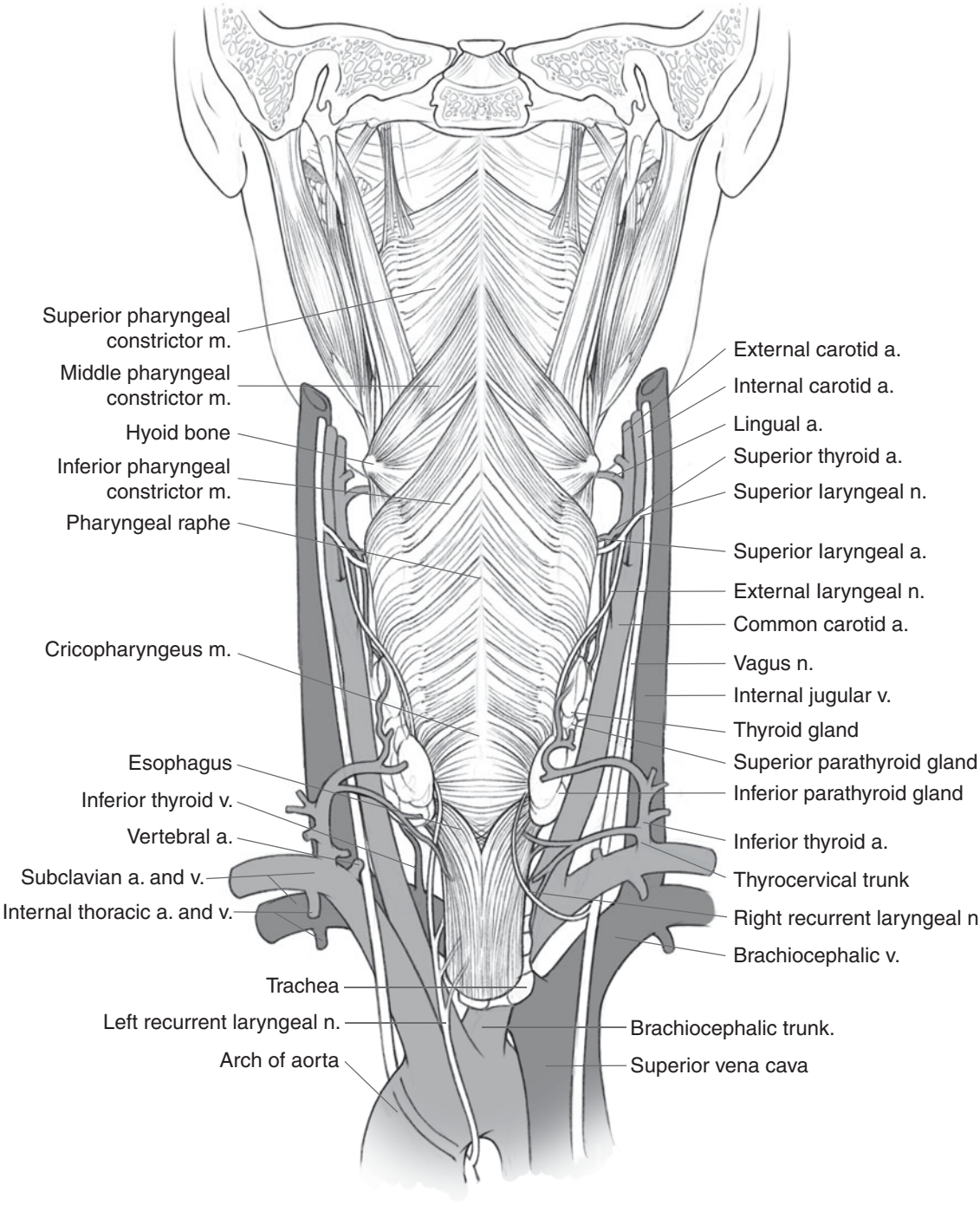
The prevertebral musculature and the scalene muscles receive motor innervation from direct branches of the cervical plexus. The sternocleidomastoid muscles and the trapezius muscles are innervated by the spinal accessory nerve (XI).

Vagus Nerve

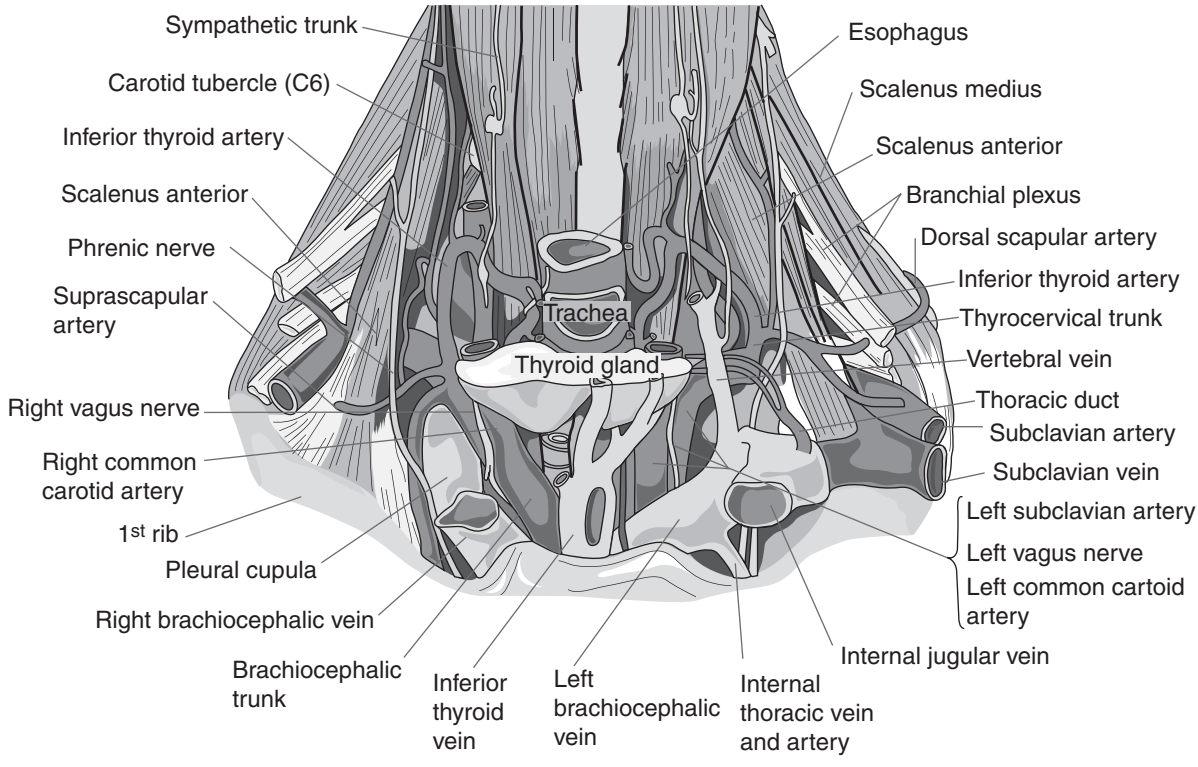
The vagus nerve (X) travels in the carotid sheath with the internal jugular vein and the carotid artery (Figures 1–20 and 1–21). In the neck, it has branches to the larynx, the pharynx, and the heart. The laryngeal and pharyngeal branches of the vagus nerve carry motor fibers that originate in the cranial component of the accessory nerve (XI).

A. Superior Laryngeal Nerve

The superior laryngeal nerve gives off two branches, the external and the internal laryngeal nerves. The external laryngeal nerve provides motor innervation to the cricothyroid muscle. The internal laryngeal nerve pierces the thyrohyoid membrane to enter the larynx. It carries sensation



▲ **Figure 1–20.** Structures in the carotid sheath and the thyroid gland.



▲ **Figure 1–21.** Root of the neck.

from the part of the larynx that lies above the vocal folds and also carries sensation from the piriform recess of the laryngopharynx.

B. Recurrent (Inferior) Laryngeal Nerve

The recurrent (inferior) laryngeal nerve provides motor innervation to all the muscles of the larynx, with the exception of the cricothyroid muscle, as previously described. In addition, it carries sensation from the part of the larynx that lies below the vocal folds and from the upper part of the trachea. It courses up the neck in the groove between the trachea and the esophagus. As a result of the differing development of the aortic arches on the right and left sides of the body, the right recurrent laryngeal nerve passes in front of the right subclavian artery and turns up and back around this vessel to course toward the larynx. In contrast, the left recurrent laryngeal nerve passes into the thorax and lies in front of the arch of the aorta before turning up and back around the aorta, behind the ligamentum arteriosum, to reach the larynx.

C. Pharyngeal Branches

The pharyngeal branches provide motor innervation to all the muscles of the pharynx, with the exception of the stylopharyngeus muscle, and to all the muscles of the palate, with the exception of the tensor veli palatini muscle.

D. Thoracic Branches

The cardiac branches descend into the mediastinum and provide parasympathetic innervation to the heart. Additional branches arise in the chest to provide parasympathetic innervation to the lungs.

E. Sensory Branches

The vagus has sensory branches that serve the meninges and the external ear.

Phrenic Nerve

The phrenic nerve arises from the ventral rami of cervical spinal nerves C3–5 and courses down in the prevertebral fascia, in front of the anterior scalene muscle, into the thorax between the subclavian artery and vein. It provides motor innervation to the diaphragm. In addition, it carries sensation from the mediastinal and diaphragmatic parietal pleura, the pericardium, and the parietal peritoneum under the diaphragm.

Sympathetic Trunk

The sympathetic trunk in the neck is an upward continuation of the thoracic part of the trunk and reaches the base of the skull, lying medial to the carotid sheath in the prevertebral fascia. Unlike the thoracic part of the trunk, which has a sympathetic ganglion associated with each spinal nerve, the cervical part of the trunk has only three ganglia. The inferior cervical ganglion lies near the first rib and is frequently fused with the first thoracic ganglion to form the stellate ganglion. The middle cervical ganglion lies at the level of the cricoid cartilage. The superior cervical ganglion lies at the base of the skull, just below the inferior opening of the carotid canal. The cervical sympathetic ganglia get preganglionic input from fibers that originate in the upper thoracic spinal cord and ascend in the sympathetic trunk to reach the neck. Postganglionic outflow from these ganglia passes to the cervical spinal nerves, the cardiac plexus, the thyroid gland, the pharyngeal plexus, and the neurons that form plexuses around the internal and external carotid arteries as those vessels course up to the head.

Fascial Planes

The deep fascia of the neck is thickened into several well-defined layers that are of clinical significance (Figure 1–22).

A. Investing Fascia

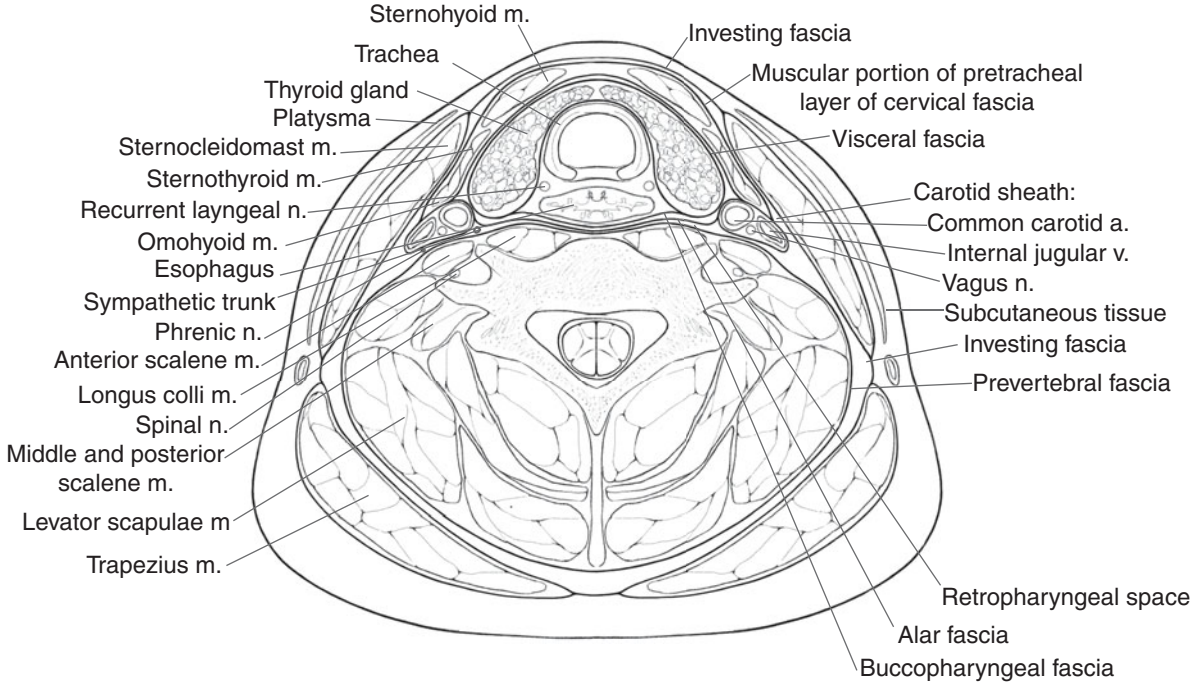
The investing fascia surrounds the neck, attached below to the sternum and the clavicle, and above to the lower border of the mandible, the zygomatic arch, the mastoid process, and the superior nuchal line of the occipital bone. The fascia splits to enclose the sternocleidomastoid and trapezius muscles and the submandibular and parotid salivary glands.

B. Prevertebral Fascia

The prevertebral fascia surrounds the prevertebral and postvertebral muscles, and is attached to the ligamentum nuchae in the back. It is attached to the base of the skull above and extends down into the mediastinum below. There is a potential space, the retropharyngeal space, between this fascial layer and the pharynx and esophagus, allowing for the free movement of these structures against the vertebral column. However, this arrangement also provides a communicating space that extends from the base of the skull down into the mediastinum, allowing for infections to easily track in either direction.

C. Carotid Sheath

The carotid sheath surrounds the carotid arteries, the internal jugular vein, the vagus nerve (X), and the deep cervical lymph nodes.



▲ **Figure 1–22.** Fascial planes of the neck. (Cross section at C7)

D. Visceral Fascia

The visceral fascia surrounds the thyroid and parathyroid glands and the infrahyoid muscles. It extends from its attachment to the thyroid cartilage above to the pericardium below and is fused with the carotid sheath and the investing fascia.

LARYNX

The larynx extends from the epiglottis and the aryepiglottic folds to the cricoid cartilage (Figure 1–23). It communicates with the laryngopharynx above—through the laryngeal aditus—and with the trachea below. Its lateral walls have two infoldings of mucous membrane: the vestibular folds above and the vocal folds below. The space between the two vestibular folds is called the rima vestibuli, and the space between the two vocal folds is called the rima glottidis. The part of the larynx that extends from the aditus to the rima vestibuli is called the vestibule of the larynx, and the part that lies between the rima vestibuli and the rima glottidis is called the ventricle of the larynx. The ventricle has a lateral extension, the saccule, between the vestibular fold and the thyroid cartilage. The mucous membrane of the larynx is primarily ciliated columnar epithelium. The larynx is made of cartilages and ligaments that are essential to its role in phonation.

Cartilages

A. Thyroid Cartilage

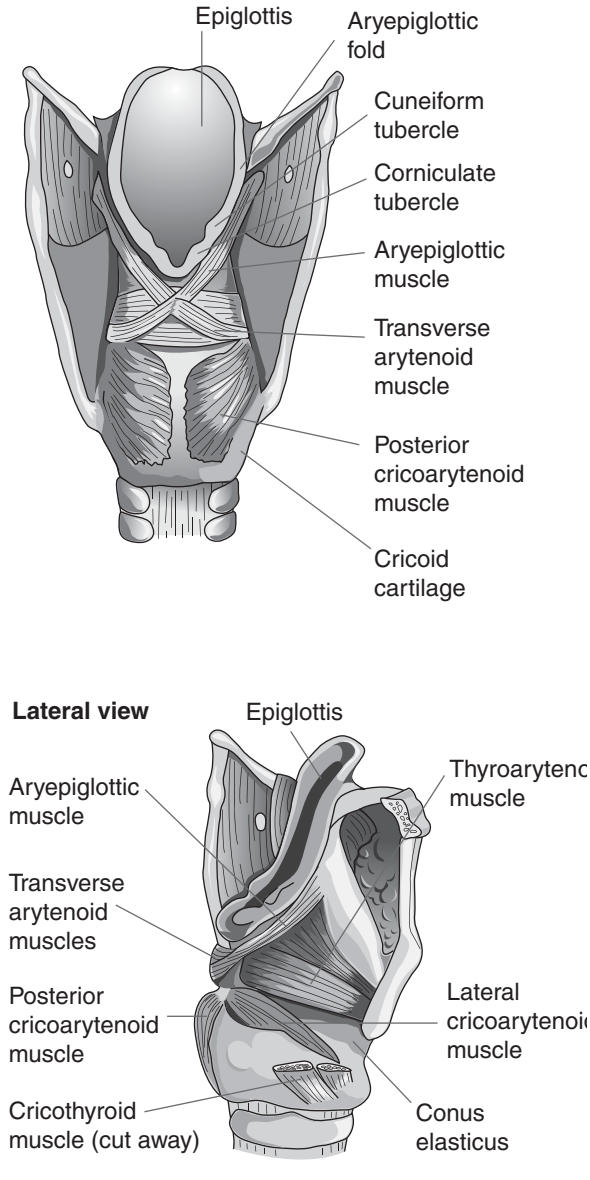
The thyroid cartilage (Adam's apple) makes up the bulk of the larynx, but is deficient posteriorly. It articulates with the cricoid cartilage below, which is narrow in front but taller in the back.

B. Arytenoid Cartilages

Articulating with the posterior lamina of the cricoid cartilage and lying directly behind the thyroid cartilage are the paired arytenoid cartilages. These cartilages have laterally extending muscular processes that allow for the attachment of several muscles of vocalization, and anteriorly extending vocal processes that allow for the attachment of the vocal ligaments.

C. Corniculate and Cuneiform Cartilages

The epiglottis forms the roof of the larynx. The aryepiglottic folds contain two additional pairs of cartilages, the corniculate and cuneiform, which add support to the folds.



▲ **Figure 1–23.** Muscles and cartilages of the larynx.

Ligaments

A. Thyrohyoid Ligament

The thyrohyoid ligament extends from the upper border of the thyroid cartilage to the hyoid bone above, anchoring the larynx to the hyoid bone and its associated muscles.

B. Quadrangular Ligament

The quadrangular ligament lies within the aryepiglottic folds, and its lower edge extends into the vestibular folds of the larynx.

C. Cricothyroid Ligament

The cricothyroid ligament (triangular ligament) extends upward from the upper border of the cricoid cartilage. However, it is not attached to the lower border of the thyroid cartilage. Instead, it ascends medial to the thyroid cartilage and is compressed sagittally, with its top edges forming the vocal ligaments that are attached to the inside of the thyroid cartilage in front and the vocal processes of the arytenoid cartilage behind.

Muscles

The muscles of the larynx change the spatial relationships of the laryngeal cartilages during speech and swallowing.

A. Posterior Cricoarytenoid Muscle

The posterior cricoarytenoid muscle arises from the posterior aspect of the cricoid cartilage and courses upward and laterally to attach to the muscular process of the arytenoid cartilage. Its contraction pulls the muscular process backward and rotates the arytenoid cartilage around a vertical axis so that the two vocal processes are abducted and the size of the rima glottidis is increased. In addition, the two arytenoid cartilages are approximated, an action that is similar to that of the transverse arytenoid muscle.

B. Lateral Cricoarytenoid Muscle

The lateral cricoarytenoid muscle arises from the front of the arch of the cricoid cartilage and courses upward and backward to attach to the muscular process of the arytenoid cartilage. Its contraction pulls the muscular processes forward and rotates the arytenoid cartilage around a vertical axis, in a direction opposite to the movement created by the contraction of the posterior cricoarytenoid muscle so that the vocal processes are adducted and the rima glottidis is closed. Additional contraction of the lateral cricoarytenoid muscle from this adducted position of the vocal ligaments, coupled with a relaxation of the transverse arytenoid muscle, pulls the two arytenoid cartilages away from each other, positioning the vocal folds for whispering, with approximated vocal ligaments but an open posterior rima glottidis.

C. Transverse Arytenoid Muscle

The transverse arytenoid muscle extends between the bodies of the two arytenoid cartilages, bringing them together by its contraction.

D. Thyroarytenoid Muscle

The thyroarytenoid muscle has fibers that run parallel with the vocal ligaments, attaching to the deep surface of the thyroid cartilage in front and the muscular process of the arytenoid cartilage behind. Its contraction brings the arytenoid and thyroid cartilages closer, decreases the length and tension of the vocal ligaments, and lowers the pitch of the voice. A part of the thyroarytenoid muscle that lies adjacent to the vocal ligament is called the vocalis muscle. Because its fibers attach to the vocal ligaments, this muscle can provide fine control of the tension in the vocal ligaments, allowing for rapid alterations in the pitch of the voice. When the vocalis muscle contracts by itself, without an accompanying contraction of the thyroarytenoid muscle, it can pull on the vocal ligaments, increase the tension in them, and raise the pitch of the voice.

E. Cricothyroid Muscle

The cricothyroid muscle arises from the front and side of the cricoid cartilage and courses upward and backward to attach to the inferior border of the posterior part of the thyroid cartilage. Its contraction produces a rocking movement at the joints between the thyroid and cricoid cartilages, so that the front of the cricoid is pulled upward and the cricoid cartilage is tilted backward. This moves the arytenoid cartilages farther from the thyroid cartilage and increases the tension in the vocal ligaments, raising the pitch of the voice.

F. Aryepiglottic Muscle

The aryepiglottic muscle arises from the muscular process of the arytenoid cartilage and extends into the epiglottis within the opposite aryepiglottic fold. Its contraction decreases the size of the laryngeal aditus and, combined with an elevation of the larynx by the suprahyoid muscles and longitudinal muscles of the pharynx as well as the push of the tongue on the epiglottis from above, prevents food from entering the larynx.

Innervation and Blood Supply

The vagus nerve (X) provides sensory and motor innervation to the larynx. These details are discussed with the vagus nerve in the neck. Briefly, sensation from the vestibule and ventricle of the larynx, above the vocal folds, is carried by the internal laryngeal branch of the vagus nerve, and sensation from below the vocal folds is carried by the recurrent laryngeal branch of the vagus nerve. Motor innervation of all the muscles of the larynx is by the recurrent laryngeal branch of the vagus nerve, except the cricothyroid muscle, which is innervated by the external laryngeal branch of the vagus nerve.

The superior laryngeal branch of the superior thyroid artery, a branch of the external carotid artery, supplies blood to the upper half of the larynx. The inferior laryngeal branch of the inferior thyroid artery, a branch of the thyrocervical trunk from the subclavian artery, supplies blood to the lower half the larynx.

ORBIT

The orbit lies between the frontal bone with the anterior cranial fossa above and the maxilla and maxillary sinus below. The sphenoid bone lies behind and separates the orbit from the middle cranial fossa. The zygomatic and sphenoid bones lie lateral to the orbit, and the ethmoid and sphenoid bones lie medial to it. The orbit communicates with the infratemporal fossa through the lateral end of the inferior orbital fissure and with the pterygopalatine fossa through the medial end of this fissure. In addition, the orbit communicates with the middle cranial fossa through the superior orbital fissure and the optic canal, and with the nose through the nasolacrimal canal. The structures in the orbit receive their blood supply from the ophthalmic branch of the internal carotid artery. The corresponding veins form the ophthalmic venous plexus, which communicates in front with the facial vein, behind with the cavernous sinus through the superior orbital fissure, and below with the pterygoid venous plexus through the inferior orbital fissure. The orbit contains the eye surrounded by orbital fat, the lacrimal gland, which lies above and lateral to the eye, the muscles that help move the eye, and the nerves and vessels related to these structures.

Muscles

All of the muscles of the orbit, with the exception of the inferior oblique, arise from the sphenoid bone at or near the opening of the optic canal behind the eye (Figure 1–24). They pass forward to attach to the sclera of the eye, except for the levator palpebrae superioris muscle, which inserts on the upper eyelid. The inferior oblique arises from the anterior and medial part of the floor of the orbit.

A. Levator Palpebrae Superious Muscle

The levator palpebrae superioris passes over the eye and attaches to the tarsal plate of the upper eyelid. It helps to elevate the eyelid and keep the eye open. A part of this muscle is made of smooth muscle fibers that get sympathetic innervation.

B. Superior Rectus Muscle

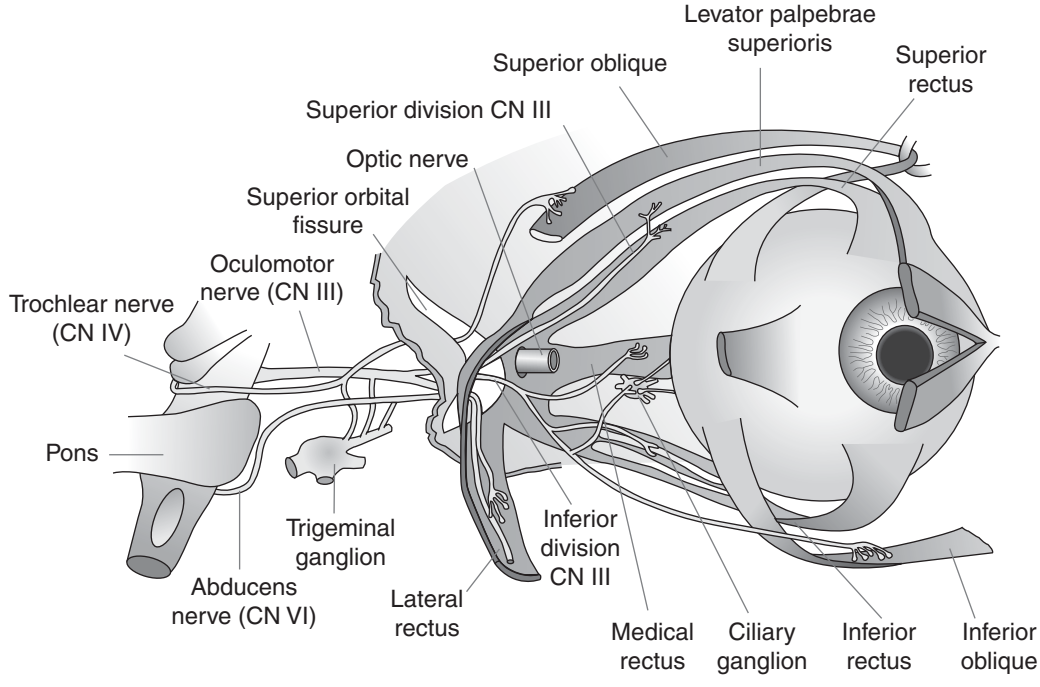
The superior rectus muscle passes over the eye and helps to turn the eye upward. It is assisted in this action by the inferior oblique muscle.

C. Inferior Rectus Muscle

The inferior rectus muscle passes below the eye and helps to turn the eye downward. It is assisted in this action by the superior oblique muscle.

D. Medial Rectus Muscle

The medial rectus muscle passes medial to the eye and helps to turn the eye medially.



▲ **Figure 1–24.** Muscles and nerves of the orbit.

E. Lateral Rectus Muscle

The lateral rectus muscle passes lateral to the eye and helps to turn the eye laterally.

F. Superior Oblique Muscle

The superior oblique muscle first passes around a fibrous pulley, the trochlea, which lies above and medial to the front of the eye. It then turns backward, downward, and laterally to attach to the sclera. Its contraction places the eye in a position of a downward and lateral gaze. In addition, the superior oblique muscle produces torsion of the eye around an anteroposterior axis such that the upper part of the eye is turned medially.

G. Inferior Oblique Muscle

The inferior oblique muscle passes upward, backward, and laterally from its origin to insert on the sclera. Its contraction places the eye in a position of an upward and lateral gaze. In addition, it produces torsion of the eye around an anteroposterior axis such that the upper part of the eye is turned laterally.

Muscle Testing

During clinical examination, the rectus muscles are tested by asking a patient to follow a target with her or his eyes in the directions of the expected actions of each muscle. The superior oblique muscle is tested for its ability to turn the eye downward, but the eye is first turned medially so that the inferior rectus muscle is unable to participate in this downward movement. Similarly, the inferior oblique muscle is tested by asking a patient to first turn the eye medially and then upward. With the eye placed in a direction of medial gaze, the superior and inferior rectus muscles are unable to assist the obliques as they normally would. In this situation, the superior and inferior oblique muscles are the only muscles that are optimally situated to turn the eye downward or upward, respectively, and are thus isolated and individually tested.

Innervation

The orbit is the location in which the ophthalmic division of the trigeminal nerve (V1) divides into its terminal branches after leaving the middle cranial fossa through the superior orbital fissure (Figure 1–25). The orbit also contains branches of the maxillary division of the trigeminal nerve (V2) and nerves that provide parasympathetic innervation to the lacrimal gland.

A. Sensory Innervation

1. Lacrimal nerve—The lacrimal nerve passes above and lateral to the eye and carries sensation from the lateral part of the upper eyelid.

2. Frontal nerve—The frontal nerve passes over the eye and divides into the supratrochlear and supraorbital nerves. The supratrochlear nerve exits the orbit above the trochlea and carries sensation from the skin of the forehead. The supraorbital nerve exits the orbit through the supraorbital notch (foramen) and carries sensation from the skin of the forehead that lies lateral to the area served by the supratrochlear nerve. The supraorbital nerve also carries sensation from the frontal sinuses.

3. Nasociliary nerve—The nasociliary nerve passes above and medial to the eye before giving off branches to the nose and the eye. The nasal component is made of the ethmoidal and nasal nerves that carry sensation from the roof of the nasal cavity, the skin of the bridge of the nose down to its tip, and the sphenoid and ethmoid sinuses. The ciliary component is made of the long and short ciliary nerves that carry sensation from the eye and cornea.

B. Motor Innervation

The orbit also contains nerves that enter the orbit through the superior orbital fissure and innervate the muscles of the eye.

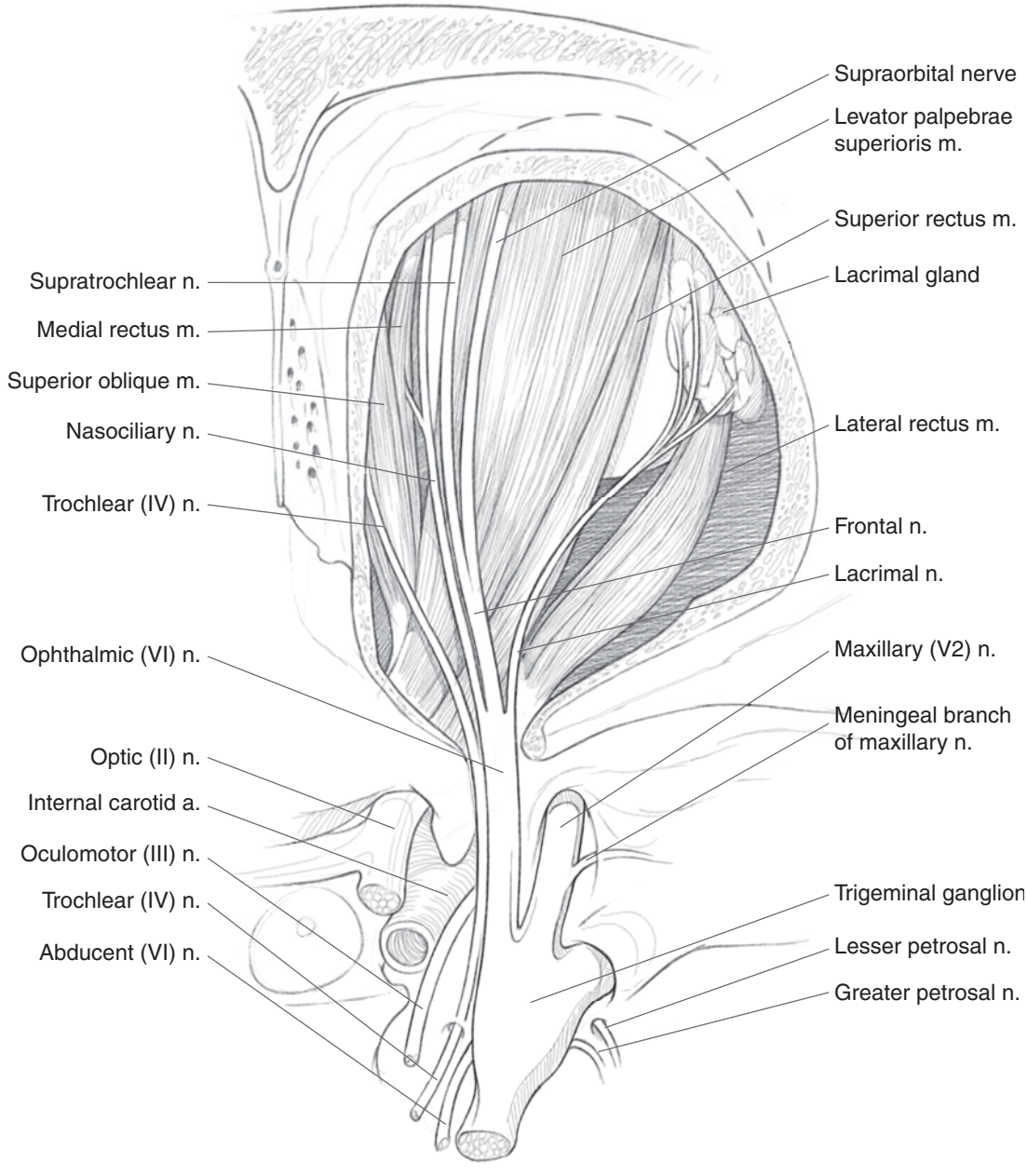
1. Oculomotor nerve—The oculomotor nerve (III) innervates the levator palpebrae superioris; the superior, inferior, and medial rectus muscles; and the inferior oblique muscles.

2. Trochlear nerve—The trochlear nerve (IV) innervates the superior oblique muscle.

3. Abducens nerve—The abducens nerve (VI) innervates the lateral rectus muscle.

C. Optic Nerve

The optic nerve (II) enters the orbit through the optic canal and is surrounded by the meninges, which fuse with the sclera. As a result of this arrangement, the cerebrospinal fluid in the subarachnoid space can extend up to the back of the sclera along the optic nerve. The nasal retina, which has a temporal field of view, transmits its visual information through optic nerve fibers that decussate at the optic chiasm to the optic tract of the opposite side. The temporal retina, which has a nasal field of view, transmits its visual information through optic nerve fibers that remain in the ipsilateral optic tract. Thus, the left optic tract contains fibers from the temporal retina of the left eye and the nasal retina of the right eye; it is responsible for carrying the visual information of objects that lie to the right of the body. Similarly, the right optic tract contains fibers from the temporal retina of the right eye and the nasal retina of the left eye; it is responsible for carrying the visual information of objects that lie to the left of the body.



▲ **Figure 1–25.** Ophthalmic nerve (V1) branches.

D. Autonomic Nerves

1. Parasympathetic nerves—The ciliary muscle and the sphincter pupillae muscle of the eye receive parasympathetic innervation from the oculomotor nerve (III). The preganglionic fibers arise in the Edinger–Westphal nucleus of the oculomotor nerve in the midbrain, travel on that nerve, and reach the ciliary ganglion in the orbit at which they synapse. From the ciliary ganglion, the postganglionic fibers travel on the short ciliary branches of the ophthalmic division of the trigeminal nerve (V1) and reach the eye and its

intrinsic muscles. Contraction of the sphincter pupillae muscle decreases the size of the pupillary opening, diminishing the amount of light entering the eye, while at the same time increasing the depth of field through which the eye remains focused. Contraction of the ciliary muscle relieves the tension in the suspensory ligaments of the lens, allows the lens to become more convex, and increases its power. Together, the actions of the intrinsic muscles help with accommodation of the eye.

2. Sympathetic nerves—The dilator pupillae muscle of the eye and a part of the levator palpebrae superioris muscle receive sympathetic innervation. The preganglionic neurons originate in the thoracic spinal cord and ascend in the sympathetic trunk to synapse in the superior cervical ganglion in the neck. Postganglionic neurons leave the superior cervical ganglion to ascend as a plexus around the internal carotid artery and then around its ophthalmic branch to reach the orbit. In the orbit, the sympathetic neurons travel on the ciliary branches of the ophthalmic division of the trigeminal nerve (V1) to reach the eye and its dilator pupillae muscle, while the sympathetic neurons to the levator palpebrae superioris muscle reach it on further branches of the ophthalmic artery. Contraction of the dilator pupillae muscle increases the size of the pupillary opening, increasing the amount of light entering the eye. Contraction of the levator palpebrae superioris elevates the upper eyelid; therefore, the loss of either its sympathetic innervation or its innervation by the oculomotor nerve produces ptosis.

PTERYGOPALATINE FOSSA

The pterygopalatine fossa is a small space that lies directly in front of the pterygoid plates of the sphenoid bone and behind the maxilla. Its floor is formed by the upper end of the palatine canal, its roof by the medial half of the inferior orbital fissure, its lateral wall by the pterygomaxillary fissure, and its medial wall by the sphenopalatine foramen and perpendicular plate of the palatine bone. Through the palatine canal, which opens in the hard palate, the pterygopalatine fossa communicates with the oral cavity below; through the inferior orbital fissure, which opens behind the floor of the orbit, the pterygopalatine fossa communicates with the orbital cavity above; through the pterygomaxillary fissure, the pterygopalatine fossa communicates with the infratemporal fossa that lies lateral to it; and through the sphenopalatine foramen, which opens near the roof of the back of the nose, the pterygopalatine fossa communicates with the nasal cavity that lies medial to it. The maxillary sinus lies in front of the pterygopalatine fossa, whereas the foramen rotundum and the pterygoid canal lead into it from behind.

The maxillary artery enters the pterygopalatine fossa after branching from the external carotid artery in the substance of the parotid gland and passing through the infratemporal fossa and the pterygomaxillary fissure. The pterygopalatine fossa is the location at which the maxillary division of the trigeminal nerve (V2) divides into its terminal branches after it leaves the middle cranial fossa through the foramen rotundum (Figure 1–26). The branches of the maxillary artery essentially match the branches of the maxillary division of the trigeminal nerve that originate in and travel out of the pterygopalatine fossa.

Maxillary Nerve Branches

The branches of the maxillary nerve are all named for the area from which they carry sensation.

A. Greater Palatine Nerve

The greater palatine nerve courses down through the palatine canal and, on reaching the palate, turns forward to carry sensation from most of the hard palate with the exception of a small area behind the upper incisor teeth. While in the palatine canal, it sends branches that pierce through the bony medial wall of the canal, formed by the perpendicular plate of the palatine bone, and carries sensation from the lateral wall of the nose. These are the lateral nasal nerves.

B. Lesser Palatine Nerve

The lesser palatine nerve also courses down through the palatine canal, but on reaching the palate, it turns backward to carry sensation from the soft palate.

C. Infraorbital Nerve

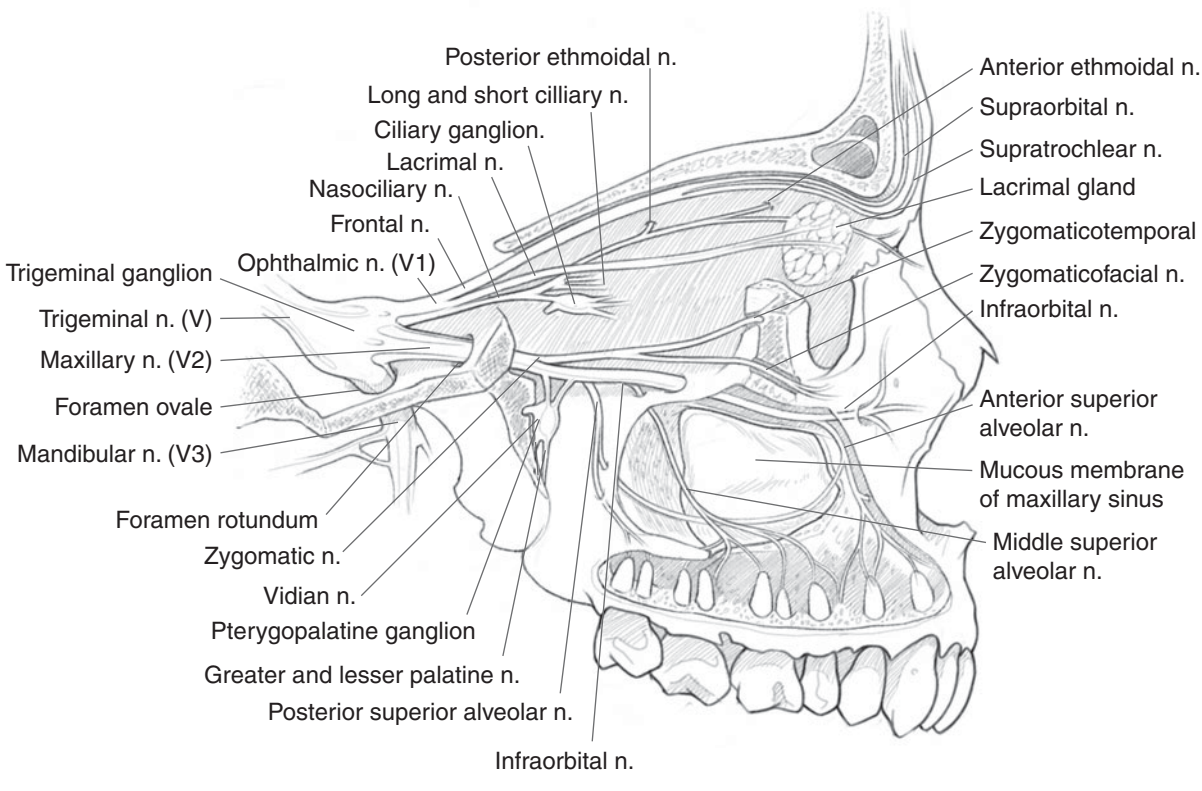
The infraorbital nerve courses up through the inferior orbital fissure and on reaching the orbital floor, it turns forward and runs in a bony canal in the floor of the orbit to emerge on the face through the infraorbital foramen. While running forward in the floor of the orbit, the infraorbital nerve lies in the roof of the maxillary sinus and gives branches that carry sensation from the roots of the upper premolar teeth, the middle superior alveolar nerve, and the roots of the upper canines and incisors, the anterior superior alveolar nerve. Once it reaches the face, the infraorbital nerve carries sensation from an area of skin that extends from the lower eyelid to the upper lip.

D. Zygomatic Nerve

The zygomatic nerve courses up through the inferior orbital fissure and up the lateral wall of the orbit. It then branches into the zygomaticofacial and zygomaticotemporal nerves, which pierce through the zygomatic bone, turning forward onto the skin of the face and backward onto the temple, respectively, from where they carry sensation.

E. Posterior Superior Alveolar Nerve

The posterior superior alveolar nerve courses laterally through the pterygomaxillary fissure and, on reaching the infratemporal fossa, pierces the back of the maxilla and carries sensation from the roots of the upper molars.



▲ **Figure 1–26.** Maxillary nerve (V2) branches.

F. Nasopalatine Nerve

The nasopalatine nerve courses medially through the sphenopalatine foramen and then over the roof of the nose to reach the nasal septum. Here, it turns forward and downward and travels along the septum to reach the incisive canal, emerging behind the upper incisors. It carries sensation from the nasal septum and the anterior part of the hard palate in an area just behind the upper incisors.

Autonomic Nerves

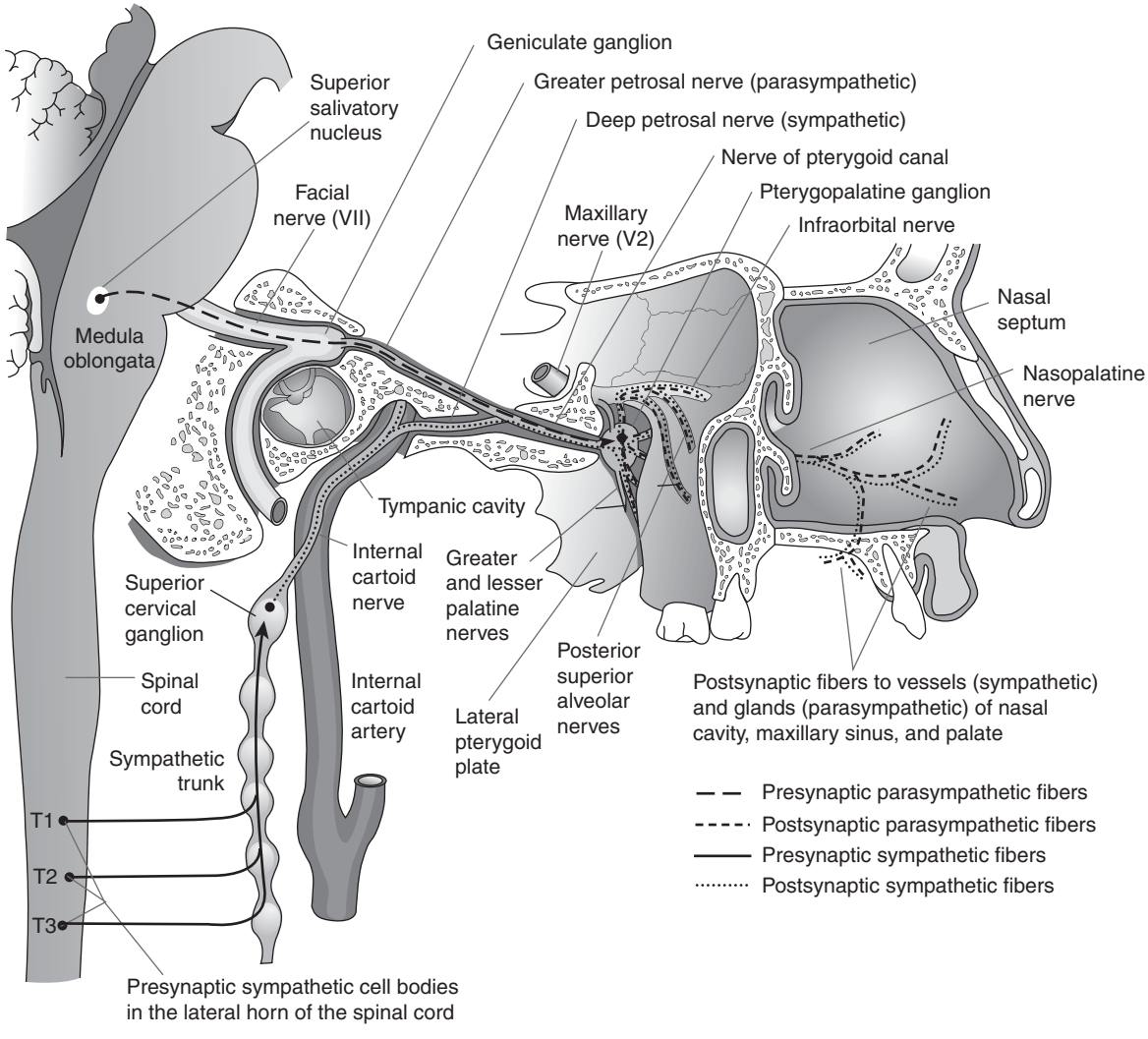
The pterygoid canal allows the carotid canal behind to communicate with the pterygopalatine fossa in front. It passes forward in the floor of the sphenoid sinus and transmits the nerve of the pterygoid canal (Vidian nerve), which has both sympathetic and parasympathetic components.

A. Deep Petrosal Nerve

The sympathetic component of the nerve of the pterygoid canal is the deep petrosal nerve, which is composed of postganglionic sympathetic neurons. The preganglionic neurons originate in the thoracic spinal cord and ascend in the sympathetic trunk to synapse in the superior cervical ganglion in the neck. Postganglionic neurons leave the superior cervical ganglion to ascend as a plexus around the internal carotid artery. Some of these postganglionic sympathetic neurons branch off the carotid plexus, in the carotid canal, and form the deep petrosal nerve, which enters the pterygoid canal to reach the pterygopalatine fossa. These sympathetic neurons then join branches of the maxillary artery and travel on their walls. Because these are postganglionic neurons that reach the pterygopalatine fossa, they do not synapse in the pterygopalatine ganglion.

B. Greater Superficial Petrosal Nerve

The parasympathetic component of the nerve of the pterygoid canal is the greater superficial petrosal nerve, which is composed of preganglionic parasympathetic neurons. These originate in the lacrimal nucleus of the facial nerve (VII) and course within the petrous part of the temporal bone before emerging on its superior surface as the greater superficial petrosal nerve, which then turns down into the carotid canal and forward into the pterygoid canal to reach the pterygopalatine fossa (Figure 1–27). There, the pregan-

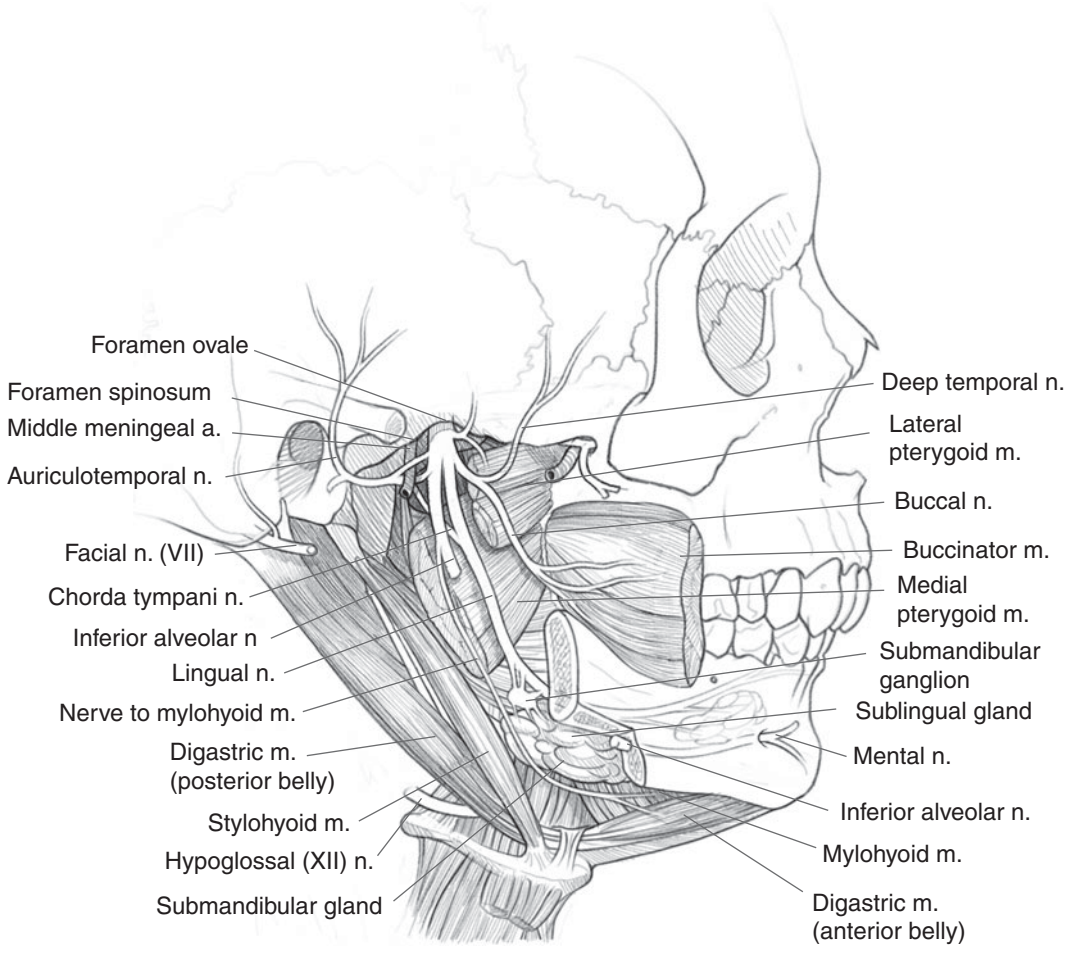


▲ **Figure 1–27.** Schematic of the innervation of the glands in the nose, mouth, and orbit by the facial nerve (VII).

glionic parasympathetic neurons synapse in the pterygopalatine ganglion. The postganglionic parasympathetic neurons then join branches of the maxillary division of the trigeminal nerve (V2) and reach mucous secreting glands in the paranasal sinuses, the palate, and the nose, to which they are secretomotor. Some postganglionic parasympathetic neurons travel on the zygomatic branch of the maxillary division of the trigeminal nerve (V2) as it courses up the lateral wall of the orbit. When the zygomatic nerve leaves the orbit by piercing through the zygomatic bone, the postganglionic parasympathetic neurons leave the zygomatic nerve, continue up the lateral wall of the orbit, and join the lacrimal branch of the ophthalmic division of the trigeminal nerve to reach the lacrimal gland, to which they are secretomotor.

INFRATEMPORAL FOSSA

The infratemporal fossa lies between the mandible laterally and the lateral pterygoid plate of the sphenoid bone medially. The maxilla lies in front and the petrous part of the temporal bone behind. It is bounded above by the base of the skull and extends down to the level of the angle of the mandible. It communicates with the temporal fossa above and with the pterygopalatine fossa medial to it. The maxillary sinus lies in front of it and the temporomandibular joint behind. The maxillary artery gives off several branches here, before passing into the pterygopalatine fossa. The infratemporal fossa is the location at which the mandibular division of the trigeminal nerve (V3) divides into its terminal branches after



▲ **Figure 1–28.** Mandibular nerve (V3) branches.

leaving the middle cranial fossa through the foramen ovale (Figure 1–28).

Muscles

The muscles of the infratemporal fossa are responsible for movements of mastication (Figure 1–29).

A. Temporalis Muscle

The temporalis muscle arises from the temporal bone and passes medial to the zygomatic arch to attach to the coronoid process of the mandible. Its anterior fibers elevate the mandible, and its posterior fibers retract the mandible.

B. Masseter Muscle

The masseter muscle arises from the lower border of the zygomatic arch and attaches to the lateral aspect of the angle of the mandible. Its contraction elevates the mandible.

C. Lateral Pterygoid Muscle

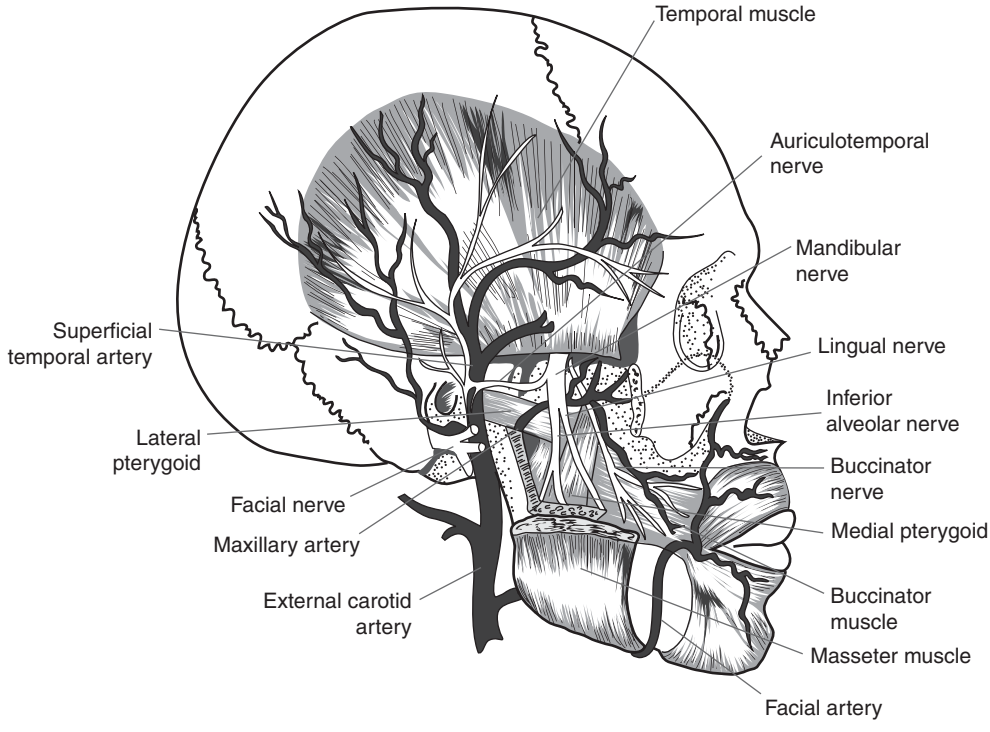
The lateral pterygoid muscle arises from both the lateral aspect of the lateral pterygoid plate and the sphenoid bone above, attaching to the neck of the mandible and the articular disc of the temporomandibular joint. Its contraction protracts the mandible along with the articular disc.

D. Medial Pterygoid Muscle

The medial pterygoid muscle arises from the medial aspect of the lateral pterygoid plate and attaches to the medial aspect of the angle of the mandible. Its contraction, like the masseter muscle, elevates the mandible.

Temporomandibular Joint

The temporomandibular joint lies between the head of the mandible and a fossa in the temporal bone. The capsule of the joint is attached to the neck of the mandible below



▲ **Figure 1–29.** Muscles of mastication and the infratemporal fossa. (Reproduced, with permission, from Lindner HH. Clinical Anatomy, McGraw-Hill, 1989.)

and the margins of the mandibular fossa above. The joint is strengthened on its medial side by the sphenomandibular ligament, on its lateral side by the temporomandibular ligament, and behind by the stylomandibular ligament.

The joint contains a fibrocartilaginous, intracapsular articular disc that divides the joint into upper and lower synovial cavities. Translational movements of the joint, produced by the protraction and retraction of the mandible, occur in the upper joint cavity such that the articular disc moves with the head of the mandible. Rotational movements of the joint, produced by elevation and depression of the mandible, occur in the lower joint cavity such that the mandibular head rotates while the articular disc remains stationary.

Protraction of the mandible is produced primarily by the lateral pterygoid muscle, assisted by the medial pterygoid and masseter muscles, whereas retraction is produced by the posterior fibers of the temporalis muscle. Elevation of the mandible (clenching the teeth) is produced by the anterior fibers of the temporalis, the masseter, and the medial pterygoid muscles. Depression of the mandible (opening the mouth) is produced by the suprahyoid muscles—namely, the geniohyoid, mylohyoid, and digastric muscles, with the infrahyoid muscles serving to hold the hyoid bone in place. As the mouth opens wide, the head of the mandible must be protracted out of the mandibular fossa; this movement is brought about by the lateral pterygoid muscle. Closing the mouth from this position requires an initial retraction of the mandible so that the head of the mandible and the articular disc are replaced into the mandibular fossa by the posterior fibers of the temporalis muscle. Side-to-side movements of the mandible are produced by contractions of the medial and lateral pterygoid muscles from one side, joined by the posterior fibers of the temporalis muscle of the other side, alternating with the opposite set of muscles.

Mandibular Nerve Branches

Unlike the ophthalmic (V1) and maxillary (V2) divisions of the trigeminal nerve, which are purely sensory in their roles, the mandibular division of the trigeminal nerve (V3) has both sensory and motor functions. Its motor branches supply all the muscles of mastication, and also the tensor veli palatini muscle, the tensor tympani muscle, the mylohyoid muscle, and the anterior belly of the digastric muscle. These are all muscles that develop from the first branchial arch. The mandibular division of the trigeminal nerve reaches the infratemporal fossa through the foramen ovale and gives off

branches that carry sensation from the areas for which they are named.

A. Buccal Nerve

The buccal nerve, which courses into the cheek, pierces the buccinator muscle but does not innervate it. This nerve carries sensation from the skin over the cheek and the mucous membrane within.

B. Lingual Nerve

The lingual nerve courses into the tongue and carries general sensation from the anterior two-thirds of the tongue. The chorda tympani branch of the facial nerve (VII) reaches the infratemporal fossa by passing through the petrotympanic fissure and joins the lingual nerve. It contains preganglionic parasympathetic fibers from the superior salivary nucleus that are secretomotor to the submandibular and sublingual salivary glands. It also contains fibers that carry the sensation of taste from the anterior two-thirds of the tongue. Additional details of the chorda tympani and the lingual nerve are described in the sections on the salivary glands and the mouth.

C. Inferior Alveolar Nerve

The inferior alveolar nerve courses into the mandibular canal and carries sensation from the roots of the lower teeth. It emerges onto the face through the mental foramen as the mental nerve and carries sensation from the lower lip and the skin of the chin. Before it enters the mandible, the inferior alveolar nerve gives off a motor branch, the nerve to the mylohyoid muscle, which innervates the mylohyoid and anterior belly of the digastric muscles.

D. Auriculotemporal Nerve

The auriculotemporal nerve courses backward, deep to the temporomandibular joint, and ascends onto the scalp, in front of and above the auricle, to carry sensation from that area. In the infratemporal fossa, the auriculotemporal nerve is split by the middle meningeal branch of the maxillary artery. The preganglionic parasympathetic fibers for the secretomotor pathway to the parotid gland originate in the inferior salivary nucleus, travel on the lesser superficial petrosal branch of the glossopharyngeal nerve, and synapse at the otic ganglion. Postganglionic fibers from the otic ganglion, which lies just below the foramen ovale, join the auriculotemporal nerve to reach the parotid gland. Additional details are described in the section on salivary glands.

Maxillary Artery

The maxillary artery, a branch of the external carotid artery, courses into the infratemporal fossa and passes through the pterygomaxillary fissure to reach the pterygopalatine fossa. It can pass either superficially or deep to the lateral pterygoid muscle and supplies blood, through several branches, to the structures that lie in the infratemporal fossa.

One branch, the inferior alveolar artery, enters the mandibular canal with the corresponding nerve. Another branch, the middle meningeal artery, splits the auriculotemporal nerve and passes through the foramen spinosum to enter the middle cranial fossa. The deep temporal arteries course up to the temporalis muscle, lying between the muscle and the skull.

Pterygoid Venous Plexus

The veins that correspond to the branches of the maxillary artery form a plexus in the infratemporal fossa, which is continuous with the plexus of veins in the pterygopalatine fossa, and is collectively called the pterygoid venous plexus. The pterygoid venous plexus communicates with the ophthalmic venous plexus through the inferior orbital fissure and with the cavernous sinus through the foramen ovale and rotundum. The interconnections of these venous plexuses among themselves and with the facial vein are described in the section on the face.

CRANIAL NERVES

The cranial nerves are depicted in Figure 1–30.

OLFACTORY NERVE

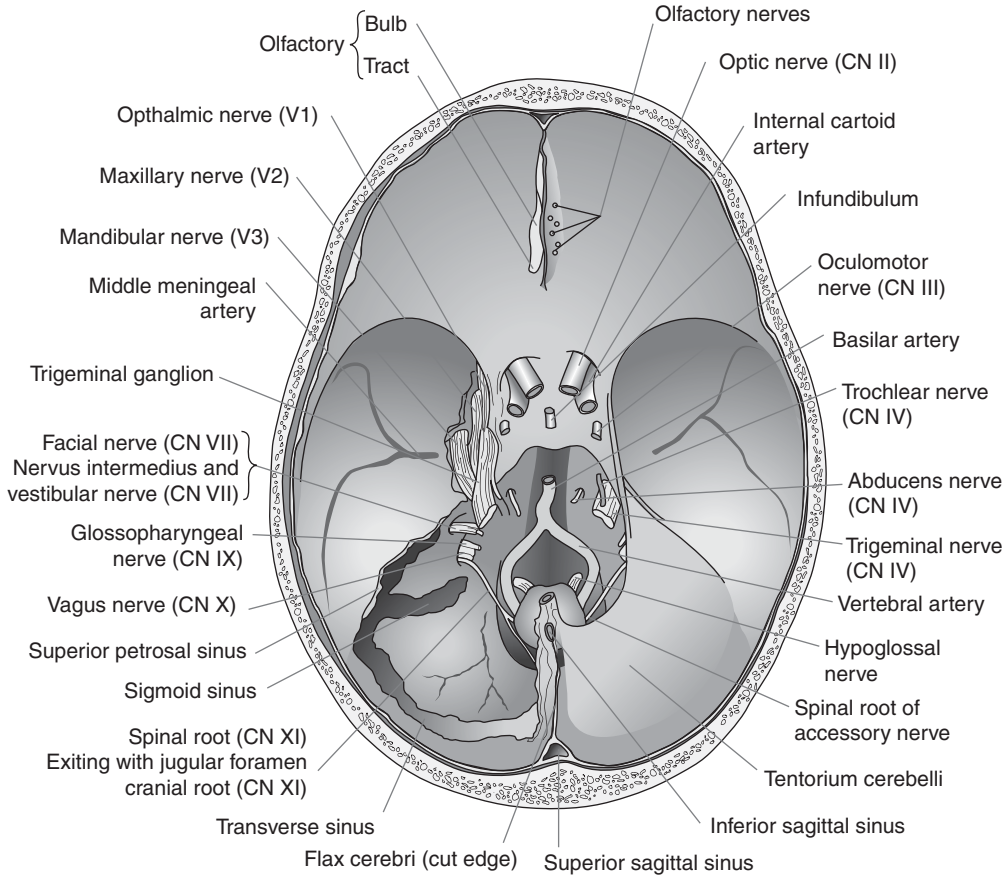
The olfactory nerve (I) carries the sensation of smell. It is solely a sensory nerve. Its fibers pass through the cribriform plate of the ethmoid bone into the olfactory bulb lying in the anterior cranial fossa, carrying the sensations of smell from the olfactory mucosa in the roof of the nose. From the olfactory bulb, the olfactory tracts pass back to the cerebrum.

OPTIC NERVE

The optic nerve (II), which is also only a sensory nerve, carries visual information from the eye. Its fibers originate from the ganglion cells of the retina and leave the orbital cavity through the optic canal. Fibers from the nasal retina decussate at the optic chiasm, which lies just above the pituitary gland. The optic tract passes backward from the chiasm and around the midbrain to reach the lateral geniculate body, from where most fibers pass to the visual cortex.

OCULOMOTOR NERVE

The oculomotor nerve (III) innervates muscles that move the eye. It is solely a motor nerve. In addition, it has a parasympathetic role as described below. Its fibers originate in



▲ **Figure 1–30.** Cranial nerves in the interior of the base of the skull.

the midbrain and pass medial to the cerebral peduncles, through the interpeduncular cistern and between the posterior cerebral and superior cerebellar branches of the basilar artery. It then passes through the lateral wall of the cavernous sinus and enters the orbit through the superior orbital fissure, where it innervates the levator palpebrae superioris, the inferior oblique, and the superior, medial, and inferior rectus muscles.

TROCHLEAR NERVE

The trochlear nerve (IV) innervates one muscle, the superior oblique, which moves the eye. It is solely a motor nerve. It is the only cranial nerve that arises from the posterior aspect of the brain and it has a long intracranial course. It runs forward around the cerebral peduncles, lying medial to the tentorium cerebelli. It then passes through the lateral wall of the cavernous sinus and enters the orbit through the superior orbital fissure, where it innervates the superior oblique muscle.

TRIGEMINAL NERVE

The trigeminal nerve (V) is the main sensory nerve for the face and deeper structures. It is both a sensory and a motor nerve. It innervates all the muscles of mastication and other muscles that are derived from the first branchial arch, including the tensor tympani muscle. In addition, it allows postganglionic parasympathetic fibers to travel on its branches to reach their target organs in the head. Its fibers arise from the anterolateral surface of the pons and course forward through the posterior cranial fossa to the trigeminal ganglion, which lies at the apex of the petrous part of the temporal bone in a dural cave. It is here that the cell bodies of the first-order sensory neurons from all sensory branches of the trigeminal nerve are located. The three divisions of the trigeminal nerve separate at the trigeminal ganglion.

Divisions of the Trigeminal Nerve

A. Ophthalmic Nerve

The ophthalmic division of the trigeminal nerve (V1) continues forward in the lateral wall of the cavernous sinus and passes through the superior orbital fissure to enter the orbit.

B. Maxillary Nerve

The maxillary division of the trigeminal nerve (V2) also continues forward from the ganglion and leaves the middle cranial fossa through the foramen rotundum to enter the pterygopalatine fossa.

C. Mandibular Nerve

The mandibular division of the trigeminal nerve (V3) continues downward and leaves the middle cranial fossa through the foramen ovale to enter the infratemporal fossa. In addition to the sensory fibers, the motor fibers of the trigeminal nerve leave the pons and, at the trigeminal ganglion, join the mandibular division to course out of the foramen ovale and reach the infratemporal fossa.

ABDUCENS NERVE

The abducens nerve (VI) innervates one muscle that moves the eye. It is solely a motor nerve. Its fibers originate just above the medullary pyramids, have a long intracranial course, and pass into the cavernous sinus. It courses through the middle of the sinus with the internal carotid artery, to which it is approximated. The abducens nerve enters the orbit through the superior orbital fissure, where it innervates the lateral rectus muscle.

FACIAL NERVE

The facial nerve (VII) innervates the muscles of facial expression and all other muscles that are derived from the second branchial arch. It carries the sensation of taste from the front of the tongue. It is both a sensory and a motor nerve. In addition, it has a parasympathetic role as described below. Its fibers originate at the pontomedullary junction, leave the posterior cranial fossa through the internal acoustic meatus, and enter the facial canal in the petrous part of the temporal bone. It has a motor root, and another part, the nervus intermedius, which is responsible for carrying the sensation of taste and for parasympathetic innervation to glands of the head.

Motor Root of Facial Nerve

The motor root travels through the facial canal and innervates the stapedius muscle. Then, the motor root turns down to emerge from the stylomastoid foramen. Here, it gives off branches to the posterior belly of the digastric and the stylohyoid muscles, whose posterior attachments are adjacent to the stylomastoid foramen. From here, the motor root lies in the substance of the parotid gland and gives off branches to the muscles of facial expression.

Nervus Intermedius

The nervus intermedius part of the facial nerve gives off two branches.

A. Chorda Tympani

The chorda tympani courses laterally through the petrous part of the temporal bone, enters the middle ear, and courses forward on the inner surface of the eardrum. It leaves the middle ear by turning down through the petrotympanic fissure and reaches the infratemporal fossa. It plays a role in carrying the sensation of taste from the anterior two-thirds of the tongue. In addition, it is secretomotor to the submandibular and sublingual salivary glands. The sensory ganglion for the facial nerve (VII) is the geniculate ganglion, which lies in the petrous part of the temporal bone.

B. Greater Superficial Petrosal Nerve

The greater superficial petrosal nerve, after coursing laterally in the facial canal, turns medially in the petrous part of the temporal bone and emerges on its superior surface. Then it turns down into the carotid canal and forward into the pterygoid canal to reach the pterygopalatine fossa. It is secretomotor to the mucous glands of the sinuses and also to the lacrimal gland.

VESTIBULOCOCHLEAR NERVE

The vestibulocochlear nerve (VIII) carries sensory information from the vestibule and the cochlea. It is solely a sensory nerve. The vestibular fibers arise from the vestibular ganglion while the cochlear fibers arise from the spiral ganglion, in the petrous part of the temporal bone. The vestibular fibers carry sensory information about the position and angular rotation of the head, both necessary to maintain equilibrium. The cochlear fibers carry the stimuli of hearing. The sensory fibers emerge from the internal acoustic meatus and reach the brain at the pontomedullary junction.

GLOSSOPHARYNGEAL NERVE

The glossopharyngeal nerve (IX) carries sensation from the pharynx and tongue. It also innervates one muscle of the pharynx that develops from the third branchial arch. It is both a sensory and a motor nerve. In addition, it has a parasympathetic role as described below. Its fibers arise from the medulla and leave the posterior cranial fossa through

the jugular foramen. Behind the pharynx, it lies with the stylopharyngeus muscle, which it innervates. In the pharynx, the glossopharyngeal nerve contributes to the pharyngeal plexus, carrying sensation from most of the pharynx and the posterior third of the tongue. In addition, as it emerges from the jugular foramen, the glossopharyngeal nerve gives off a branch that enters the petrous part of the temporal bone and reaches the tympanic cavity to form the tympanic plexus which carries sensation from the middle ear. These fibers then emerge on the surface of the petrous part of the temporal bone in the middle cranial fossa as the lesser superficial petrosal nerve which exits the skull through the foramen ovale and is secretomotor to the parotid gland. The sensory ganglia for the glossopharyngeal nerve lie just below the jugular foramen.

VAGUS NERVE

The vagus nerve (X) innervates the muscles of the palate, the pharynx, and the larynx, with some exceptions. It carries sensation from the larynx. It is both a sensory and a motor nerve. In addition, it has a parasympathetic role as described below. Its fibers arise from the medulla, are joined by the cranial root of the accessory nerve, and leave the posterior cranial fossa through the jugular foramen. Thus, the laryngeal and pharyngeal branches of the vagus nerve carry motor fibers that originated in the cranial component of the accessory nerve (XI).

Innervation

A. Motor Innervation

1. Palate—All the muscles of the palate, except for the tensor veli palatini, are innervated by the vagus nerve (X). The tensor veli palatini is innervated by the mandibular division of the trigeminal nerve (V3).

2. Pharynx—All the muscles of the pharynx, except for the stylopharyngeus, are innervated by the vagus nerve (X). The stylopharyngeus muscle is innervated by the glossopharyngeal nerve (IX).

3. Larynx—All the muscles of the larynx, except for the cricothyroid muscle, are innervated by the recurrent laryngeal branch of the vagus nerve (X). The cricothyroid muscle is innervated by the external laryngeal branch of the vagus nerve.

B. Sensory Innervation

The sensory ganglia for the vagus lie just below the jugular foramen. The superior laryngeal branch of the vagus nerve carries sensation from the upper part of the larynx, above the vocal folds, whereas the recurrent laryngeal branch of the vagus nerve carries sensation from the lower part of the larynx.

ACCESSORY NERVE

The accessory nerve (XI) innervates two muscles in the neck and is solely a motor nerve. It has a cranial root and a spinal root. The fibers of the cranial root arise from the medulla. The fibers of the spinal root originate from the upper spinal cord segments (C1–5) and ascend into the skull to join the cranial root. The two roots separate almost immediately. The fibers of the cranial root join the vagus nerve (X) in the posterior cranial fossa, exit through the jugular foramen, and are distributed in the motor branches of the vagus nerve to the pharynx, the larynx, and the palate. The fibers of the spinal root reach the neck by passing through the jugular foramen and innervate the sternocleidomastoid and trapezius muscles.

HYPOGLOSSAL NERVE

The hypoglossal nerve (XII) innervates the muscles of the tongue and is solely a motor nerve. Its fibers arise from the medulla, leave the posterior cranial fossa through the hypoglossal canal, and go on to innervate the extrinsic and intrinsic muscles of the tongue.

AUTONOMIC INNERVATION

A. Sympathetic Innervation

The sympathetic innervation of the head and neck is from the thoracic sympathetic outflow. The preganglionic neurons originate in the thoracic spinal cord and ascend in the sympathetic trunk to synapse in the middle and superior cervical ganglia in the neck. From here, postganglionic sympathetic fibers travel as plexuses on the branches of the internal and external carotid arteries to reach target structures in the head and neck.

B. Parasympathetic Innervation

The oculomotor (III), facial (VII), glossopharyngeal (IX), and vagus (X) nerves are the four cranial nerves that carry the parasympathetic outflow from the brain to most of the body. Parasympathetic innervation of the pelvic organs and lower gastrointestinal tract is from the sacral parasympathetic outflow (S2–4).

1. Ciliary ganglion—Preganglionic parasympathetic fibers from the Edinger–Westphal nucleus travel on the oculomotor nerve (III) and synapse at the ciliary ganglion (see Figure 1–24). Postganglionic fibers from the ciliary ganglion join the short ciliary branches of the ophthalmic division of the trigeminal nerve (V1) to reach the ciliary muscle and the sphincter pupillae muscle of the eye.

2. Pterygopalatine ganglion—Preganglionic parasympathetic fibers from the lacrimal nucleus travel on the greater

superficial petrosal branch of the facial nerve (VII) and synapse at the pterygopalatine ganglion (see Figure 1–27). Postganglionic fibers from the pterygopalatine ganglion join branches of the maxillary division of the trigeminal nerve (V2) to reach the lacrimal gland and the mucous secreting glands of the nose and mouth.

3. Submandibular ganglion—Preganglionic parasympathetic fibers from the superior salivary nucleus travel on the chorda tympani branch of the facial nerve (VII) and synapse at the submandibular ganglion (see Figure 1–9). Postganglionic fibers from the submandibular ganglion join the lingual branch of the mandibular division of the trigeminal nerve (V3) to reach the submandibular and sublingual salivary glands.

4. Otic ganglion—Preganglionic parasympathetic fibers from the inferior salivary nucleus travel on the lesser superficial petrosal branch of the glossopharyngeal nerve (IX) and synapse at the otic ganglion (see Figure 1–8). Postganglionic fibers from the otic ganglion join the auriculotemporal branch of the maxillary division of the trigeminal nerve (V3) to reach the parotid salivary gland.

5. Visceral ganglia—The vagus nerve (X) is the only cranial nerve that leaves the head and neck. It carries preganglionic parasympathetic fibers to the rest of the body, with the exception of the pelvic organs and organs associated with the hindgut. These fibers synapse at ganglia in the walls of the organ being innervated, from where short postganglionic fibers serve their secretomotor role.

2 Antimicrobial Therapy for Head & Neck Infection

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A summary of empiric antimicrobial therapy for common conditions encountered in otolaryngology can be found in Table 2–1. In general, when culture and susceptibility data are finalized, it is important to use the narrowest agent possible. This may not only be cost effective in many cases but will also decrease selection pressure for the development of antimicrobial resistance.

ANTIBACTERIAL AGENTS

PENICLLINS

Penicillins are a large group of β-lactam antibiotics. All share a common nucleus (6-aminopenicillanic acid) that contains a β-lactam ring, which is the biologically active moiety. The drugs work by binding to penicillin-binding proteins on the bacterial cell wall, which inhibits peptidoglycan synthesis. They also activate autolytic enzymes in the cell wall, resulting in cell lysis and death.

1. Natural Penicillins

This class includes parenteral penicillin G (eg, aqueous crystalline, procaine, and benzathine penicillin G) and oral formulations (eg, penicillin V).

Adverse Effects

The most common side effect of agents in the penicillin family is hypersensitivity, with anaphylaxis presenting in 0.05% of cases.

Clinical Uses

These drugs are most active against gram-positive organisms, but resistance is increasing. Natural penicillins are still widely used for streptococci, such as in streptococcal pharyngitis; however, 30–35% of pneumococci have intermediate- or high-level resistance to penicillin. They are also used for meningococci, *Treponema pallidum* and other spirochetes, and actinomyces.

2. Aminopenicillins

This extended-spectrum group includes ampicillin, which is administered intravenously, and amoxicillin (only oral formulation in the United States). These agents are susceptible to destruction by β-lactamases produced by staphylococci and other bacteria.

Adverse Effects

A maculopapular rash may occur in 65–100% of patients with infectious mononucleosis who are prescribed amoxicillin. This symptom is not a true penicillin allergy.

Clinical Uses

In addition to having the same spectrum of activity against gram-positive organisms as the natural penicillins, aminopenicillins also have some activity against gram-negative rods. Because of its pharmacokinetics, amoxicillin is active against strains of pneumococcus with intermediate resistance to penicillin, but not against strains with high-level resistance; it is therefore a first-line drug for the treatment of sinusitis and otitis.

3. Penicillinase-Resistant Penicillins

This class includes methicillin, dicloxacillin, and nafcillin. They are relatively resistant to β-lactamases produced by staphylococci.

Adverse Effects

Nafcillin in high doses can be associated with a modest leukopenia, particularly if given for several weeks.

Clinical Uses

These agents are used as antistaphylococcal drugs because they are less active than the natural penicillins against other gram-positives. They are still adequate in streptococcal infections.

Table 2–1. Examples of Initial Antimicrobial Therapy for Selected Conditions in Head and Neck Infection.

Suspected Clinical Diagnosis	Likely Etiologic Diagnosis	Treatment of Choice	Comments
Infections of the Ear			
External otitis	Gram-negative rods (*Pseudomonas,* Enterobacteriaceae, *Proteus*) or fungi (*Aspergillus*)	Otic drops containing a mixture of an aminoglycoside and corticosteroids, such as neomycin sulfate and hydrocortisone	In refractory cases, particularly if there is cellulitis of the adjacent periauricular tissue, oral fluoroquinolones such as ciprofloxacin 500 mg twice a day can be used for their antipseudomonal activity. However, there is increasing resistance being reported. Acute infection may be due to *Staphylococcus aureus*; dicloxacillin 500 mg 4 times a day may be used.
Malignant external otitis	*Pseudomonas aeruginosa*	Antibiotics with antipseudomonal activity (such as ciprofloxacin) for a prolonged period until there is radiographic evidence of improvement.	Surgical debridement may be necessary if medical therapy is unsuccessful. It may also be necessary to rule out osteomyelitis by CT scan or MRI, as osteomyelitis requires prolonged therapy for 4–6 weeks.
Acute otitis media	*Streptococcus pneumoniae, Haemophilus influenzae, Moraxella catarrhalis,* and viruses (RSV, rhinoviruses)	Amoxicillin is the first drug of choice at 45 mg/kg/d in two or three divided doses. If drug resistance is suspected, a higher dose of amoxicillin or amoxicillin–clavulanate (90 mg/kg/d) may be used. Prevention of recurrent acute otitis media may be treated with oral doses of sulfisoxazole 50 mg/kg or amoxicillin 20 mg/kg at bedtime. If this strategy fails, the insertion of ventilating tubes may be necessary.	Treatment is a combination of antibiotics and nasal decongestants. Without treatment, there may be a spontaneous resolution of illness (less likely with *S pneumoniae*).
Mastoiditis	*S pneumoniae, Streptococcus pyogenes, H influenzae,* and *P aeruginosa*	Myringotomy for culture and drainage and ceftriaxone, 1 g IV every 24 hours.	Antibiotics may be modified based on culture results.
Infections of the Nose & Paranasal Sinuses			
Rhinitis (common cold)	Can be caused by a variety of viruses, including several serologic types of rhinoviruses and adenoviruses	Mainly reassurance of the patient and supportive therapy, such as decongestants (pseudoephedrine 30–60 mg every 4–6 hours). Nasal sprays such as oxymetazoline or phenylephrine can be immediately effective but must not be used for more than a few days at a time since rebound congestion may occur.	Secondary (bacterial) infection may occur and present as acute sinusitis.
Acute sinusitis	*S pneumoniae, H influenzae, M catarrhalis*, Group A streptococcus, anaerobes, viruses, and *S aureus*	Amoxicillin or amoxicillin–clavulanate 500 mg by mouth 3 times a day is a reasonable first choice. If drug-resistant *S pneumoniae* is suspected, an oral fluoroquinolone such as levofloxacin may be used.	Because two-thirds of untreated patients will improve symptomatically within 2 weeks, antibiotic treatment is usually reserved for those who have maxillary or facial pain (or both), and purulent nasal discharge after 7 days of decongestants and analgesics. In cases of clinical failure, endoscopic sampling or maxillary sinus puncture can yield a specimen for microbiologic evaluation and the targeted selection of antibiotics.

(*continued*)

Table 2–1. Examples of Initial Antimicrobial Therapy for Selected Conditions in Head and Neck Infection. (*Continued*)

Suspected Clinical Diagnosis	Likely Etiologic Diagnosis	Treatment of Choice	Comments
Sinusitis in an immunocompromised host	Various molds, including *Aspergillus* and *Mucormycosis*	Wide surgical debridement and amphotericin B. Liposomal amphotericin, the echinocandins, and the new broad-spectrum azoles may be alternatives in appropriate patients.	These molds are highly angioinvasive and rapid dissemination and death can occur if they are not recognized in a timely fashion.
Infections of the Oral Cavity & Pharynx			
Candidiasis (thrush)	*Candida albicans* (usually)	Fluconazole (100 mg by mouth daily for 7–14 days) or an oral solution of itraconazole (200 mg by mouth once daily)	AIDS patients may have fluconazole-resistant disease and may be treated with higher doses of fluconazole or itraconazole solution, or with amphotericin B administered intravenously.
Necrotizing ulcerative gingivitis (trench mouth, Vincent infection)	Usually coinfection with spirochetes and fusiform bacilli	Penicillin, 250 mg 3 times a day orally, with peroxide rinses	Clindamycin for patients with penicillin allergies.
Aphthous stomatitis (canker sore, aphthous ulcers)	Unknown, although human herpesvirus 6 is suspected	Mainly untreated. Options include topical steroids (eg, Kenalog in Orabase), other compounds such as mouthwashes containing amyloglucosidase and glucose oxidase, or a short course of systemic steroids.	Immunocompromised hosts, such as HIV-positive patients, may have more severe disease.
Herpetic stomatitis	Reactivation of herpes simplex virus 1 or 2	Oral acyclovir 400 mg 3 times daily, famciclovir 125 mg 3 times daily for 5 days, or valacyclovir 500 mg twice a day for 5 days may decrease healing time if initiated within 48 hours from the onset of symptoms. For recurrent disease, suppression with acyclovir 400 mg twice a day, famciclovir 250 mg twice daily, or valacyclovir 1 g daily is effective.	Most adults require no intervention. Immunocompromised hosts, such as HIV-positive patients, may have more severe and acyclovir-resistant disease and should be treated.
Pharyngitis	Group A, C, and G (*β-hemolytic*) streptococci, viruses (EBV-related infectious mononucleosis), *Neisseria gonorrhoeae, Mycoplasma pneumoniae,* human herpesvirus 6, *Corynebacterium diphtheriae, Arcanobacterium haemolyticum,* and *Chlamydia trachomatis*	Penicillin V (500 mg orally twice a day for 10 days), a single dose of benzathine penicillin intramuscularly (1–2 million units), or clarithromycin 500 mg by mouth twice a day for 10 days. If gonococcus is diagnosed, this may be treated with ceftriaxone 125 mg intramuscularly once, cefixime 400 mg orally in one dose, or cefpodoxime 400 mg orally in one dose. All patients with gonorrhea must also be treated for the possibility of concomitant genital *Chlamydia trachomatis* with azithromycin 1 g orally once, or doxycycline 100 mg orally twice daily for 7 days.	One of the main goals in management is to diagnose and treat Group A streptococcal infection and decrease the risk of rheumatic fever.
Epiglottitis	*H influenzae,* Group A streptococcus, *S pneumoniae*, and *S aureus*	Ceftriaxone (50 mg/kg daily for children) or cefuroxime. Adjunctive steroids are sometimes given but are not of proven benefit. Urgent tracheostomy in children or intubation in adults may be necessary.	

Parapharyngeal space infection (including Ludwig angina)	Often polymicrobial and include streptococcal species, anaerobes, and *Eikenella corrodens*	Clindamycin 600–900 mg intravenously every 8 hours, or a combination of penicillin and metronidazole	External drainage is sometimes necessary.
Jugular vein septic phlebitis (Lemierre disease)	*F necrophorum*	Clindamycin, or a combination of penicillin and metronidazole	Surgical drainage of the lateral pharyngeal space and ligation of the internal jugular vein may be performed as well.
Laryngitis	Viral (>90% of cases)	Antibiotics are not usually indicated	
Sialadenitis	*S aureus*	Antistaphylococcal intravenous antibiotics such as nafcillin 2 g every 4 hours	
Acute cervical lymphadenitis	*Bartonella henselae* (catscratch disease), Group A streptococcus, *S aureus*, anaerobes, *M tuberculosis* (scrofula), *Mycobacterium avium*, toxoplasmosis, and tularemia	Depends on the specific diagnosis after fine-needle aspiration is performed	

4. Antipseudomonal Penicillins

This class includes the carboxypenicillins, such as ticarcillin (Ticar), and the ureidopenicillins, such as piperacillin (Pipracil).

Clinical Uses

These agents are used primarily for their activity against many strains of *Pseudomonas*. They also have better enterococcal coverage compared with penicillin, with piperacillin having better activity than ticarcillin.

5. Penicillins Combined with β-Lactamase Inhibitors

The addition of β-lactamase inhibitors to aminopenicillins and antipseudomonal penicillins can prevent inactivation by bacterial β-lactamases. These agents inactivate β-lactamases produced by *S aureus, H influenzae, Moraxella catarrhalis*, and *Bacteroides fragilis*, extending the activity of the parent drug to include these organisms. Augmentin (amoxicillin and clavulanic acid) is given orally. Unasyn (ampicillin and sulbactam), Zosyn (piperacillin and tazobactam), and Timentin (ticarcillin and clavulanic acid) are administered intravenously.

Adverse Effects

Augmentin is associated with some gastrointestinal intolerance, particularly diarrhea, which is decreased if administered twice a day.

Clinical Uses

Augmentin is used clinically for the treatment of refractory cases of sinusitis and otitis media that have not responded to less costly agents and may be due to anaerobes or *S aureus*. Unasyn, Zosyn, and Timentin are used as general broad-spectrum agents, with Zosyn having the most broad-spectrum activity. They are not active against methicillin-resistant *S aureus* and atypical organisms such as chlamydia and mycoplasma. Unasyn has no activity against *Pseudomonas*.

6. Other β-Lactam Drugs

Other β-lactam drugs include monobactams (aztreonam [Azactam]), and carbapenems (imipenem [Primaxin], meropenem [Merrem], doripenem [Doribax], and ertapenem [Invanz]). Monobactams have activity limited to gram-negative organisms, including *Pseudomonas*. Carbapenems have a wider spectrum. Imipenem is a broad-spectrum antibiotic and covers most gram-negative organisms, gram-positive organisms, and anaerobes, with the exception of *Stenotrophomonas maltophilia, Enterococcus faecium,* and most methicillin-resistant *S aureus* and *Staphylococcus epidermidis*. Meropenem and doripenem has a similar spectrum of activity. Ertapenem has a narrower spectrum of activity, with no coverage against *Pseudomonas*, *Acinetobacter*, or *Enterococcus faecalis*.

Adverse Effects

Despite the structural similarity of aztreonam to penicillin, cross-reactivity is limited and the drug can be given to those with a history of penicillin allergy, including IgE-mediated reactions. Patients allergic to penicillins may be allergic to imipenem and meropenem. Imipenem is associated with seizures, particularly if used in higher doses in elderly patients with decreased renal function, cerebrovascular disease, or seizure disorders. Meropenem is less likely to cause seizures and is associated with less nausea and vomiting than imipenem.

Clinical Uses

Aztreonam is useful for the treatment of confirmed pseudomonal infections in patients with allergies to penicillin and cephalosporins. Imipenem and meropenem should not be routinely used as a first-line therapy unless treating known multidrug-resistant organisms that are sensitive to these agents. However, in an appropriate patient who has been hospitalized for a prolonged period and who may experience infection with organisms resistant to multiple drugs, imipenem or meropenem may be used while awaiting culture results.

CEPHALOSPORINS

1. First-Generation Cephalosporins

These agents generally have good activity against aerobic gram-positive organisms (group A streptococcus, methicillin-sensitive *S aureus*, and viridans streptococci) and some community-acquired gram-negative organisms (*Proteus mirabilis, E coli,* and the *Klebsiella* species). Agents in this class include the orally administered cephalexin (eg, Keflex) and the parenteral cefazolin (eg, Ancef).

Adverse Effects

In general, cephalosporins are safe. However, patients with a history of IgE-mediated allergy to a penicillin (eg, anaphylaxis) should not be administered a cephalosporin. Patients with a history of developing a maculopapular rash in response to penicillins have a 5–10% risk of a similar rash with cephalosporins.

Clinical Uses

Oral first-generation cephalosporins are commonly used for the treatment of minor staphylococcal infections such as in cellulitis. Intravenous first-generation cephalosporins are the drugs of choice for surgical prophylaxis in head and neck surgery if oral or pharyngeal mucosa is involved, such as in laryngeal tumor resection.

2. Second-Generation Cephalosporins

This is a heterogeneous group that includes cefuroxime (Zinacef), cefoxitin (Mefoxin), and cefotetan. In general, they

provide slightly more gram-negative coverage than the first-generation cephalosporins, including activity against indole-positive *Proteus, Klebsiella, M catarrhalis,* and the *Neisseria* species. They have slightly less gram-positive activity than the first-generation cephalosporins. Cefoxitin and cefotetan also have activity against many strains of *Bacteroides*.

Clinical Uses

In patients with a mild allergy to ampicillin or amoxicillin, cefuroxime is an alternative agent for the treatment of sinusitis and otitis because it has activity against β-lactamase-producing strains such as *H influenzae* and *M catarrhalis.* Because of additional anaerobic activity, cefoxitin and cefotetan may be options for mixed (aerobic and anaerobic) infections of the head and neck.

3. Third-Generation Cephalosporins

Examples of these agents include orally administered cefixime (Suprax), cefpodoxime (Vantin), and intravenously or intramuscularly administered ceftazidime (Fortaz), ceftriaxone (Rocephin), and cefotaxime. In general, these agents are less active against gram-positive organisms, including *S aureus*, but most streptococci are inhibited. Of these, ceftriaxone has the most reliable pneumococcal coverage. They all have expanded gram-negative coverage. Ceftazidime has good activity against *Pseudomonas aeruginosa*. Ceftriaxone is the first-line agent for gonorrhea. Cefixime and cefpodoxime are oral alternatives for gonorrhea.

Adverse Effects

Ceftriaxone is associated with a dose-dependent gallbladder sludging (which can be seen by ultrasound imaging) and pseudocholelithiasis; both of these disorders can be found particularly in patients who are not eating and who are receiving total parenteral nutrition.

Clinical Uses

Because of their penetration into cerebrospinal fluid, third-generation cephalosporins are widely used to treat meningitis. Ceftriaxone can be used to treat meningitis caused by susceptible pneumococci, meningococci, *H influenzae*, and enteric gram-negative rods. It is also used for meningitis caused by the *Pseudomonas* species. Ceftriaxone, cefpodoxime, and cefixime are used for the treatment of gonorrhea, including pharyngeal disease.

4. Fourth-Generation Cephalosporins

Cefepime (Maxipime) is currently the only available fourth-generation cephalosporin. It has activity against *Enterobacter, Citrobacter,* and *Pseudomonas* species and similar activity to ceftriaxone against gram-positive organisms.

Clinical Uses

Cefepime is typically used for gram-negative organisms resistant to other cephalosporins, such as *Enterobacter* and *Citrobacter*. It is also used empirically in patients with febrile neutropenia.

5. Fifth-Generation Cephalosporins

Ceftaroline (Teflaro) is a new fifth-generation cephalosporin. It has activity against gram-positive organisms, including methicillin-resistant *S aureus,* and gram-negative organisms with the notable exception of *P aeruginosa*.

Clinical Uses

Based on clinical studies, ceftaroline can be used as an alternative agent for the treatment of skin and soft tissue infections, or community acquired pneumonia where methicillin-resistant *S aureus* is suspected.

QUINOLONES

This class has a broad spectrum of activity and generally low toxicity. Quinolones include the newer fluorinated agents such as ciprofloxacin (Cipro), levofloxacin (Levaquin), gemifloxacin (Factive), and moxifloxacin (Avelox). The drugs inhibit bacterial DNA synthesis by blocking the action of the enzyme DNA gyrase. In general, quinolones have moderate gram-positive activity, especially levofloxacin, gemifloxacin, and moxifloxacin, and good gram-negative activity, with ciprofloxacin and levofloxacin providing the best activity against *P aeruginosa*, although resistance has been increasing. Only moxifloxacin has moderate anaerobic activity (eg, *B fragilis* and oral anaerobes). In contrast to ciprofloxacin and levofloxacin, moxifloxacin has poor activity against *P aeruginosa*.

Adverse Effects

The most commonly reported side effects are nausea, vomiting, and diarrhea. The prolongation of the QT interval has been observed in fluoroquinolones as a class. Tendonitis and tendon rupture have been reported, particularly in patients taking glucocorticoids or who have concomitant liver or renal failure. There is also a possible adverse effect on joint cartilage, which has been noted only in animal studies. Gemifloxacin is associated with rash in women under 40 years old taking drug for more than 7 days.

Clinical Uses

Because of their broad spectrum, quinolones should not be typically used as first-line agents in relatively minor infections such as sinusitis, otitis, and pharyngitis when there are less expensive alternatives with narrower spectrums available.

Because of the increasing prevalence of fluoroquinolone-resistant *Neisseria gonorrhoeae* in the United States and in some areas of the world, quinolones are no longer being recommended for the treatment of gonorrhea, including gonococcal pharyngitis in the United States. Ciprofloxacin has been used for the treatment of complicated soft tissue infections and osteomyelitis caused by gram-negative organisms. Ciprofloxacin, administered as 500–750 mg twice daily for at least 6 weeks, is used for the treatment of malignant external otitis. Ciprofloxacin has also been used to eradicate meningococci from the nasopharynx of carriers. Because of their superior activity against *Pneumococcus*, some of the newer quinolones such as levofloxacin can be used when drug-resistant *Streptococcus pneumoniae* is suspected in cases of sinusitis. However, quinolones are not reliable in the treatment of methicillin-resistant *S aureus* or enterococcal infections.

SULFONAMIDES & ANTIFOLATE DRUGS

Sulfonamides are structural analogs of *p*-aminobenzoic acid (PABA) and compete with PABA to block its conversion to dihydrofolic acid. Almost all bacteria, with the exception of enterococci, that use PABA to synthesize folates and pyrimidines are inhibited by these agents. Mammalian cells use exogenous folate and are unaffected. Antifolate drugs such as trimethoprim block the conversion of dihydrofolic acid to tetrahydrofolic acid by inhibiting the enzyme dihydrofolate reductase. Typically, these agents are used in combination, such as trimethoprim–sulfamethoxazole (eg, Bactrim, Septra) to treat a variety of bacterial and parasitic infections.

Adverse Effects

At high doses, some of the antifolate drugs also inhibit mammalian dihydrofolate reductase (pyrimethamine and trimetrexate) so that these drugs are typically coadministered with folinic acid (leucovorin) to prevent bone marrow suppression. Adverse effects to sulfonamides, usually mild rashes or gastrointestinal disturbances, occur in 10–15% of patients without AIDS; in patients with AIDS, these adverse effects are experienced in up to 50% of patients and include rash, fever, neutropenia, and thrombocytopenia, all of which may be severe enough to discontinue therapy.

Clinical Uses

Sulfonamides are the drugs of choice for infections caused by *Nocardia*. Trimethoprim–sulfamethoxazole (Bactrim, Septra) is often used for the treatment of acute sinusitis and otitis, although resistant *Pneumococcus* is limiting its use.

ERYTHROMYCINS (MACROLIDES)

This class includes erythromycin, azithromycin (Zithromax), and clarithromycin (Biaxin). They inhibit protein synthesis of bacteria by binding to the 50S ribosomal subunits. In vitro data demonstrating an effect on cytokine production suggest an anti-inflammatory effect as well.

Adverse Effects

Nausea, vomiting, and diarrhea may occur, particularly with erythromycin, which can cause uncoordinated peristalsis. Azithromycin and clarithromycin cause milder symptoms. Reversible ototoxicity can occur after high doses of these agents, especially with concomitant hepatic and renal insufficiency. Macrolides (especially erythromycin and clarithromycin) inhibit cytochrome P450 and can significantly increase levels of oral anticoagulants, digoxin, cyclosporin, and theophylline with concomitant use. Levels should be monitored and doses appropriately adjusted.

Clinical Uses

Macrolides are the drugs of choice for infections caused by *Legionella, Mycoplasma*, and *Chlamydia*. Azithromycin and clarithromycin are approved for the treatment of streptococcal pharyngitis, but some areas are reporting high rates (20%) of resistance, and less expensive alternatives are available. Azithromycin and clarithromycin are frequently used to treat sinusitis, although amoxicillin and doxycycline are equally efficacious and less expensive.

KETOLIDES

Ketolides such as telithromycin (Ketek) are derivatives of the macrolides, but they have activity against macrolide-resistant and penicillin-resistant *S pneumoniae*. They inhibit bacterial protein synthesis by binding to two sites on the 50S bacterial ribosome. They do not have significant gram-negative activity.

Adverse Effects

Upper gastrointestinal symptoms are the most common drug-associated effect. Other potential effects include blurred vision, resulting from reversible alteration in accommodation (seen in young women in particular). Fatal exacerbations of myasthenia gravis have been reported. There have been several reports of severe liver toxicity including death or the need for liver transplantation. Telithromycin is a potent inhibitor of cytochrome P450 and can significantly increase levels of several drugs such as warfarin and benzodiazepines. Statins should be temporarily stopped while patients are taking telithromycin.

Clinical Uses

Telithromycin is an alternative to quinolones for community-acquired pneumonia in which resistant *S pneumoniae* is suspected. However, patients should be carefully monitored for liver toxicity. Telithromycin is no longer recommended

for the treatment of acute bacterial sinusitis or bronchitis, given the risk of severe hepatotoxicity.

TETRACYCLINES

Doxycycline and other drugs in this class inhibit protein synthesis. Their spectrum of activity is similar to that of macrolides.

Adverse Effects

Gastrointestinal side effects are common. Drugs in this class can be bound to calcium in growing bones and teeth, causing discoloration and growth inhibition.

Clinical Uses

Similar to the macrolides, tetracyclines can be used to treat infections caused by *Legionella, Mycoplasma,* and *Chlamydia*.

GLYCYLCYCLINES

Tigecycline (Tygacil), a derivative of minocycline, is the first of this new class of antibiotics. The spectrum of activity includes resistant gram-positive organisms (eg, methicillin-resistant *S aureus*, penicillin-resistant *S pneumoniae*, and vancomycin-resistant enterococci) as well as several gram-negative organisms and anaerobes, but not *P aeruginosa*.

Adverse Effects

Nausea and vomiting are the most commonly reported effects reported with glycylcyclines. Like tetracyclines, tigecycline may also cause photosensitivity and pseudotumor cerebri. Its use is contraindicated in children and pregnant women.

Clinical Uses

These agents constitute another intravenously administered option against complicated skin and soft tissue infections with resistant gram-positive organisms.

AMINOGLYCOSIDES

This group includes gentamicin and tobramycin. They inhibit protein synthesis in bacteria by attaching to the 30S ribosomal subunit.

Adverse Effects

All aminoglycosides can cause ototoxicity and nephrotoxicity. Ototoxicity can be irreversible and is cumulative. It can be manifested both as cochlear injury (eg, hearing loss) and vestibular injury (eg, vertigo and ataxia). Nephrotoxicity is more common and is frequently reversible.

Clinical Uses

These agents are generally used in serious infections caused by gram-negative bacteria. Their use is limited by toxicity.

CLINDAMYCIN

Clindamycin (Cleocin) acts by inhibiting the initiation of peptide chain synthesis in bacteria. It resembles the macrolides in its spectrum and structure.

Adverse Effects

These drugs are the most frequently implicated in causing *Clostridium difficile* colitis.

Clinical Uses

Clindamycin is one of the first-line drugs for the treatment of parapharyngeal space infections (including Ludwig angina), as well as jugular vein septic phlebitis (eg, Lemierre disease). It is recommended as an alternative to amoxicillin as prophylaxis against endocarditis following oral procedures. Clindamycin has good anaerobic activity, but resistance has been reported in up to 25% of *B fragilis* isolates, thus limiting its use in serious anaerobic infections due to these organisms. Because of existing evidence suggesting that clindamycin reduces toxin production in several organisms, it is often used concomitantly with penicillin in the treatment of group A streptococcal toxic shock syndrome. Clindamycin can also be used in the treatment of brain abscesses, although it is not effective in treating meningitis.

METRONIDAZOLE

Metronidazole (Flagyl) is an antiprotozoal drug that has excellent anaerobic activity, particularly against anaerobic gram-negative organisms.

Adverse Effects

Alcohol must be avoided for the duration of the antibiotic and for 48 hours afterward to prevent a disulfiram-like reaction. Metronidazole can also decrease the metabolism of warfarin and increase the prothrombin time, necessitating careful monitoring during concomitant use.

Clinical Uses

This agent can be used in the treatment of brain abscesses, parapharyngeal space infections (including Ludwig angina), as well as septic phlebitis of the jugular vein (Lemierre disease), in combination with either penicillin or a third-generation cephalosporin. It is more predictable than

clindamycin and second-generation cephalosporins in the treatment of *B fragilis* infections.

GLYCOPEPTIDES

1. Vancomycin

Vancomycin activity is limited to gram-positive organisms, and it is used as a bactericidal agent for most of these organisms, including staphylococci and streptococci. Vancomycin-resistant enterococcal strains have become a major problem.

Adverse Effects

This agent is rarely ototoxic when given with aminoglycosides. There is also potential nephrotoxicity when coadministered with aminoglycosides. The rapid infusion of vancomycin can result in diffuse hyperemia ("red man syndrome").

Clinical Uses

Vancomycin is the drug of choice for methicillin-resistant *S aureus* and *S epidermidis*. Serious staphylococcal, enterococcal, and other gram-positive infections in patients allergic to penicillin can also be treated with vancomycin.

2. Telavancin

Like vancomycin, the spectrum of activity is limited to gram-positive microbes. Telavancin inhibits cell wall synthesis and disrupts membrane permeability. Given a long half-life of up to 9 hours, once-daily dosing is possible.

Adverse Effects

The most common adverse effects in trials are gastrointestinal, including metallic taste, nausea, and vomiting. Central nervous system symptoms such as insomnia and headaches are also reported.

Clinical Uses

Telavancin has U.S. FDA approval for its use in complicated skin and soft tissue infections. It can be considered as an alternative to vancomycin for methicillin-resistant *S aureus* skin and soft tissue infections, but there is less clinical experience compared with other drugs. The precise role for this agent in other methicillin-resistant *S aureus* infections such as endocarditis, bacteremia, and pneumonia still needs to be defined.

STREPTOGRAMINS

These agents are structurally similar to macrolides. They work by binding to bacterial ribosomes and include Synercid (a combination of quinupristin and dalfopristin). Synercid has a spectrum of activity primarily against gram-positive organisms, including *E faecium* (but not *E faecalis*) and methicillin-resistant *S aureus*.

Adverse Effects

Phlebitis occurs with peripheral administration, so a central line is recommended. The most common adverse effects are myalgias and arthralgias.

Clinical Uses

Streptogramins are rarely used and only in cases of serious infections secondary to vancomycin-resistant *E faecium*.

OXAZOLIDINONES

Linezolid (Zyvox) is the first agent of this class of antibiotics. It is active against aerobic gram-positive infections, including *E faecium, E faecalis,* and methicillin-resistant *S aureus* and *S epidermidis*.

Adverse Effects

Nausea, vomiting, and diarrhea are the most common adverse effects. Reversible thrombocytopenia, neutropenia, and anemia can occur if treatment is prolonged. If more than 2 weeks of treatment are planned, blood counts should be monitored.

Clinical Uses

These agents are used in cases of serious infections secondary to vancomycin-resistant *E faecium* and *E faecalis,* and in patients with methicillin-resistant *S aureus* infections who are intolerant to vancomycin.

DAPTOMYCIN

This bactericidal lipopeptide works by inserting itself into the bacterial cell membrane, causing depolarization, efflux of potassium, and cell death. Its spectrum of activity is similar to that of linezolid, targeting resistant gram-positive organisms (eg, methicillin-resistant *S aureus* and vancomycin-resistant enterococci). It is available only as a parenteral agent.

Adverse Effects

The main potential drug-related effect is reversible, dose-dependent myopathy, which is seen more than 7 days after initiating therapy.

Clinical Uses

Daptomycin is used in complicated skin and soft tissue infections with known or suspected resistant gram-positive organisms.

ANTIFUNGAL AGENTS

AMPHOTERICIN B

Amphotericin B has a broad spectrum of activity against many fungi that can cause systemic disease, such as *Aspergillus, Histoplasmosis, Coccidioides*, and *Candida*. Notable exceptions are *Pseudallescheria boydii* and *Fusarium*. Lipid-based amphotericin B products, such as amphotericin B lipid complex, amphotericin B colloidal dispersion, and liposomal amphotericin B, have less nephrotoxicity than amphotericin.

Adverse Effects

Amphotericin B often produces fever, chills, vomiting, and headaches. Premedication with acetaminophen and diphenhydramine may help, and the addition of 25 mg of hydrocortisone to the infusion may decrease the incidence of rigors. Nephrotoxicity and electrolyte disturbances are common side effects, and close monitoring is essential.

Clinical Uses

In immunocompromised patients, this agent is used as an initial therapy for sinus disease or other invasive disease caused by *Aspergillus*, Zygomycetes, and other molds. Amphotericin is sometimes used in the treatment of resistant thrush.

TRIAZOLES

These drugs inhibit ergosterol synthesis, resulting in inhibition of membrane-associated enzyme activity and cell wall growth and replication. Fluconazole (Diflucan) can be effective in treating infections due to *Candida* (*albicans* in particular), *Cryptococcus,* and *Blastomyces.* Itraconazole (Sporanox) has a similar spectrum to fluconazole, but may also be used to treat invasive disease caused by *Aspergillus*. There is no activity against *Fusarium* and Zygomycetes. Newer-generation azoles such as voriconazole (Vfend) have a broader spectrum of activity, including *Aspergillus* and *Fusarium*, but not Zygomycetes. Posaconazole has a similar spectrum of activity as voriconazole, but can also be used to treat Zygomycetes.

Adverse Effects

Triazoles are generally well tolerated. Itraconazole and voriconazole have several drug interactions. Itraconazole can increase levels of cyclosporin, digoxin, and warfarin with concomitant use, necessitating the dose adjustment of these medications. Voriconazole is a potent inhibitor of cytochrome P450 isoenzymes, also mandating the dose adjustment and monitoring of cyclosporin and warfarin, as well as tacrolimus. Sirolimus is contraindicated. The most common adverse effects associated with voriconazole were reversible visual disturbances and liver toxicity.

Clinical Uses

Itraconazole, voriconazole, and posaconazole can be used in the treatment of sinus disease caused by *Aspergillus*. Voriconazole can also be used in disease caused by *Fusarium*. Fluconazole is typically a first-line treatment of thrush. Itraconazole and voriconazole also have activity against *Candida,* including some of the non-*albicans* species. Posaconazole is an alternative amphotericin for the treatment of Zygomycetes.

CANDINS

These drugs act by inhibiting fungal wall synthesis. Caspofungin (Cancidas), micafungin (Mycamine), and anidulafungin (Eraxis) are FDA-cleared agents in this class. They are active against *Candida*, including non-*albicans* species, and *Aspergillus*. They are not active against the other molds.

Adverse Effects

Candins are remarkably well-tolerated drugs and are associated with few significant drug interactions.

Clinical Uses

These drugs are recommended for patients intolerant of or refractory to treatment of *Aspergillus* disease with amphotericin or itraconazole.

ANTIVIRAL AGENTS

ACYCLOVIR, FAMCICLOVIR & VALACYCLOVIR

In cells infected with herpesvirus, these drugs are selectively active against viral DNA polymerase, inhibiting viral proliferation. They are useful for infections caused by herpes simplex and in herpes zoster–varicella infections. Famciclovir (Famvir) is selectively active against herpes DNA polymerase and inhibits viral proliferation. It is a prodrug of penciclovir. Herpes simplex and varicella zoster strains resistant to acyclovir are also resistant to famciclovir. Valacyclovir (Valtrex) is the prodrug of acyclovir and has increased oral bioavailability, allowing less frequent dosing.

Adverse Effects

These drugs are relatively nontoxic.

Clinical Uses

Antiviral agents are used for the treatment and prophylaxis of mucocutaneous oral lesions caused by herpes simplex. Oral acyclovir is significantly more effective than the currently available topical ointment, 5% acyclovir. Penciclovir 1% cream is effective but must be applied every 2 hours to work.

3 Radiology

Nancy J. Fischbein, MD & Kenneth C. Ong, MD

DIAGNOSTIC IMAGING TECHNIQUES

Diagnostic imaging is an essential component of the evaluation of many otolaryngologic problems. Computed tomography (CT) and magnetic resonance imaging (MRI) are the most commonly used imaging modalities, with positron emission tomography (PET) playing an ever-increasing role.

COMPUTED TOMOGRAPHY

CT scanning uses ionizing radiation to generate cross-sectional images based on differences in the X-ray attenuation of various tissues. Modern scanners are typically helical, meaning that X-ray source rotation and patient translation occur simultaneously; this results in the acquisition of a "volume" of data that is then partitioned and reconstructed into individual slices. Helical scanning is significantly faster than traditional slice-by-slice acquisition, thereby diminishing artifacts related to motion (eg, breathing, swallowing, and gross patient motion). The rapid data acquisition also allows a larger number of thinner slices to be obtained, which facilitates diagnosis by decreasing partial-volume averaging effects and allows for improved quality of multiplanar reconstructions. The most recent advance in CT imaging has been the introduction of "multislice" scanners. Multislice scanners have a variable number (typically 8–64, though scanners with 320 are now available) of parallel arcs of detectors that are capable of simultaneously acquiring volumes of data. The increased speed that results from multislice sampling can be traded for improved longitudinal resolution, an increased volume of coverage, or an improved signal-to-noise ratio.

CT scanning of the head and neck is ideally performed with thin sections, usually ≤3 mm, in the axial plane; with multislice scanners, 0.625- or 1.25-mm slices are typically acquired and then combined for ease of viewing into slightly thicker 2.5- to 3-mm slices. Direct coronal imaging or coronal reformations are useful in many situations, notably in imaging of the paranasal sinuses and the skull base, and sagittal reformations can also be useful. Because of growing concerns over medical radiation, coronal reformations are generally preferred to a second acquisition if axial images are also acquired. CT scanning of the neck is generally performed following injection of iodinated contrast material because opacification of vessels helps to separate them from other structures such as lymph nodes and also helps to delineate and characterize pathology. If bony anatomy is the focus of the imaging study, as in imaging of the paranasal sinuses or temporal bones, then intravenous contrast material is not required. If a patient has a contrast allergy or renal insufficiency, then contrast administration should be avoided; premedication with steroids and antihistamines can be useful if a patient has a history of a contrast reaction, but contrast administration is necessary.

MAGNETIC RESONANCE IMAGING

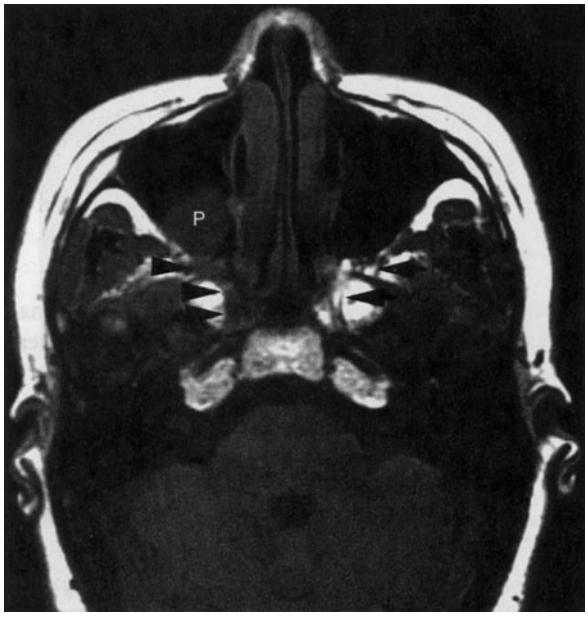
MRI exploits differences in relaxation characteristics and spin density of protons in different tissue environments to produce an image that is exquisitely sensitive to soft tissue contrast. Depending on the parameters that are selected, variable tissue characteristics and contrast are produced. At least two different types of sequences in two planes are generally necessary to characterize lesions of the head and neck. The slice thickness should be no more than 5 mm. A gadolinium-based contrast agent is generally used to enhance the detection of pathology and improve tissue characterization, and also to aid in the generation of a differential diagnosis. In some circumstances, thinner sections covering a smaller anatomic area may be necessary for more precise diagnosis.

In the head and neck, the following imaging sequences are typically obtained: (1) sagittal, axial, and coronal T1-weighted images; (2) axial fast spin-echo T2-weighted images with fat saturation; and (3) axial and coronal postgadolinium T1-weighted images with fat saturation.

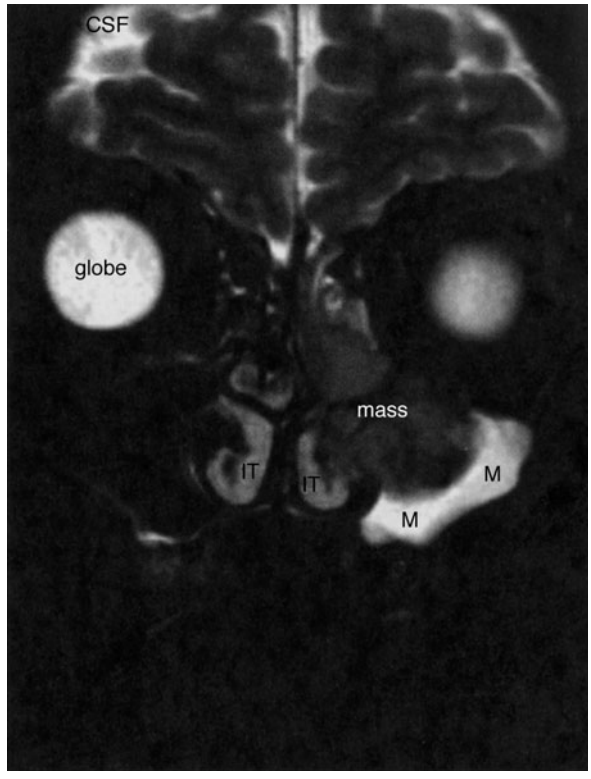
Additional planes may be useful in some circumstances, such as coronal fast spin-echo T2-weighted images with fat saturation for the assessment of paranasal sinus and anterior skull base pathology. Additional sequences such as magnetic resonance angiography (MRA) may be useful in certain

circumstances (eg, paragangliomas and dural fistulas), but are not necessary for evaluating most processes of the head and neck. MR venography may be useful in the assessment of patients with pulsatile tinnitus and in the assessment of the patency of the sigmoid sinus in patients with adjacent neoplastic or inflammatory disorders. Sequences such as FIESTA (fast imaging employing steady-state acquisition) or CISS (constructive interference in the steady state) allow heavily T2-weighted, thin-section imaging that is particularly useful in assessing the basal cisterns and fluid-filled inner ear structures and will generally be included in temporal bone-imaging protocols. Advanced modalities in widespread use in the brain (eg, MR spectroscopy, diffusion-weighted imaging, functional MRI) have for the most part not found a place in routine head and neck imaging, with the exception of diffusion-weighted imaging, which is particularly useful in the evaluation of the skull base and temporal bone for epidermoid cysts and cholesteatomas.

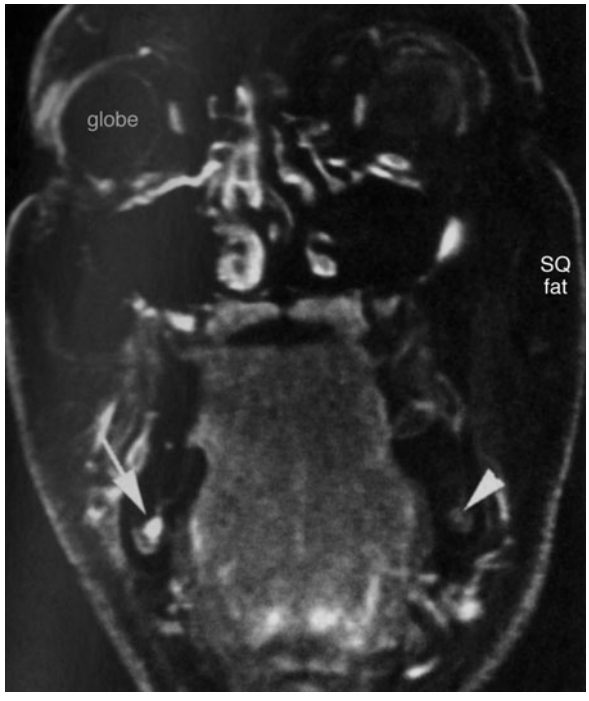
On a T1-weighted image, fat is bright and fluid (eg, cerebrospinal fluid [CSF]) is relatively dark. Muscle and most pathologies are of intermediate signal intensity. The large amount of fat in the head and neck provides intrinsic tissue contrast, which makes the T1-weighted image very sensitive to infiltrative processes that obliterate tissue planes or that replace marrow fat (Figure 3–1). Some hemorrhagic or proteinaceous lesions cause shortening of T1 relaxation time and appear bright on a T1-weighted image. On a T2-weighted image, fluid is very bright and most pathologies are relatively bright, whereas normal muscle is quite dark. The fast spin-echo technique is very useful in limiting artifacts related to motion and magnetic susceptibility compared with conventional spin-echo T2-weighted imaging. Because fat remains bright on a fast spin-echo image, however, fat saturation should ideally be applied when imaging the head and neck or skull base. In the nasal cavity and paranasal sinuses, T2-weighted images are particularly useful in distinguishing neoplastic masses from polyps, thickened mucosa, and retained secretions (Figure 3–2). Gadolinium



▲ **Figure 3–1.** Axial T1-weighted image. Note the high signal intensity of subcutaneous fat and the marrow of the central skull base. Infiltrative neoplasm replaces normal fat in the right pterygopalatine fossa, the vidian canal, and portions of the sphenoid body (black arrowheads). The normal left pterygopalatine fossa (PPF) and vidian canal (VC) are indicated. A maxillary sinus polyp (P) is incidentally noted.



▲ **Figure 3–2.** Coronal fast spin-echo T2-weighted image with fat saturation (FS). Note the high signal intensity of the vitreous humor of the ocular globe, the high signal intensity of the CSF, and the lack of signal from subcutaneous fat. In this patient with squamous cell carcinoma, the intermediate signal intensity tumor (mass) stands in contrast to the very high signal intensity of edematous mucosa and retained secretions (M) in the left maxillary sinus and the mildly high signal intensity of the inferior turbinates (IT).



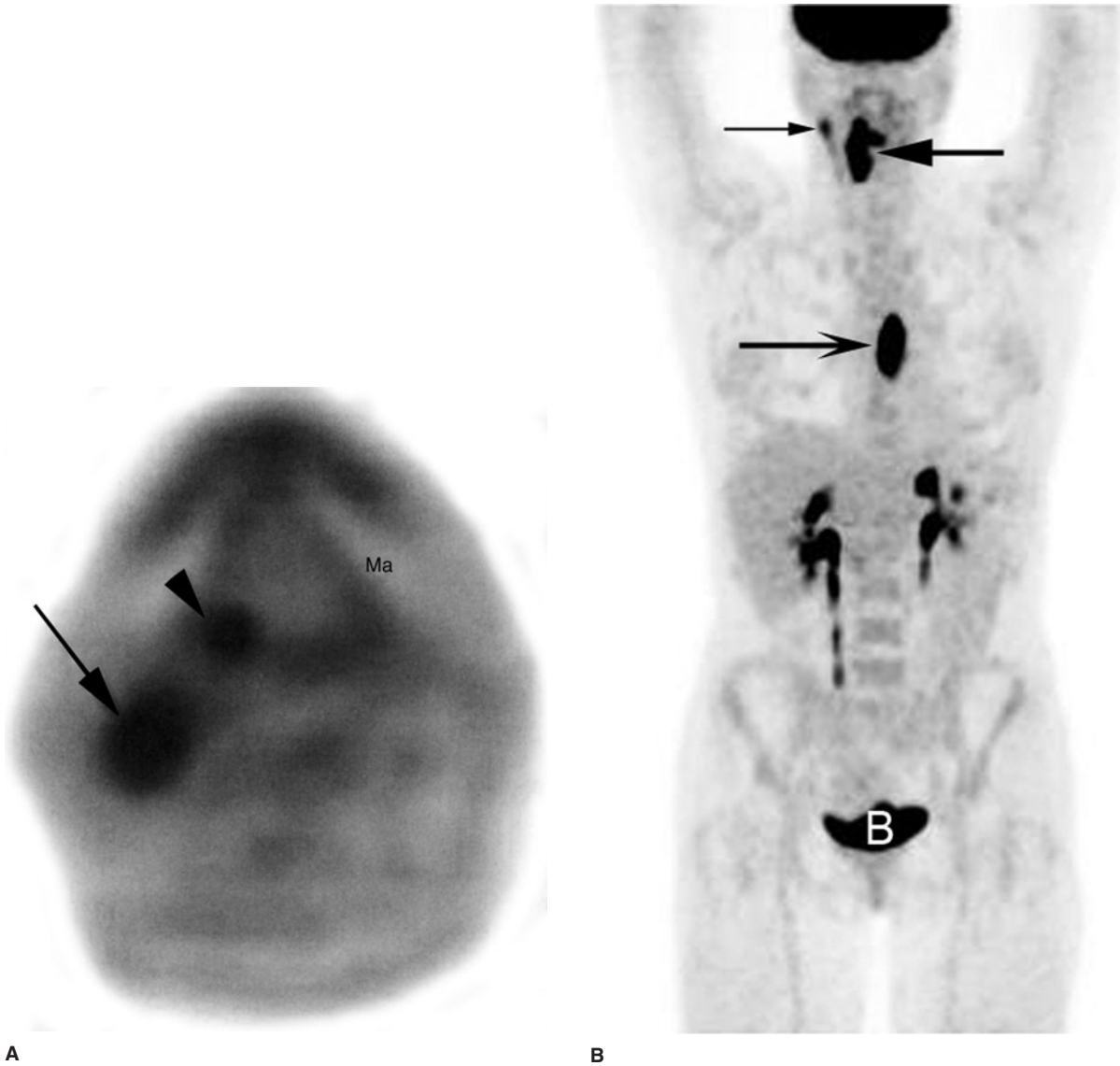
▲ **Figure 3–3.** Coronal T1-weighted image, postgadolinium, with fat saturation. Note the vitreous humor is dark as in a T1-weighted image, but subcutaneous and orbital fat are also dark due to fat suppression. The high signal intensity of the nasal mucosa, as well as the enhancement of vessels and extraocular muscles, indicates that gadolinium has been given. In this patient with a history of squamous cell carcinoma of the gingivobuccal sulcus and new chin numbness, the abnormal enlargement and enhancement of V3 in the inferior alveolar canal is seen (white arrow), consistent with perineural spread of tumor. The contralateral normal canal is also indicated (white arrowhead).

is very useful for demonstrating pathology and tailoring a differential diagnosis based on the enhancement characteristics of a lesion. In a patient with head and neck cancer, postgadolinium imaging is also very useful in assessing cavernous sinus invasion, meningeal infiltration, and perineural spread of tumor (Figure 3–3). Fat saturation should ideally be applied on a postgadolinium T1-weighted image; otherwise, the contrast between an enhancing lesion and the high signal intensity of surrounding fat may actually be reduced compared with the pregadolinium image. Because low-field scanners often do not have fat saturation capability, high-field imaging (1.5 T or higher) is generally preferred for assessing the head and neck and skull base. If a patient is severely claustrophobic, then sedation may be necessary to accomplish the scan on a high-field system.

It should be kept in mind that MRI requires more time and more patient cooperation than does CT, and therefore, it is not necessarily suitable for acutely ill or uncooperative patients. In addition, there are certain absolute contraindications to MRI, including ferromagnetic intracranial aneurysm clips, cardiac pacemakers, and many cochlear implants. Therefore, patients must be carefully screened for these and other contraindications before undergoing MRI. Also note that gadolinium administration should be avoided whenever possible in patients with renal insufficiency due to concerns regarding nephrogenic systemic fibrosis (NSF), a progressive syndrome that involves fibrosis of skin, joints, eyes, and internal organs and that has been associated with exposure to gadolinium in the setting of renal dysfunction.

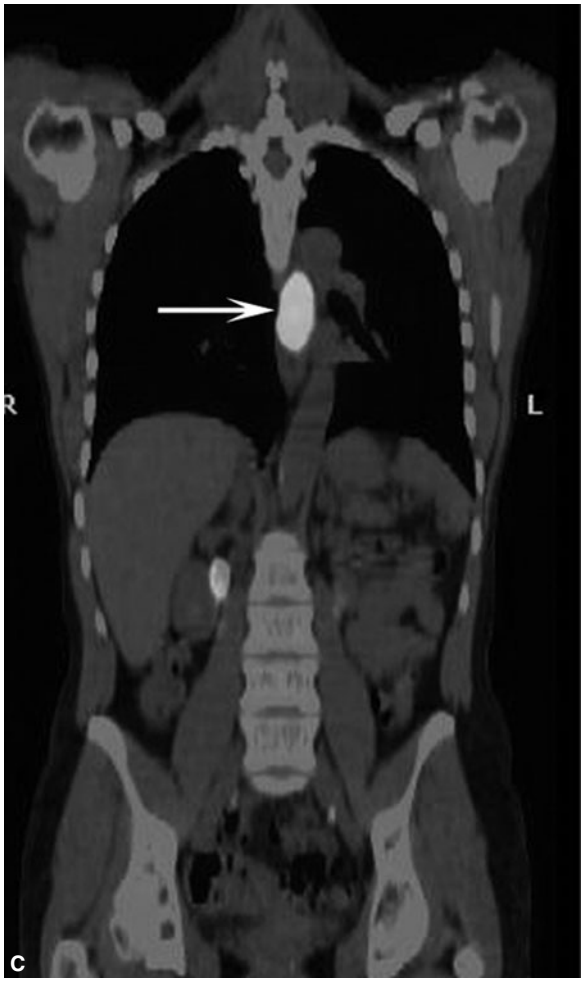
POSITRON EMISSION TOMOGRAPHY

PET provides a functional view of tissues rather than simply depicting anatomy. In the head and neck, it is used primarily for oncologic diagnosis and evaluation and is performed with the radiopharmaceutical ^{18}F-fluorodeoxyglucose (FDG). FDG is taken up into tissues in proportion to the glycolytic rate, which is generally increased in neoplastic processes. Focal asymmetric uptake is suggestive of a tumor but is nonspecific, since FDG is also concentrated in areas of inflammation. FDG PET scanning is particularly helpful in the following situations: (1) the search for an unknown primary lesion in a patient presenting with metastatic neck disease (Figure 3–4A), (2) the assessment of residual or recurrent disease after primary therapy, and (3) the search for synchronous or metachronous primary lesions or distant metastases. FDG PET scanning can also be useful for staging the neck, but there may be a significant number of false-negative studies in patients with clinically N0 necks because small tumor deposits (<5 mm) are generally not detectable on an FDG PET scan. These small tumor deposits are found if a neck dissection is performed. FDG PET scanning may also be used to assess response to organ-preserving therapy: if a short-interval PET scan demonstrates a marked decrease in metabolic activity, then the patient will continue to be treated with an organ-preserving regimen. If the metabolic activity of the tumor is not decreasing as expected, however, then the patient may be triaged to surgical resection at an earlier point in time. At present, most FDG PET scanning is done on dedicated PET-CT scanners; this allows fusion of the metabolic and anatomical information such that precise anatomic localization of regions of FDG uptake can be achieved (Figure 3–4B and 3–4C). PET-MRI scanners are currently being developed but are not yet available for clinical use outside of a few select research centers.



A B

▲ **Figure 3–4. (A)** Axial FDG PET image in a patient presenting with metastatic cervical adenopathy and no primary site visible on clinical examination or MRI. A large focus of activity (black arrow) is related to known level II lymphadenopathy, and a smaller focus of activity (black arrowhead) is suspicious for a primary site at the right base of the tongue. This was confirmed by panendoscopy and biopsy. The photopenic mandible (Ma) is indicated for orientation. **(B)** A whole-body FDG PET image in a different patient who presented for staging of a large right-sided oropharyngeal tumor (large straight black arrow) demonstrates metastatic lymphadenopathy in the right neck (small straight black arrow) as well as an intense focus of activity in the mediastinum (large concave black arrow). Expected activity is seen in the renal collecting systems, ureters, and bladder, B. *(continued)*



▲ **Figure 3–4.** *(continued)* **(C)** A coronal FDG PET-CT fusion image in the same patient as in part B localizes the FDG-avid mass (concave white arrow) to the mediastinum, and specifically to the esophagus. At endoscopy, this patient was found to have an asymptomatic second primary tumor involving the mid-thoracic esophagus.

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IMAGING THE HEAD & NECK

SPATIAL ANATOMY OF THE HEAD & NECK

The spaces of the suprahyoid head and neck are defined by the three layers of the deep cervical fascia: the superficial, middle, and deep layers. The spaces so defined include the pharyngeal mucosal space (which includes the nasopharynx, oropharynx, and hypopharynx), the parapharyngeal space, the masticator space, the parotid space, the carotid space, the retropharyngeal space, and the perivertebral space. The infrahyoid neck has traditionally been clinically defined by a series of surgical triangles, but can also be described as a series of fascia-defined spaces, which facilitates the understanding and interpretation of cross-sectional imaging modalities such as CT and MRI.

The spaces of the infrahyoid neck are also defined by the three layers of the deep cervical fascia and include the superficial space (external to the superficial layer of the deep cervical fascia), the visceral space (including the thyroid gland, the larynx, and the esophagus), the carotid space, the retropharyngeal space, and the perivertebral space. The nasal cavity, paranasal sinuses, skull base, and temporal bone are considered unique subregions of the head.

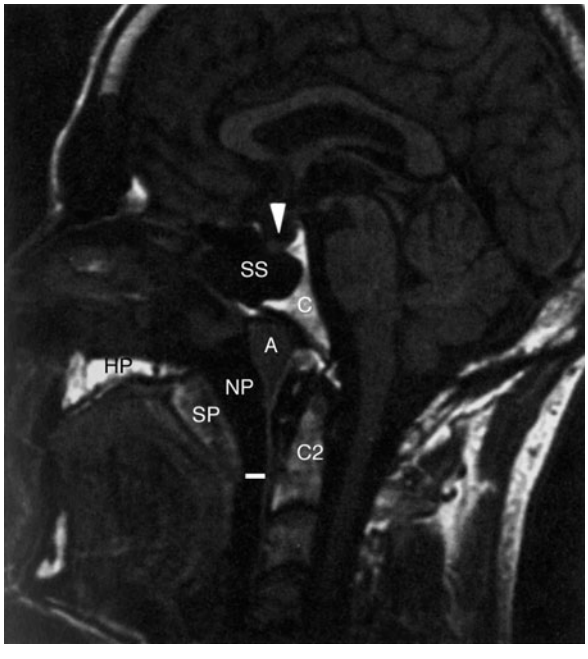
MUCOSAL DISEASE OF THE HEAD & NECK

For mucosal disease of the head and neck, of which squamous cell carcinoma (SCC) is by far the dominant lesion, the traditional subdivisions are the nasopharynx, oropharynx, oral cavity, larynx, and hypopharynx. The pharyngeal mucosal space includes the nasopharynx, oropharynx, and hypopharynx.

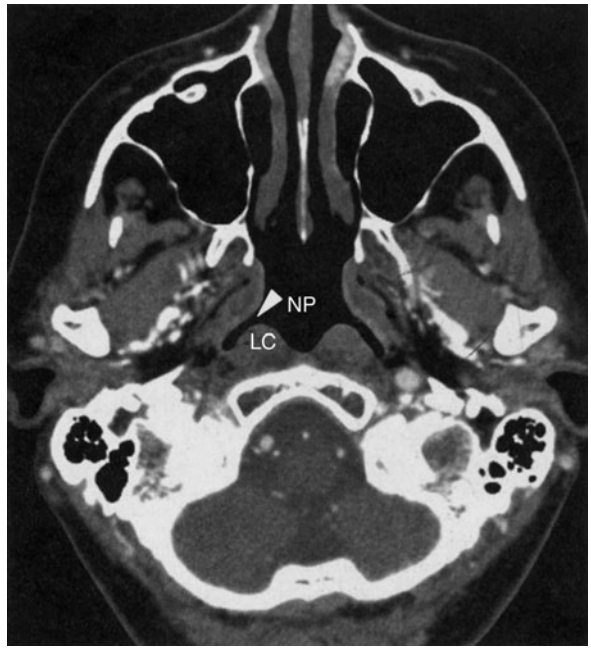
NASOPHARYNX

Anatomy

The nasopharynx is bounded anteriorly by the posterior nasal cavity at the posterior choana; posterosuperiorly by the lower clivus, upper cervical spine, and prevertebral muscles; and inferiorly by a horizontal line drawn along the hard and soft palates (Figure 3–5). The lateral wall of the nasopharynx is composed of the torus tubarius, the eustachian tube orifice, and the lateral pharyngeal recess, also known as the fossa of Rosenmüller (Figure 3–6). In addition to squamous mucosa, the contents of the



▲ **Figure 3–5.** Midline sagittal T1-weighted image indicates the bony and soft tissue anatomy related to the nasopharynx (NP), with the approximate inferior margin of the nasopharynx indicated by the horizontal white line. Indicated are the adenoids (A), clivus (C), C2 vertebral body (C2), sphenoid sinus (SS), soft palate (SP), hard palate (HP), and pituitary gland in the sella turcica (white arrowhead).



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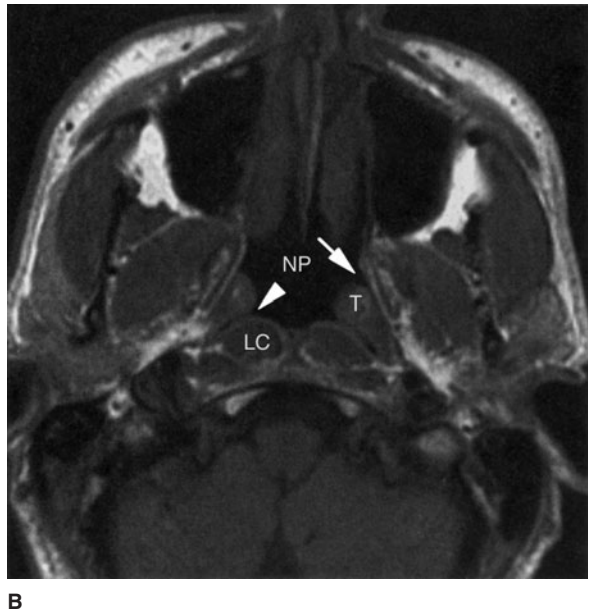


B

▲ **Figure 3–6. (A)** Axial CT image demonstrates the nasopharyngeal airway (NP) and the lateral pharyngeal recess (white arrowhead), as well as the longus colli muscle (LC). **(B)** Axial T1-weighted image of the nasopharynx (NP) demonstrates the lateral pharyngeal recess (white arrowhead), torus tubarius (T), and eustachian tube opening (white arrow).

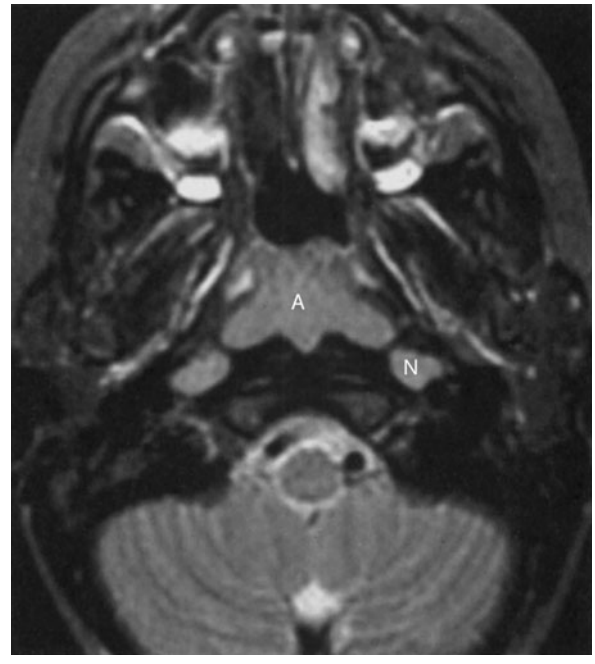
Table 3–1. Common Mass Lesions of the Nasopharynx.

Benign	Malignant
Adenoidal hypertrophy	Nasopharyngeal carcinoma
Postinflammatory retention cyst	Non-Hodgkin lymphoma
Thornwaldt cyst	Malignant tumor of minor salivary gland
Benign tumor of minor salivary gland	Rhabdomyosarcoma (in a child)

nasopharynx include lymphoid tissue (adenoids), minor salivary glands, the pharyngobasilar fascia, and the pharyngeal constrictor muscles. The pharyngobasilar fascia represents the aponeurosis of the superior constrictor muscle and attaches it to the skull base. A gap in the upper margin of the pharyngobasilar fascia is known as the sinus of Morgagni. The distal eustachian tube and levator palatini muscle normally pass through this gap, which also serves as a potential route of spread for nasopharyngeal carcinoma to access the skull base.

Pathology

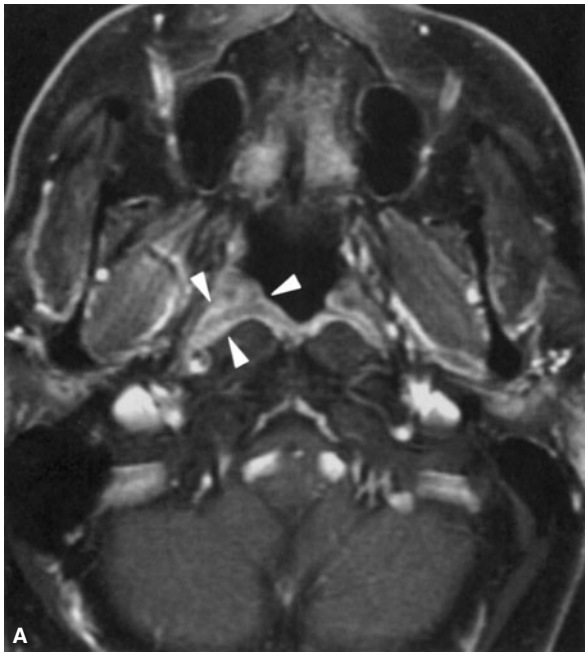
Lesions that may be encountered on imaging studies of the nasopharynx are listed in Table 3–1. Adenoidal hypertrophy (Figure 3–7) is commonly seen in children, young adults, and patients who test positive for the human immunodeficiency virus (HIV), although in the latter group, lymphoma must be considered in the differential diagnosis. Nasopharyngeal carcinoma is the most common malignant lesion of the nasopharynx, and the spectrum of imaging findings that may be encountered with nasopharyngeal carcinoma is illustrated in Figure 3–8. Important issues to consider in the imaging assessment of a patient with nasopharyngeal carcinoma include the presence of extension to the parapharyngeal space and pterygopalatine fossa, the presence of skull base invasion, and the presence of extension to the cranial nerves or the cavernous sinus.

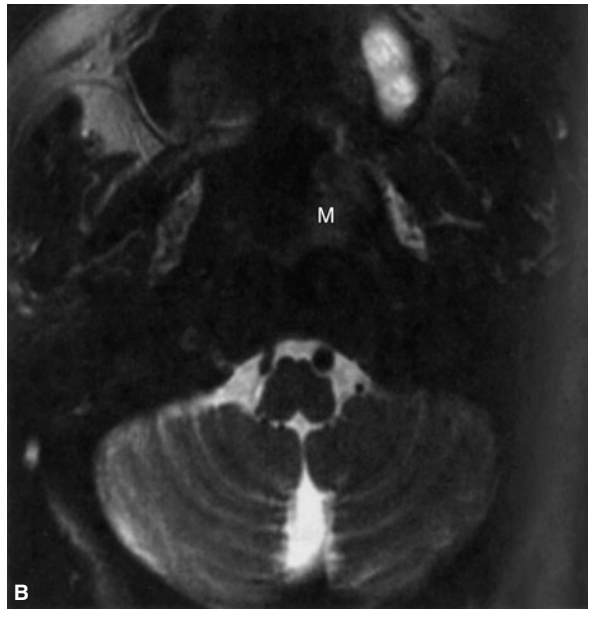


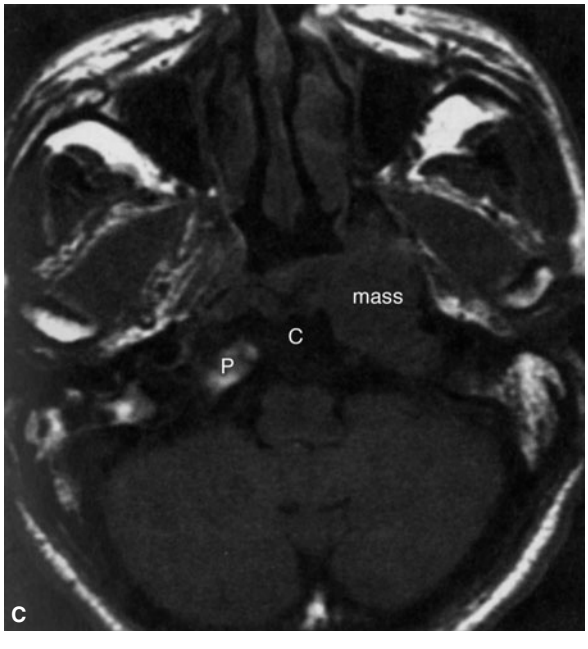
▲ **Figure 3–7.** Axial T2-weighted image in a young child demonstrates prominent symmetrical hypertrophy of the adenoids (A) and prominent retropharyngeal lymph nodes (N). This degree of adenoidal enlargement is common in young children and adolescents.

Key Imaging Points

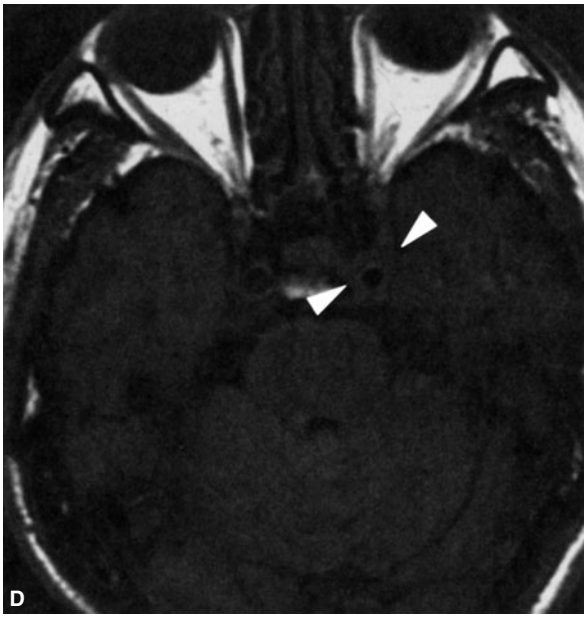
- The lateral pharyngeal recesses may be asymmetric owing to mucosal coaptation rather than a true mass lesion. This "pseudomass" can be diagnosed when the clinician or radiologist identifies the "kissing" mucosal surfaces rather than a true mass lesion (Figure 3–9).
- The nasopharynx should be carefully scrutinized for a mass lesion obstructing the eustachian tube orifice in any adult patient with unilateral middle ear or mastoid fluid (Figure 3–10).
- Asymmetrically or unusually prominent nasopharyngeal soft tissue that is seen on an imaging study should prompt a clinical evaluation for neoplasm, especially lymphoma (particularly in the setting of HIV) or nasopharyngeal carcinoma (particularly if the patient is of southern Chinese descent) (Figure 3–11).
- Patients with nasopharyngeal carcinoma should undergo MRI rather than CT scanning for the most complete staging. In patients with nasopharyngeal carcinoma, the skull base should be carefully assessed on T1-weighted images for evidence of invasion, with particular attention to the clivus on a sagittal T1-weighted image. Postgadolinium, the cavernous sinuses and cranial nerves (notably V2 and V3) should be assessed for tumor involvement.
- Radiation necrosis of the temporal lobes may occur following high-dose radiation therapy for nasopharyngeal carcinoma, as may osteoradionecrosis of the skull base and cranial neuritis. These may mimic tumor recurrence on imaging studies (Figure 3–12).
- A patient with nasopharyngeal carcinoma may present with massive cervical lymphadenopathy yet a relatively small primary lesion. The nasopharynx should be carefully scrutinized in a patient presenting with noninfectious cervical lymphadenopathy, particularly when she or he is of southern Chinese descent.

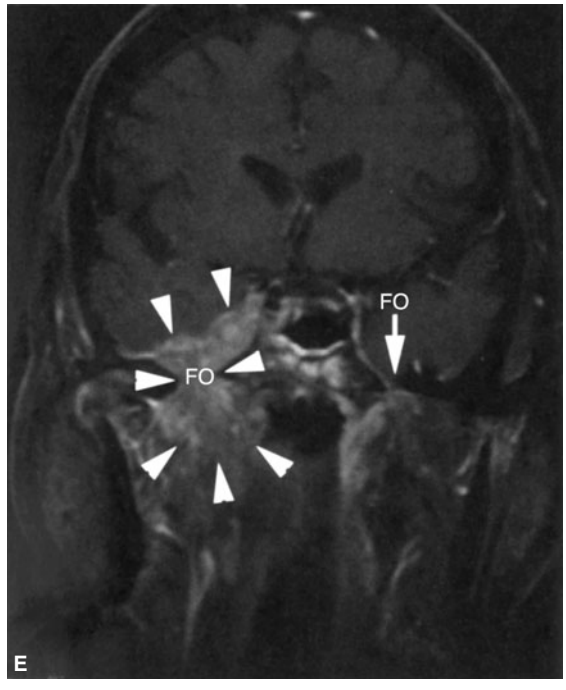




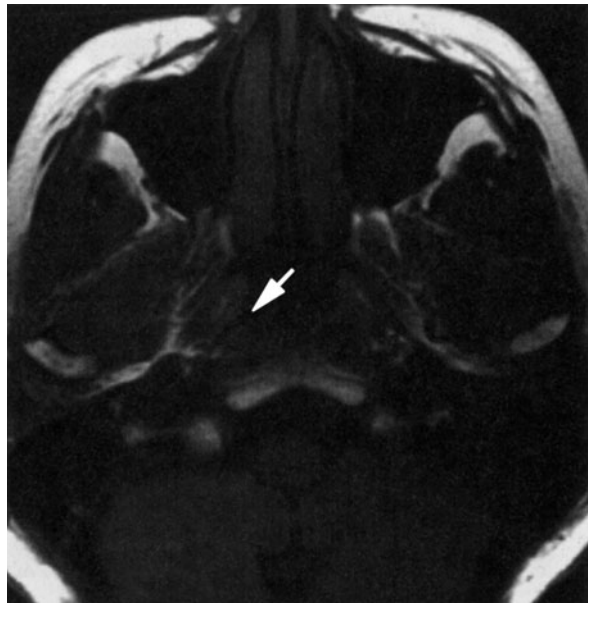


▲ **Figure 3–8.** The spectrum of imaging findings in nasopharyngeal carcinoma (NPC). **(A)** Axial postgadolinium T1-weighted image with fat saturation demonstrates a small mass lesion (white arrowheads) filling the right fossa of Rosenmüller and outlined against adjacent soft tissues by the "white line" of the adjacent enhancing mucosa and mucosal venous plexus. This patient presented with a neck mass (not shown) that revealed poorly differentiated carcinoma on fine needle aspiration. **(B)** Axial fast spin-echo T2-weighted image with fat saturation in a 45-year-old Chinese woman with a complaint of left ear fullness demonstrates a mass (M) centered on the left fossa of Rosenmüller with extension both anteriorly and medially. **(C)** Axial T1-weighted image in an older Chinese man with headache, ear pain, and diplopia demonstrates a large mass centered on the left fossa of Rosenmüller, with effacement of adjacent fat planes, erosion of the left petrous bone (compare the normal petrous bone and fatty marrow shown on the right, P), and replacement of the normal high signal intensity marrow within the clivus, C. *(continued)*

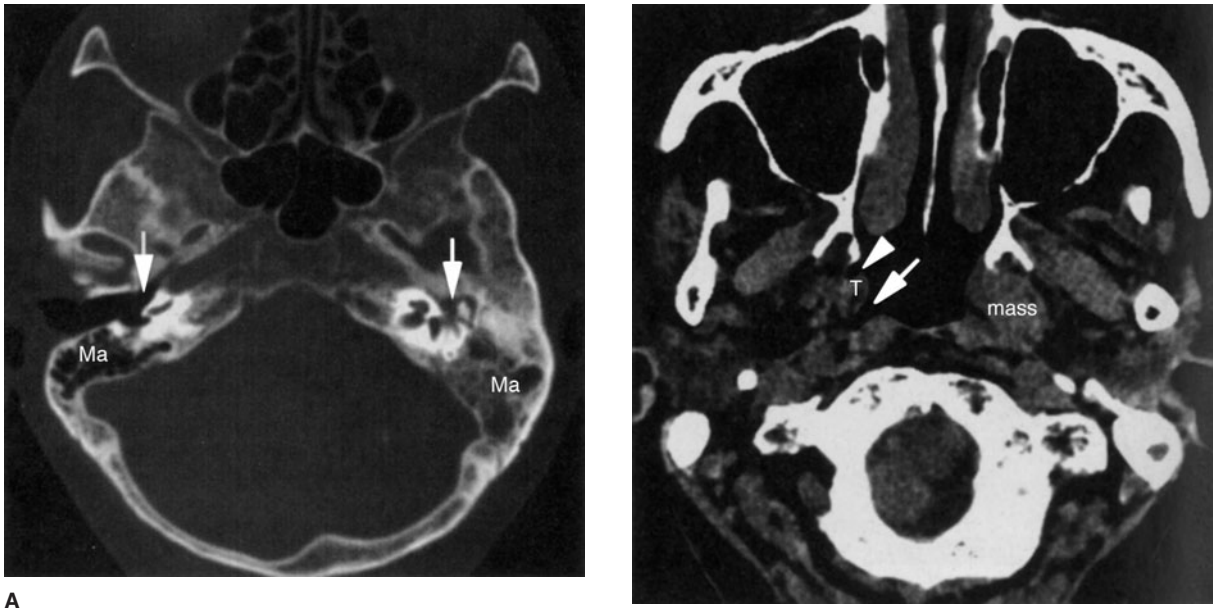




▲ **Figure 3–8.** *(continued)* **(D)** A more superior image in the same patient shown in part C demonstrates asymmetry of the cavernous sinuses with increased soft tissue on the left (arrowheads), as well as a mild narrowing of the encased cavernous segment of the internal carotid artery, consistent with tumor extension into the cavernous sinus. **(E)** Coronal T1-weighted image postgadolinium with fat saturation in another Chinese patient with nasopharyngeal carcinoma and right facial numbness in a V3 distribution demonstrates both direct and perineural extension of tumor through a markedly widened right foramen ovale (FO) into the middle cranial fossa (arrowheads). The normal appearance of foramen ovale is demonstrated on the left (white arrow).



▲ **Figure 3–9.** Axial T1-weighted image demonstrates a normal right fossa of Rosenmüller (white arrow). The left fossa is poorly seen, but no mass lesion is present, and the poor visualization is due to coaptation of mucosal surfaces and a lack of air in the fossa to provide contrast.



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B

▲ **Figure 3–10. (A)** Axial CT image viewed in bone window in an elderly woman presenting with unilateral serous otitis demonstrates fluid or soft tissue density in the left middle ear and mastoid. The right mastoid air cells are well pneumatized. Mastoid air cells are indicated by "Ma" and the middle ear cavities by the white arrows. **(B)** A more inferior axial noncontrast CT image viewed in a soft tissue window demonstrates a left submucosal nasopharyngeal mass that is obliterating normal anatomic landmarks. The right fossa of Rosenmüller (arrow), torus tubarius (T), and eustachian tube orifice (arrowhead) are shown for comparison. A biopsy of the lesion was suggestive of amyloidosis.

OROPHARYNX

Anatomy

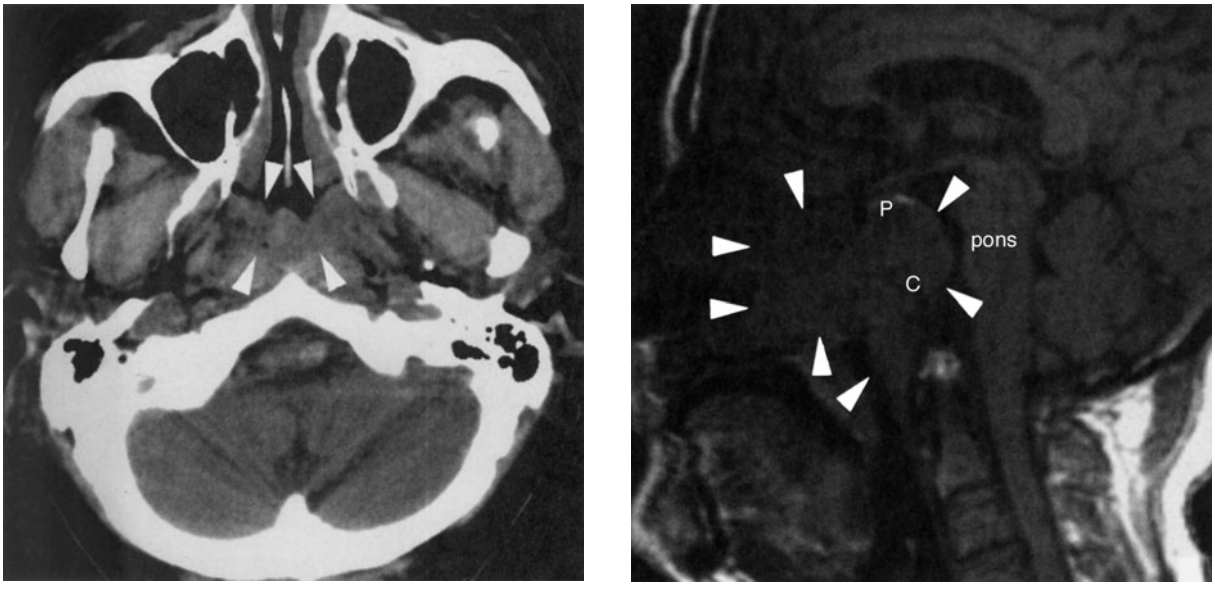
The oropharynx (Figure 3–13) is bounded anteriorly by the circumvallate papilla of the tongue, the soft palate, and the anterior tonsillar pillars, posteriorly by the superior and middle constrictor muscles, and superiorly by the soft palate. Inferiorly, it is separated from the larynx by the epiglottis and the glossoepiglottic fold and from the hypopharynx by the pharyngoepiglottic folds. In addition to squamous mucosa, contents of the oropharynx include the faucial and lingual tonsils, minor salivary glands, and pharyngeal constrictor muscles.

Pathology

Lesions that may be encountered on imaging studies of the oropharynx are listed in Table 3–2. Commonly encountered entities include tonsillar hypertrophy and tonsillar inflammatory processes, especially peritonsillar abscess. In a patient with inflammatory disease, it is important to look for underlying predisposing factors, such as an unsuspected foreign body, and also to look for potentially clinically occult complications, such as septic thrombophlebitis of the jugular vein (Figure 3–14). SCC of the faucial tonsil or base of tongue may present as a bulky exophytic mass lesion or an infiltrative mass lesion, or may have both infiltrative and exophytic components (Figure 3–15). In some cases the primary lesion may be very subtle (Figure 3–16). The margins of the lesion are often poorly defined, and there may be infiltration of adjacent normal fat planes. SCC is typically intermediate in signal intensity on both T1- and T2-weighted images and shows moderately intense enhancement postgadolinium. In a patient with known oropharyngeal SCC, the level II lymph nodes should be carefully scrutinized for evidence of metastatic involvement. Imaging of lymph nodes is discussed in more detail in a later section.

Key Imaging Points

- Lymphoid hyperplasia of the palatine or lingual tonsils, especially if asymmetric, may mimic an aggressive process such as SCC, but no invasive or infiltrative component will be identified (Figure 3–17).
- In a patient with a prior unilateral tonsillectomy, the remaining contralateral tonsil may appear to represent a mass lesion but is really a pseudomass (Figure 3–18).



A B

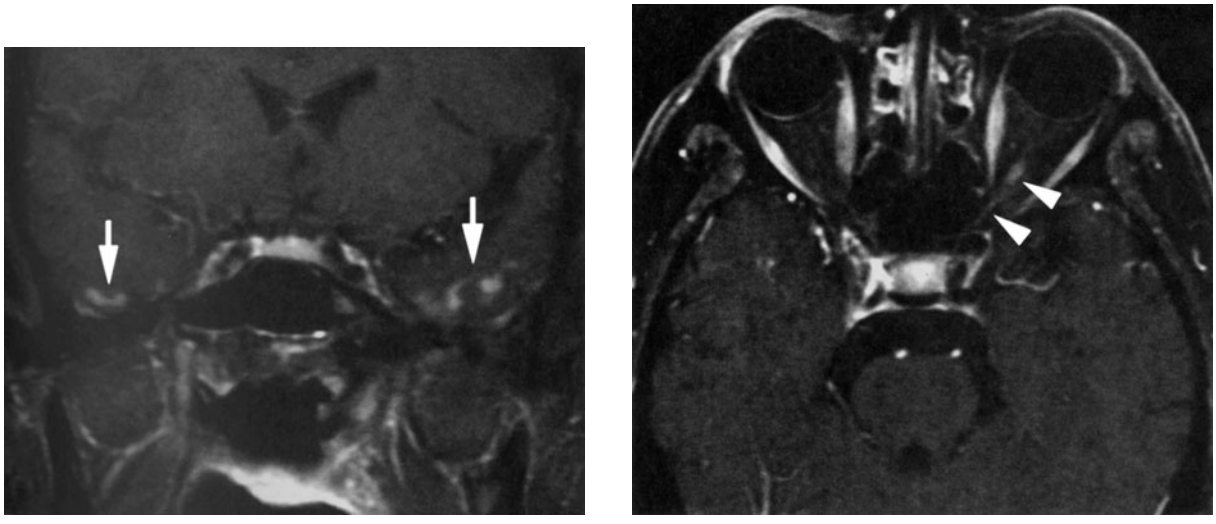
▲ **Figure 3–11. (A)** Axial noncontrast CT image viewed in soft tissue window of elderly man of southern Chinese descent demonstrates abnormal fullness of the nasopharyngeal soft tissues for the patient's age (arrowheads). This was noted, but the patient was lost to clinical follow-up. **(B)** Sagittal T1-weighted image obtained 4 years later when the patient complained of nasal congestion, epistaxis, and deep pain demonstrates replacement of the clivus (C) and sphenoid sinus by a large soft tissue mass (arrowheads) that is extending anteriorly into the ethmoid sinus and nasal cavity. The pons is displaced posteriorly by a large extradural component of the mass, and the pituitary gland (P) is elevated. A biopsy was consistent with nasopharyngeal carcinoma.

- CT imaging is generally the modality of choice for the assessment of infectious and inflammatory processes because of its sensitivity to calcification, foreign bodies, and gas within soft tissues; it is also rapid and widely available. In the setting of peritonsillar abscess, CT scanning may show extension of the process beyond the confines of the pharyngeal constrictor muscles into adjacent deep spaces.
- Lingual thyroid tissue is seen as a rounded, midline soft tissue mass at the level of the foramen cecum. The lesion is intrinsically dense on a noncontrast CT scan because of its iodine content and enhances intensely postcontrast (Figure 3–19). In a patient with lingual thyroid tissue, the lower neck should be carefully scrutinized to assess whether any thyroid gland is present in the normal location.
- A well-circumscribed mass of the soft palate most commonly represents a pleomorphic adenoma, although a low-grade minor salivary gland malignant neoplasm may have an identical imaging appearance (Figure 3–20).
- The palatine tonsil and the base of tongue are common sites for "unknown" primary lesions in patients who present with metastatic cervical lymphadenopathy but with no obvious primary site lesion on careful head and neck examination. In some of these cases, CT scanning or MRI may demonstrate a primary site. FDG PET/CT scanning has also been shown to play a role in the search for the unknown primary.
- The possibility of perineural spread of tumor should be evaluated. Tonsillar SCC may invade the masticator space and access V3, whereas SCC of the base of tongue may access cranial nerves (CN) IX and XII (the glossopharyngeal and hypoglossal nerves, respectively), as well as the lingual nerve. Tumors of the palate may access the palatine nerves and the pterygopalatine fossa, from which they may spread intracranially via the vidian canal and foramen rotundum.

ORAL CAVITY

Anatomy

The oral cavity (Figure 3–21) is bounded superiorly by the hard palate, the superior alveolar ridge, and the maxillary teeth, laterally by the cheek, posteriorly by the circumvallate papilla and anterior tonsillar pillars (which separate it from



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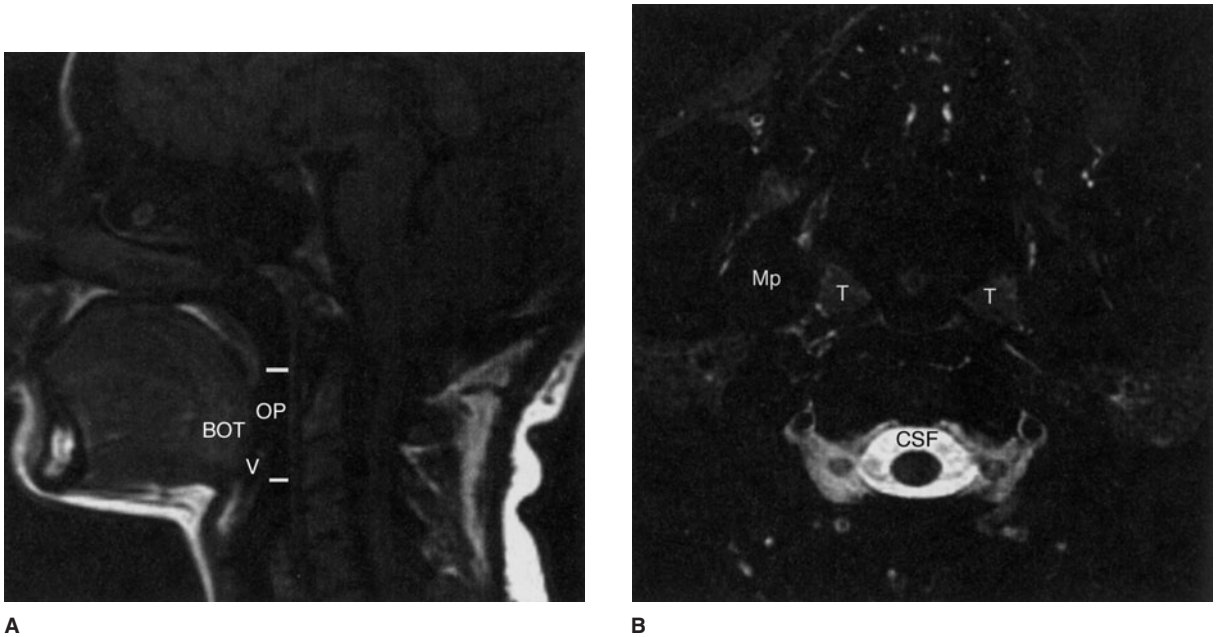
▲ **Figure 3–12.** **(A)** Coronal postgadolinium T1-weighted image with fat saturation demonstrates irregular enhancement (white arrows) in the inferior temporal lobes bilaterally in a patient with a history of high-dose radiation therapy for nasopharyngeal carcinoma. This is a typical location and appearance of radionecrosis. **(B)** An axial postgadolinium T1-weighted image with fat saturation in the same patient demonstrates enhancement of the left optic nerve (arrowheads). The patient complained of decreased vision in the left eye, which is consistent with radiation-induced optic neuritis. The patient has been followed and has had no evidence of recurrent carcinoma.



A B

▲ **Figure 3–13.** **(A)** Sagittal T1-weighted image demonstrates the superior and inferior limits of the oropharynx (OP), the region of the upper aerodigestive tract that can be seen posteriorly through an open mouth. Indicated are the vallecula (V) and the base of tongue (BOT). **(B)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates the normal palatine tonsils (T), which, like other lymphoid tissue, are intermediate in signal intensity (note the much darker muscle [Mp, medial pterygoid muscle] and much brighter CSF) on a T2-weighted image.

Table 3–2. Lesions of the Oropharynx that may be Encountered on Imaging.

Benign	Malignant
Lingual or faucial tonsillar hypertrophy	Squamous cell carcinoma
Tonsillar or peritonsillar abscess	Non-Hodgkin lymphoma
Lingual thyroid	Malignant tumor of minor salivary gland
Postinflammatory retention cyst	Rhabdomyosarcoma (child)
Dystrophic calcification ("tonsillolith")	
Benign tumor of minor salivary gland	

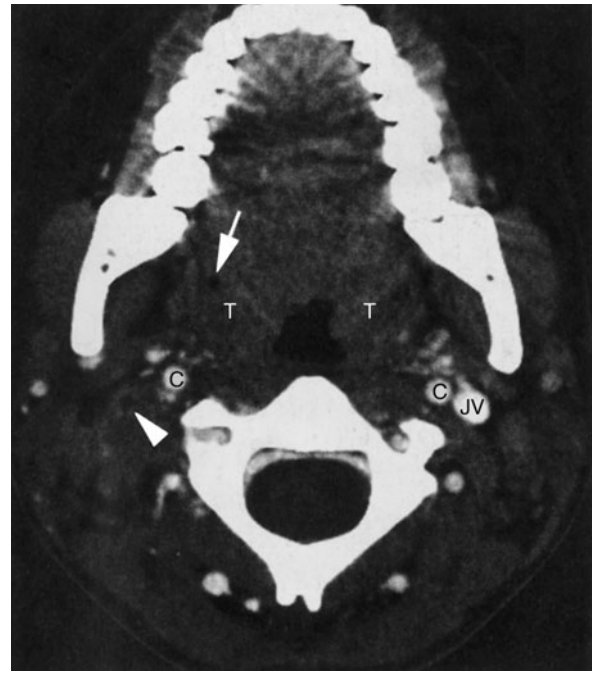
the oropharynx), and inferiorly by the mylohyoid muscle, the inferior alveolar ridge, and the mandibular teeth. The mucosal area of the oral cavity includes the oral tongue and mucosa-covered surfaces, which are readily accessible to clinical examination. The oral mucosa has buccal, gingival, lingual, sublingual, and palatal surfaces. In addition to the ubiquitous squamous epithelium, minor salivary glands are located throughout the oral cavity.

Two other major spaces are also considered in any discussion of the oral cavity: the sublingual and submandibular spaces (Figure 3–22). These spaces are separated from each other by the mylohyoid muscle, which defines the muscular floor of mouth. The sublingual space is not a true fascia-defined space; rather, it is located in the oral tongue between the mylohyoid muscle inferolaterally and the genioglossus–geniohyoid complex medially. It freely communicates with the submandibular space around its posterior edge, and its important contents include the sublingual glands and ducts, the submandibular (Wharton) duct, the lingual artery and vein, the lingual nerve, and CN IX and XII. The submandibular space is located inferolateral to the mylohyoid muscle and superior to the hyoid bone. It is partly defined by the superficial layer of deep cervical fascia, but communicates freely with both the sublingual space around the back edge of the mylohyoid muscle and also the inferior parapharyngeal space. Important contents of the submandibular space include the submandibular gland, the level I lymph nodes, the facial artery and vein, and CN XII.

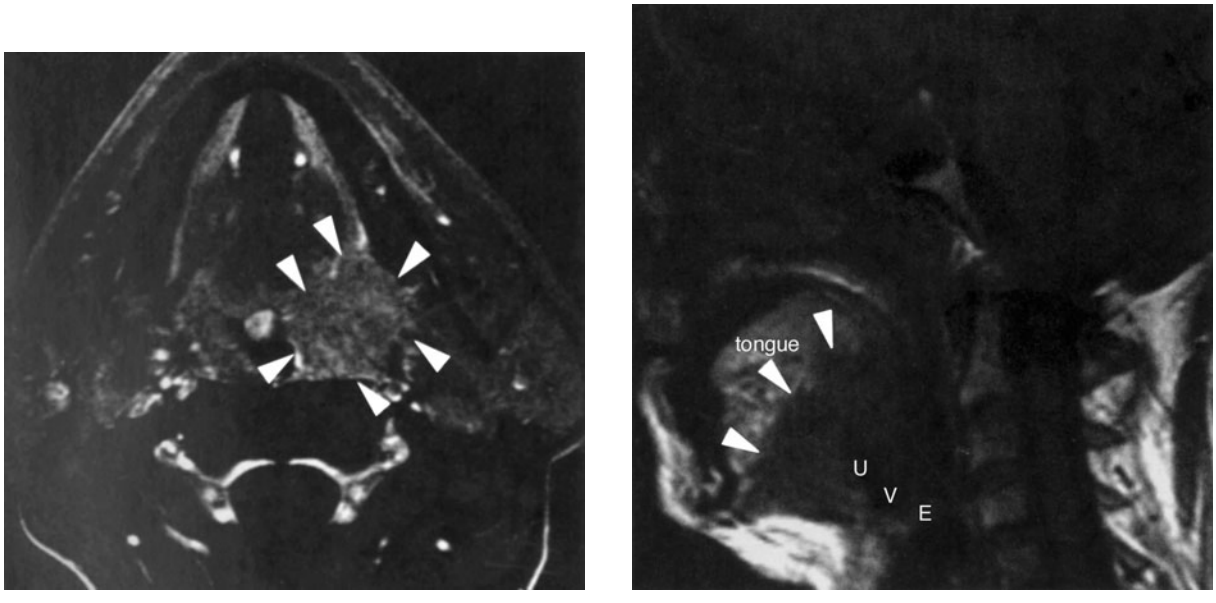
Pathology

The oral cavity is readily accessible to direct visualization and palpation, but imaging studies can be very helpful in assessing the deep extent of processes and guiding surgical management. In the mucosal area and oral tongue itself, the most common pathologies encountered are SCC (Figure 3–23) and extension of odontogenic infections. Benign or malignant minor salivary gland lesions may also be seen, as may congenital lesions such as venolymphatic malformations (Figure 3–24) and dermoids and epidermoids. In the setting of injury to or a lesion of CN XII, denervation change may be seen in the ipsilateral hemitongue, which may mimic a mass lesion to the unsuspecting observer.

Within the sublingual space, lesions that may be encountered on imaging studies are most frequently masses of congenital, inflammatory, or malignant neoplastic etiology. As in the mucosal space, venolymphatic malformations and dermoids and epidermoids may occur. A dilated submandibular duct due to stenosis, calculus, or neoplastic

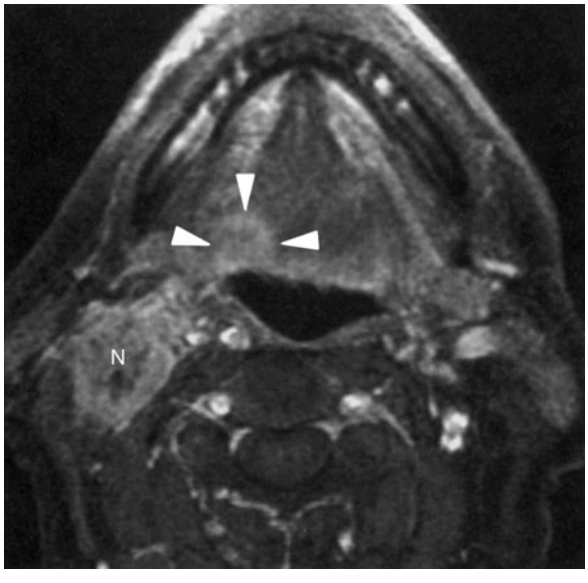


▲ **Figure 3–14.** Axial contrast-enhanced CT image in a 16-year-old girl who had pharyngitis for a week as well as the recent incision and drainage of a right peritonsillar abscess demonstrates prominence of both palatine tonsils (T), right more than left. A dot of air (white arrow) is related to the recent incision and drainage. In addition, abnormal soft tissue is seen around the right internal jugular vein, and the vein itself (arrowhead) is thrombosed. The normal carotid arteries (C) and left internal jugular vein (JV) are indicated. The patient's chest CT scan (not shown) demonstrated multiple pulmonary nodules, some of which were cavitary, consistent with septic pulmonary emboli in a patient with Lemierre syndrome.

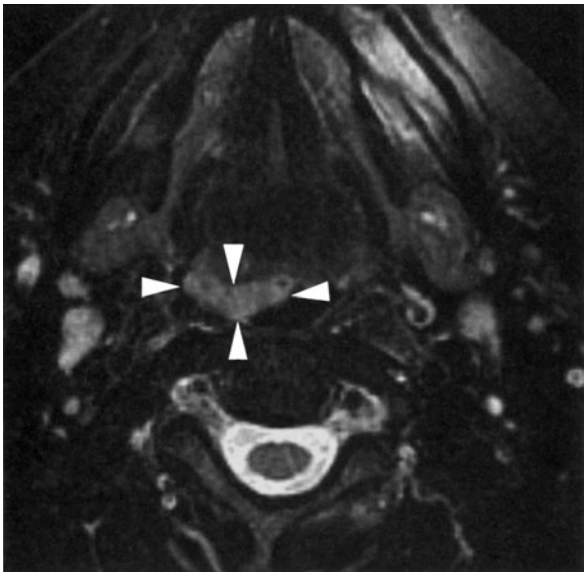


A B

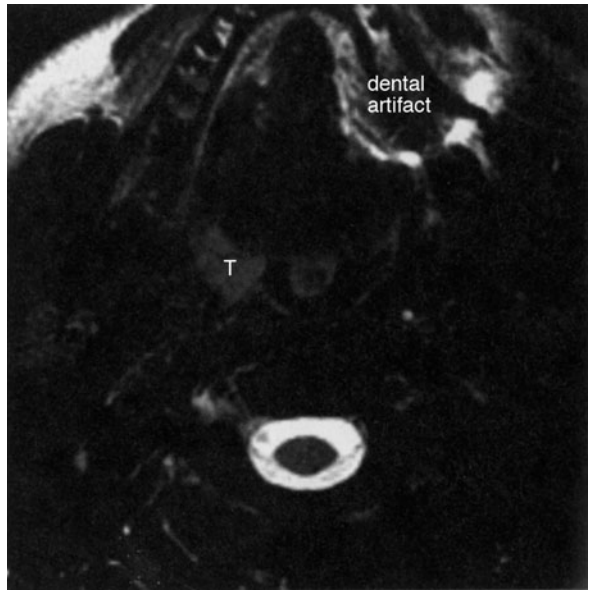
▲ **Figure 3–15.** **(A)** Axial postgadolinium Tl-weighted image with fat saturation demonstrates a bulky mass in the left tonsillar fossa (white arrowheads), consistent with squamous cell carcinoma. There is mass effect on the left base of tongue, but no gross invasion. **(B)** Sagittal Tl-weighted image in a different patient with squamous cell carcinoma of the base of tongue demonstrates a large mass lesion (arrowheads) that is deeply infiltrative into the tongue as well as being exophytic into the vallecula (V) and displacing the epiglottis (E) posteriorly. A deep ulceration (U) is present. Note that the oral tongue shows high signal intensity consistent with extensive fatty infiltration. This is related to denervation change secondary to neoplastic invasion of CN XII.



▲ **Figure 3–16.** Axial postgadolinium Tl-weighted image with fat saturation in an older man presenting with metastatic cervical adenopathy from squamous cell carcinoma and no clear primary site on clinical examination demonstrates a large metastatic node (N) as well as a subtle, infiltrative lesion at the right base of tongue (arrowheads) consistent with squamous cell carcinoma of the base of tongue.



▲ **Figure 3–17.** Axial fast spin-echo T2-weighted image with fat saturation in an older woman complaining of a sore throat demonstrates asymmetric soft tissue at the right base of tongue (arrowheads), which may be suggestive of lymphoma or squamous cell carcinoma, although no invasive component is identified. Operative resection for a definitive biopsy yielded only normal lingual tonsillar tissue.

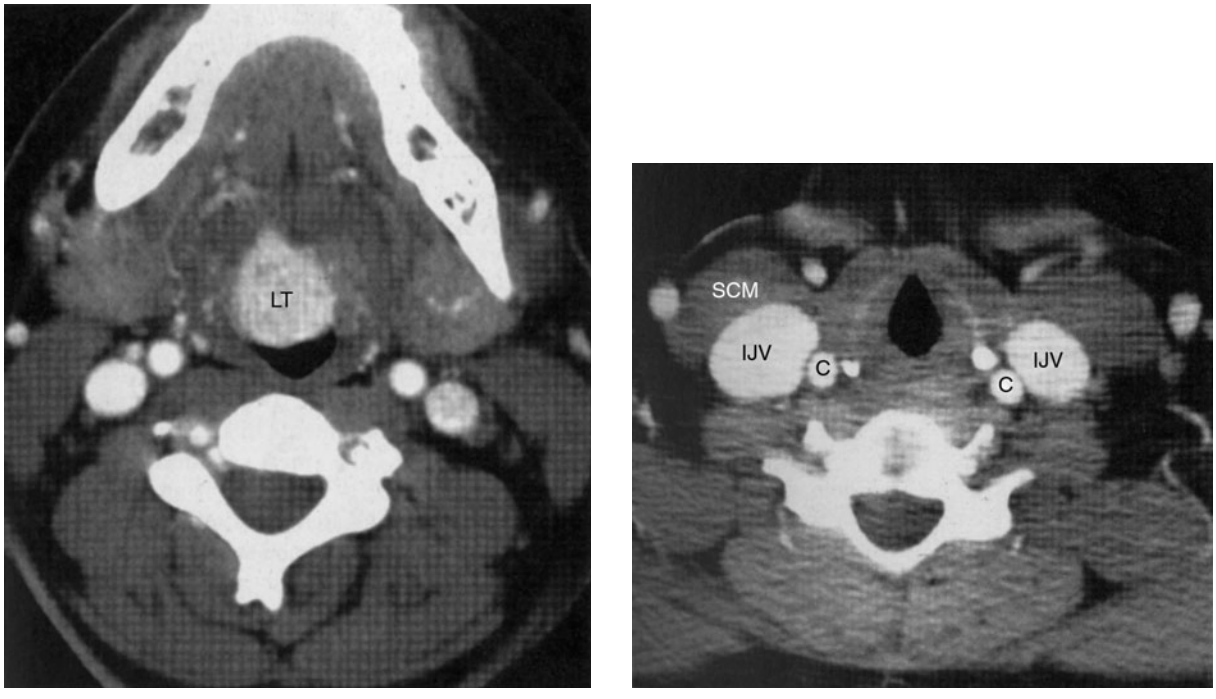


▲ **Figure 3–18.** Axial fast spin-echo T2-weighted image with fat saturation in a patient who has undergone a prior left tonsillectomy demonstrates marked oropharyngeal asymmetry due to the presence of normal tonsillar tissue on the right (T) and no tissue on the left. Inhomogeneity along the left anterior aspect of the image is related to a ferromagnetic nonremovable dental appliance.

obstruction may be seen (Figure 3–25), as may a ranula (Figure 3–26). Changes due to cellulitis (Ludwig angina) and frank abscess formation may also be present. Finally, SCC extending from the mucosal surface of the oral cavity (Figure 3–27) or due to deep anterior extension from the tongue base may be encountered. A similar list of diagnostic considerations can be applied in the submandibular space, with a few important additions: notably, a second branchial cleft cyst (see Cystic Neck Masses later in this chapter) and lymphadenopathy, which may be reactive, inflammatory, or neoplastic, with nodal lymphoma and metastatic SCC accounting for most cases of neoplastic submandibular lymphadenopathy. Neoplastic lesions of the submandibular gland itself most commonly represent pleomorphic adenoma, but on imaging studies alone, these are often indistinguishable from carcinomas. The more common pathologies of the oral cavity and associated spaces are summarized in Table 3–3.

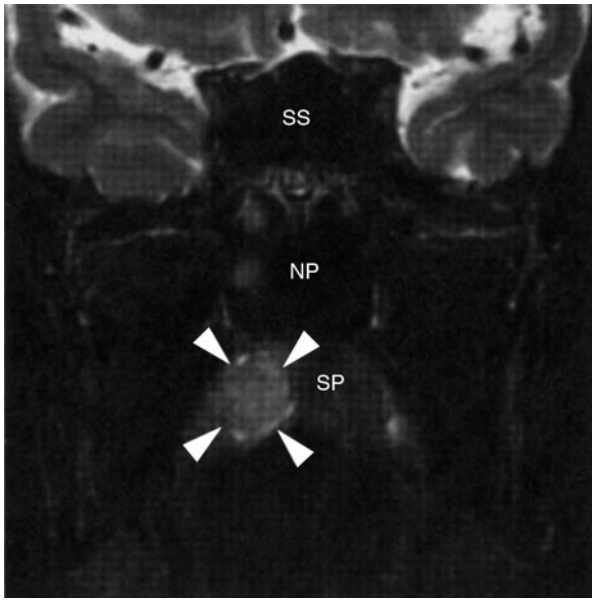
Key Imaging Points

- Because so much of the oral cavity is readily accessible to inspection and palpation, imaging studies must focus on addressing specific issues: submucosal and deep extension of neoplastic or inflammatory processes, bone involvement, and perineural spread of disease (Figure 3–28).
- Level I and II lymph nodes should be carefully assessed bilaterally in patients with oral cavity carcinoma, as bilateral nodal spread is common.
- The mucosal area of the oral cavity, particularly the buccal mucosa, can be better assessed on imaging examinations if the patient is asked to "puff out" his or her cheeks during a CT or MRI study to separate the buccal mucosa from the underlying teeth and gums (Figure 3–29).
- MRI is generally the study of choice to assess neoplasms of the oral cavity because it is less sensitive to dental artifact than CT scanning and provides superior soft tissue contrast for most processes (Figure 3–30).
- MRI is less sensitive to calcification than CT scanning; therefore, CT imaging is the study of choice for assessment of calculus disease, as well as for most infectious and inflammatory processes (Figure 3–31).
- In some cases, cellulitis and phlegmonous changes can be difficult to distinguish from an abscess. An abscess has a well-defined enhancing rim and a nonenhancing pus-filled center, and it exerts mass effect on local tissues rather than infiltrating along and obscuring fascial planes.

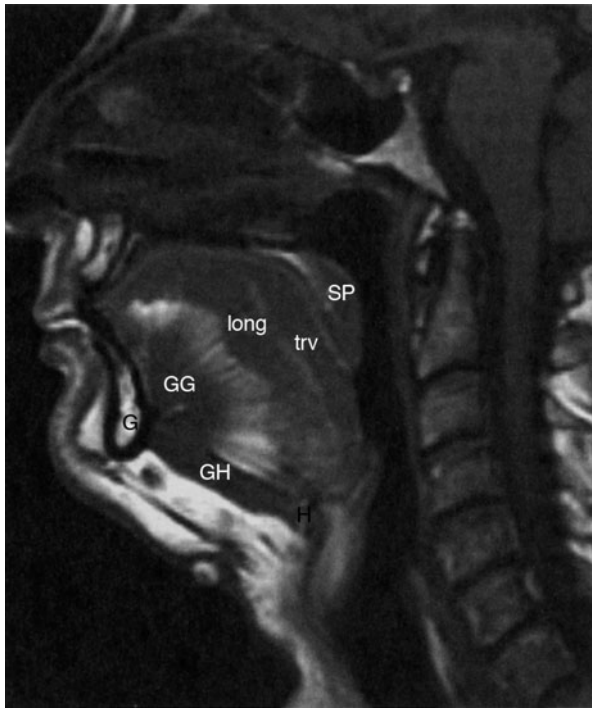


A B

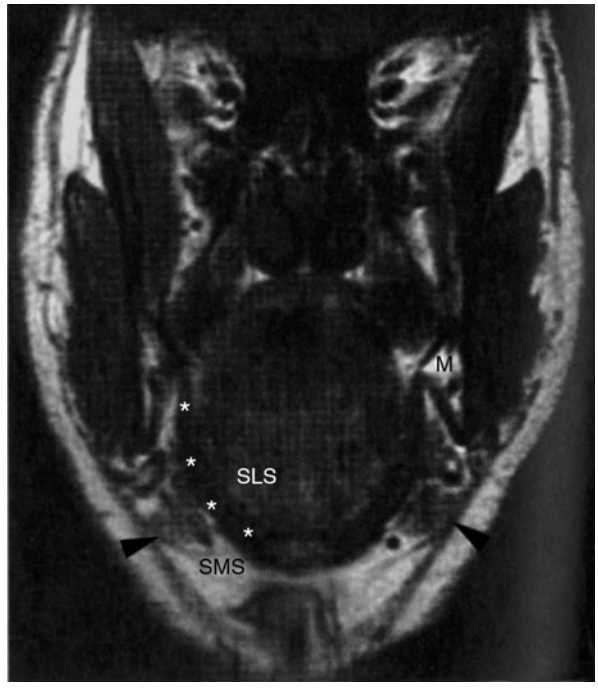
▲ **Figure 3–19.** **(A)** Axial contrast-enhanced CT scan demonstrates a densely enhancing soft tissue mass in the midline of the base of tongue, consistent with lingual thyroid (LT). **(B)** A more inferior image through the low neck shows no normal thyroid tissue. Indicated are the common carotid artery (C), the internal jugular vein (IJV), and the sternocleidomastoid muscle (SCM).



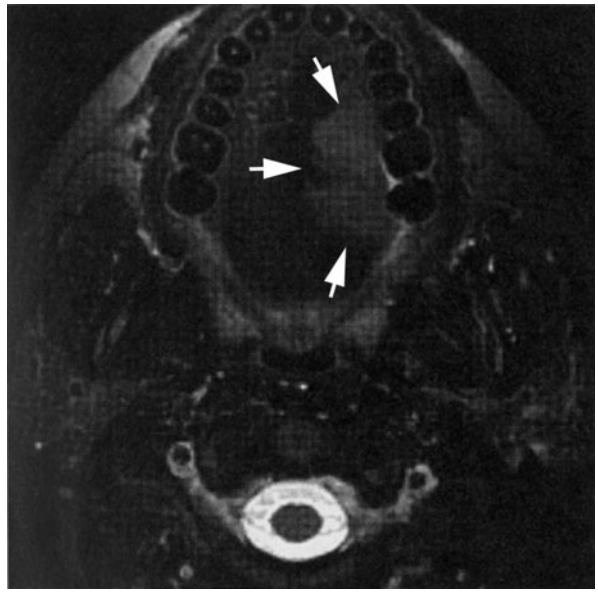
▲ **Figure 3–20.** Coronal fast spin-echo T2-weighted image with fat saturation in a 50-year-old man with HIV demonstrates a fairly well-circumscribed mass (arrowheads) arising from the soft palate (SP). A pleomorphic adenoma was expected, but at resection, this mass was found to be a low-grade adenocarcinoma. The sphenoid sinus (SS) and nasopharynx (NP) are indicated.



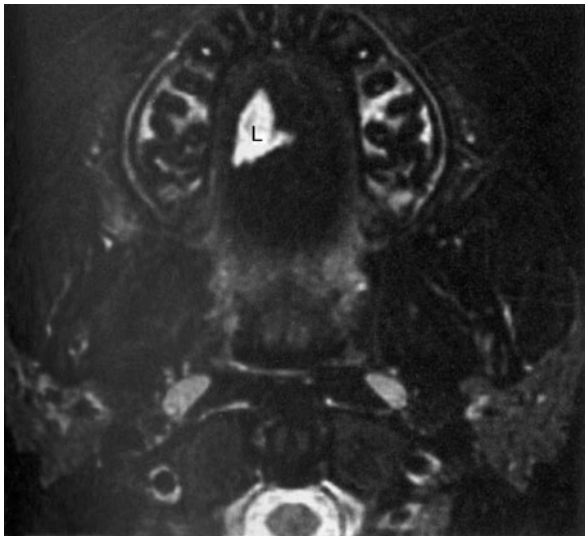
▲ **Figure 3–21.** Sagittal T1-weighted image demonstrates the normal anatomy of the oral cavity. The genu (G) of the mandible and the hyoid bone (H) are indicated, along with extrinsic tongue musculature (genioglossus [GG] and geniohyoid [GH]) and intrinsic tongue musculature (longitudinal and transverse muscle fibers). The soft palate (SP) is also shown.



▲ **Figure 3–22.** Coronal T1-weighted image demonstrates the mandible (M) and the mylohyoid muscle (*). The mylohyoid defines two spaces, the sublingual space (SLS) above and the submandibular space (SMS) below. The submandibular glands are indicated (black arrowheads).



▲ **Figure 3–23.** Axial fast spin-echo T2-weighted image with fat saturation in a 34-year-old woman with tongue cancer demonstrates an irregularly marginated left-sided lesion (arrows) that is deeply infiltrative into the tongue musculature.



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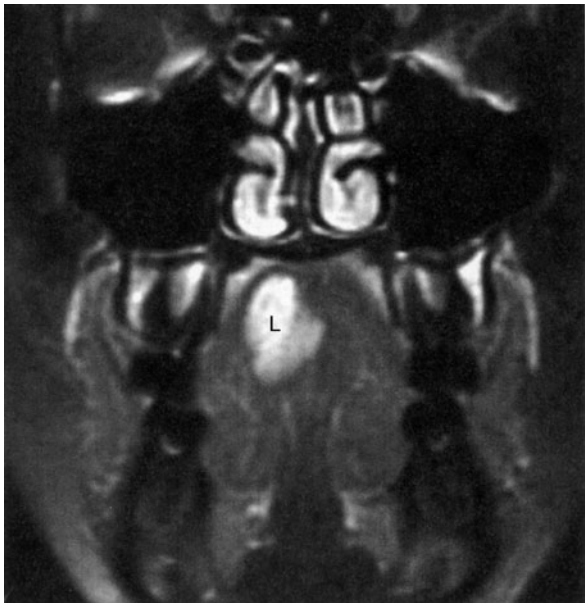
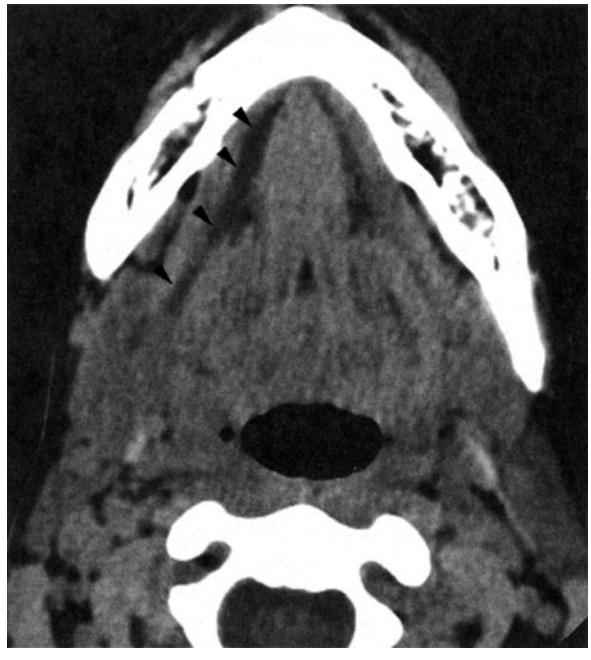


B

▲ **Figure 3–24.** **(A)** Axial fast spin-echo T2-weighted image with fat saturation in a young woman with fullness in her right hemitongue and a slight bluish discoloration on clinical examination demonstrates a multilobulated, well-circumscribed, hyperintense mass lesion (L). **(B)** Postgadolinium, a coronal Tl-weighted image with fat saturation demonstrates intense and homogeneous enhancement. The appearance is consistent with a venous malformation.



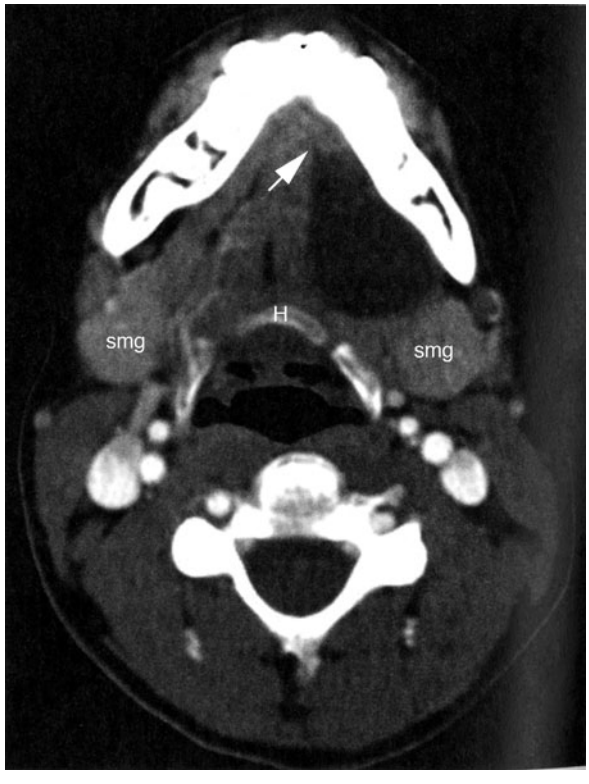
▲ **Figure 3–25.** Axial noncontrast CT scan through the floor of mouth demonstrates asymmetric dilatation of the submandibular duct (black arrowheads) in a patient who has had prior removal of calculi and has a postinflammatory stenosis of the distal duct.

- A denervated hemitongue due to palsy of CN XII can mimic a mass lesion in the acute and subacute phases of denervation, when the tongue may be bright on a T2-weighted image and show enhancement postgadolinium (Figure 3–32). Denervation changes respect the midline perfectly, unlike most mass lesions. In addition, the lingual septum deviates toward rather than away from the "lesion," and the tongue flops back into the oropharynx owing to atrophy and loss of muscle tone.
- A pedunculated mass of the parotid tail (Figure 3–33) may present clinically as a mass in the posterior submandibular space.

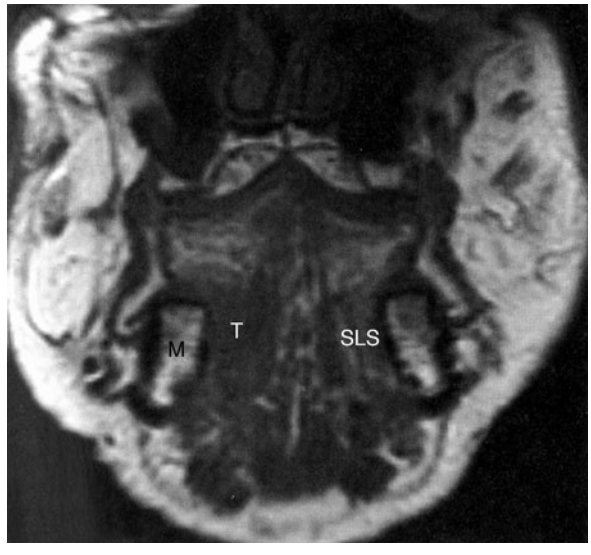
HYPOPHARYNX

Anatomy

The hypopharynx represents the inferior continuation of the pharyngeal mucosal space, distinct from the oropharynx above and the larynx anteroinferiorly. Three major subsites of the hypopharynx are recognized: the pyriform



▲ **Figure 3–26.** Axial contrast-enhanced CT scan through the floor of mouth in a patient with a painless swelling of the left sublingual space demonstrates a well-circumscribed fluid-density mass with a narrow extension (white arrow) to the anterior aspect of the sublingual space. A simple ranula was confirmed surgically. The submandibular glands (smg) and hyoid bone (H) are indicated.



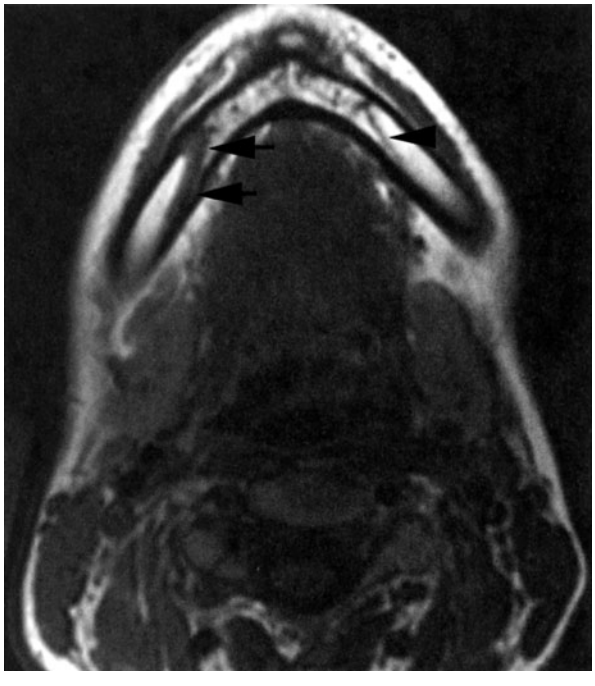
▲ **Figure 3–27.** Coronal Tl-weighted image in an elderly man with squamous cell carcinoma of the anterior floor of mouth demonstrates infiltration of tumor (T) into the right sublingual space; the normal fatty left sublingual space (SLS) is shown for comparison. The mandible (M) is also indicated. Note how useful a pregadolinium Tl-weighted image is for demonstrating the replacement of normal fat by infiltrative soft tissue.

sinus, the postcricoid area, and the posterior pharyngeal wall (Figure 3–34). The pyriform sinuses are bilaterally symmetric spaces marginated by the aryepiglottic folds anteromedially, the posterior thyroid cartilage ala laterally, and the most lateral aspect of the posterior hypopharyngeal wall posteriorly. The pyriform sinuses are shaped like inverted pyramids such that the tip of the sinus, also known as the pyriform apex, lies at the true vocal cord level. The postcricoid area forms the anterior wall of the

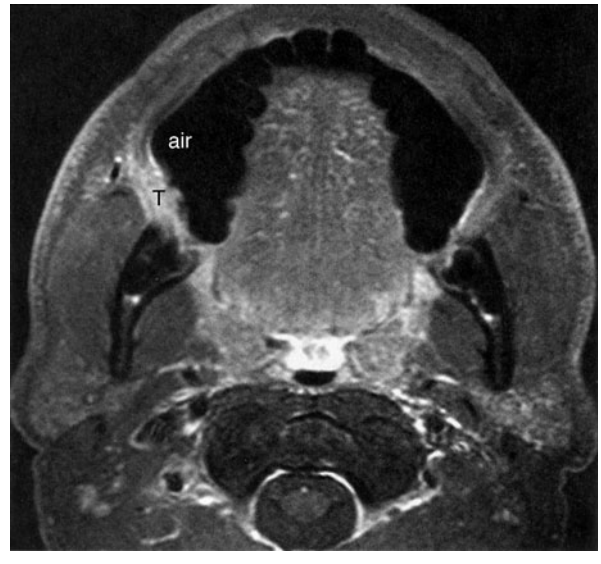
Table 3–3. Lesions of the Oral Cavity, Including the Mucosal Area, the Sublingual Space, and the Submandibular Space.

Congenital/Developmental	Infectious/Inflammatory	Neoplastic	
		Benign	*Malignant*
Hemangioma	Cellulitis or Ludwig angina	Pleomorphic adenoma	Squamous cell carcinoma
Venolymphatic malformation	Abscess	Other benign lesions of minor salivary origin	Malignant neoplasm of minor salivary origin
Dermoid or epidermoid	Dilated submandibular (Wharton) duct	Lipoma	Nodal metastases from SCC (SM space)
Second branchial cleft cyst (SM space)	Ranula, simple or plunging		Nodal involvement by lymphoma (SM space)

SCC, squamous cell carcinoma; SM, submandibular.



▲ **Figure 3–28.** Axial Tl-weighted image in a 45-year-old woman with a history of squamous cell carcinoma of the right gingivobuccal sulcus and new chin numbness demonstrates abnormal soft tissue in the right inferior alveolar canal (arrows) compared with the left (arrowhead), consistent with the perineural spread of disease. This was confirmed at the time of mandibulectomy.



▲ **Figure 3–29.** Axial postgadolinium Tl-weighted image with fat saturation in a patient with squamous cell carcinoma of the right buccal mucosa obtained during a "puffed cheek" maneuver. This maneuver places air between the teeth and the tumor, making the extent of tumor (T) easier to define.

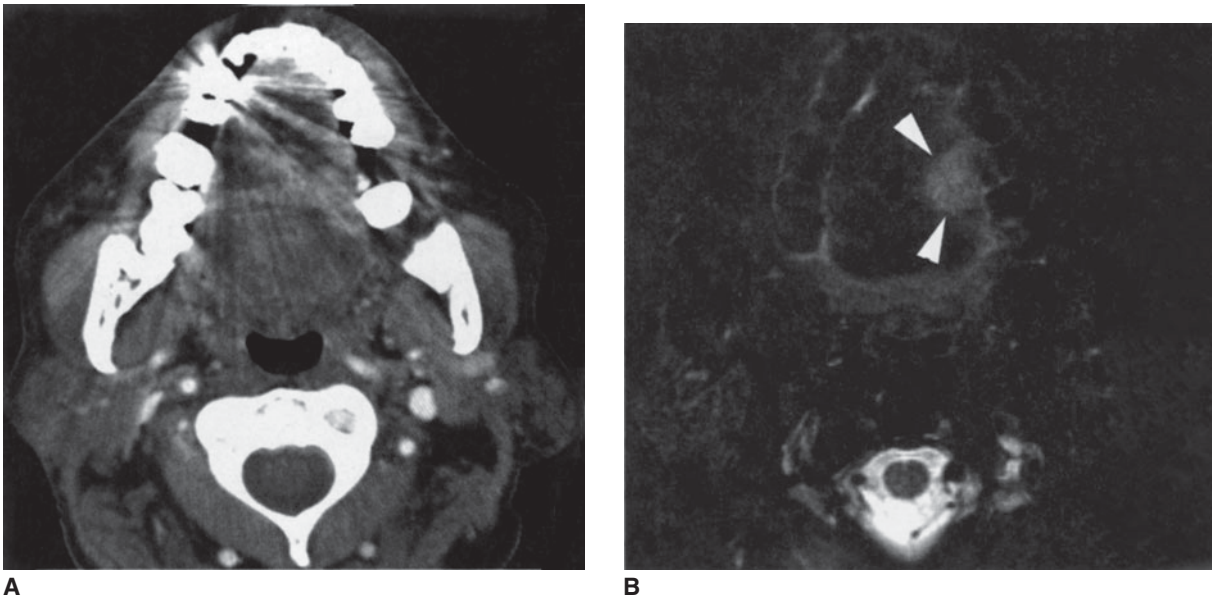
lower pharynx at the level of the pharyngoesophageal junction, extending from the level of the arytenoid cartilages above to the inferior border of the cricoid cartilage below. This area is difficult to delineate on imaging studies because mucosal surfaces are usually coapted. The hypopharyngeal segment of the posterior pharyngeal wall extends from the bottom of the vallecula above to the esophageal inlet below. The hypopharynx contains only squamous mucosa, minor salivary glands, and the inferior constrictor muscles.

Pathology

The dominant pathology of the hypopharynx is SCC. Other lesions include retention cysts, benign and malignant tumors of minor salivary origin, and extranodal lymphoma. The pyriform sinus is the subsite most commonly involved with SCC, and these lesions are usually advanced at presentation and have a high incidence of nodal metastases (Figure 3–35).

Key Imaging Points

- The walls of the pyriform sinus are frequently coapted during imaging studies. Certain maneuvers, such as the Valsalva or "trumpet" maneuver, may help dilate the pyriform sinus and improve the imaging assessment.
- The pyriform sinus is a site where a small primary lesion may not be readily apparent in a patient who presents with metastatic cervical lymphadenopathy and no evidence of a primary lesion ("unknown primary"). It must therefore be carefully assessed on imaging studies performed in patients with metastatic cervical lymphadenopathy of unknown primary.
- A lesion of the pyriform apex approaches the upper margin of the cricoid cartilage and may erode cartilage even when relatively small. Cricoid erosion may also be secondary to a primary tumor of the postcricoid region (Figure 3–36).
- Symmetric lesions of the posterior pharyngeal wall may be subtle and difficult to detect on imaging studies. A sagittal T1-weighted image can be very helpful in these cases.
- Lesions of the hypopharynx have a propensity to spread to retropharyngeal nodes, so these nodes should be carefully scrutinized in patients with hypopharyngeal cancers (Figure 3–37).



A B

▲ **Figure 3–30.** **(A)** Axial contrast-enhanced CT image in an older man with a left lateral squamous cell carcinoma of the tongue. The lesion is difficult to demonstrate given extensive streak artifact related to the patient's dental work as well as the relatively poor contrast between the lesion and the tongue musculature. **(B)** The tumor (arrowheads) is very well seen on an axial fast spin-echo T2-weighted image with fat saturation.

LARYNX

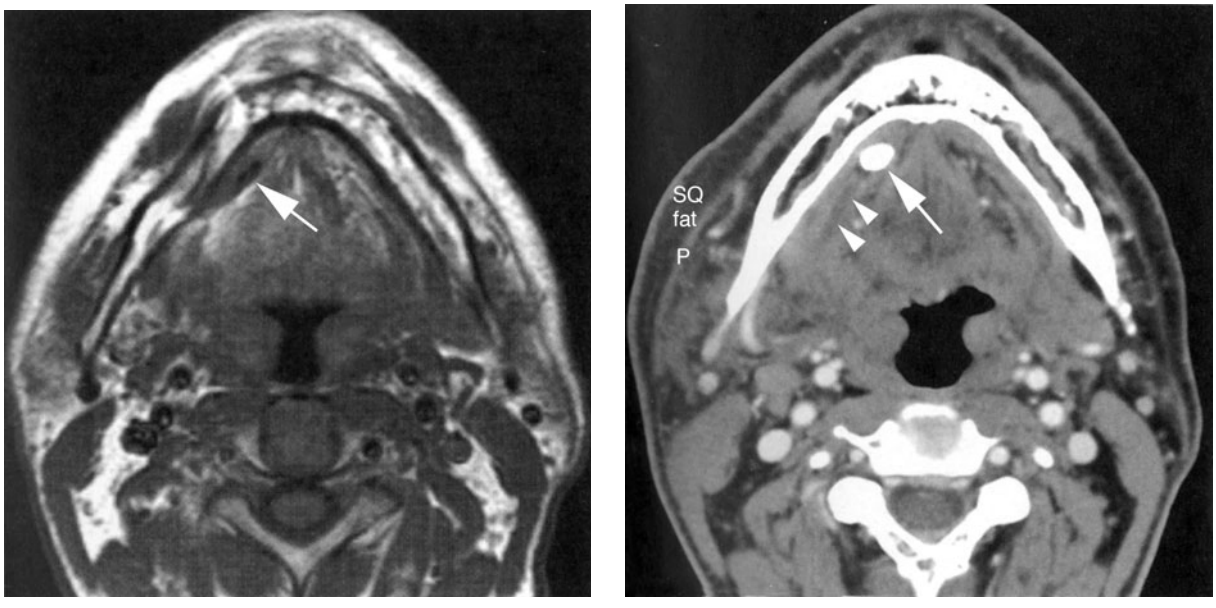
Anatomy

The soft tissues of the larynx (ie, the mucosa, the submucosa, and muscle) are draped over and attached to a supporting framework of cartilage, which gives the larynx its form. The endolarynx is divided into three subsites: the supraglottis, the glottis, and the subglottis (Figure 3–38). The supraglottis extends from the tip of the epiglottis above to the level of the laryngeal ventricles below and includes the epiglottis, the preepiglottic space, the aryepiglottic folds, the false vocal cords, the paraglottic space, and the arytenoid cartilages. The preepiglottic space is a fat-filled space bounded by the hyoid bone anteriorly and the epiglottis posteriorly, and halved by the hyoepiglottic ligament. The preepiglottic space communicates laterally with the paraglottic space, which is a bilateral, fat-filled space deep to the true and false vocal cords. The glottis includes the true vocal cords as well as the anterior and posterior commissures, whereas the subglottis extends from the undersurface of the true vocal cords above to the inferior surface of the cricoid cartilage below. The fibroelastic membrane known as the conus elasticus defines the lateral margin of the subglottis and extends from the cricoid cartilage below to the medial margin of the true vocal cord above.

The laryngeal cartilages include thyroid, cricoid, and arytenoid cartilages. The thyroid cartilage is composed of two anterior laminae that meet in the anterior midline. Posteriorly, the laminae elongate and form superior and inferior cornua; the superior cornua provide attachment to the thyrohyoid ligament, while the inferior cornua articulate medially with the cricoid cartilage and the cricothyroid joint. The cricoid cartilage is a complete ring that has a narrow arch anteriorly and a wide posterior lamina. The paired, pyramidal arytenoid cartilages sit atop the posterior cricoid lamina and provide attachment for the posterior margins of the vocal cords at the level of the vocal processes. The laryngeal cartilages progressively calcify and eventually ossify with age; in children and young adults they are of soft tissue density on CT scanning.

Pathology

Lesions that may be encountered on imaging studies of the larynx are listed in Table 3–4. SCC is the most common pathology of the larynx that requires an imaging assessment. Small lesions may not require imaging assessment and may in fact not even be visible on imaging studies, but CT scanning or MRI is useful in staging larger lesions. Involvement of preepiglottic and paraglottic spaces is well assessed on CT and MR scans, as is subglottic extension (Figure 3–39).



A B

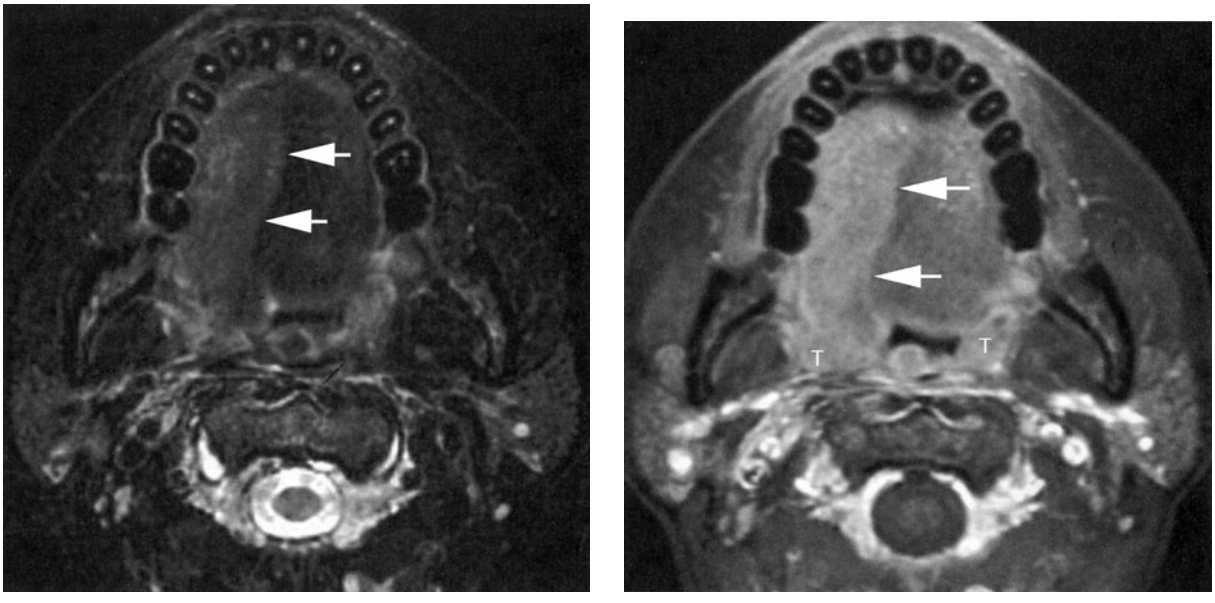
▲ **Figure 3–31.** **(A)** Axial Tl-weighted image in a young man complaining of fullness and slight tenderness in the right submandibular region. An ovoid low signal intensity structure in the right anterior floor of mouth (white arrow) was overlooked. This patient should probably have been referred for a CT scan rather than an MRI, given that inflammatory disease was more likely than neoplasm. **(B)** Axial contrast-enhanced CT scan obtained 4 weeks later, when the patient presented with fever and dramatic pain and swelling of the submandibular region. A calculus (arrow) obstructing the right submandibular duct (arrowheads) is seen, as well as inflammatory changes in the sublingual space with the effacement of fat planes. The platysma (P) is thickened, and the infiltration of subcutaneous fat is consistent with cellulitis. More inferiorly, a large abscess involving the submandibular gland was seen (not shown).

Involvement of the laryngeal cartilages, notably the thyroid cartilage, may not be appreciated clinically but can be identified on imaging studies and has significant implications for therapy. MRI is more sensitive than CT scanning to neoplastic infiltration of the laryngeal cartilages, although neither technique is entirely reliable for detecting subtle invasion and both techniques may lead to overinterpretation of reactive changes as neoplastic infiltration. CT scanning or MRI is also useful in staging the neck, and both can detect pathologic lymphadenopathy that may be missed by clinical palpation.

Lesions primary to the laryngeal cartilages are classically chondroid in nature—for example, chondroma and chondrosarcoma. These lesions are centered on the cartilage, usually the cricoid cartilage, and appear as submucosal masses on direct inspection. A calcified matrix is typically present on CT scans, and these lesions are usually extremely bright on T2-weighted MRI. Ossified laryngeal cartilages may also be involved with systemic malignant processes such as lymphoma, leukemia, multiple myeloma, and hematogenously disseminated metastases from any primary site.

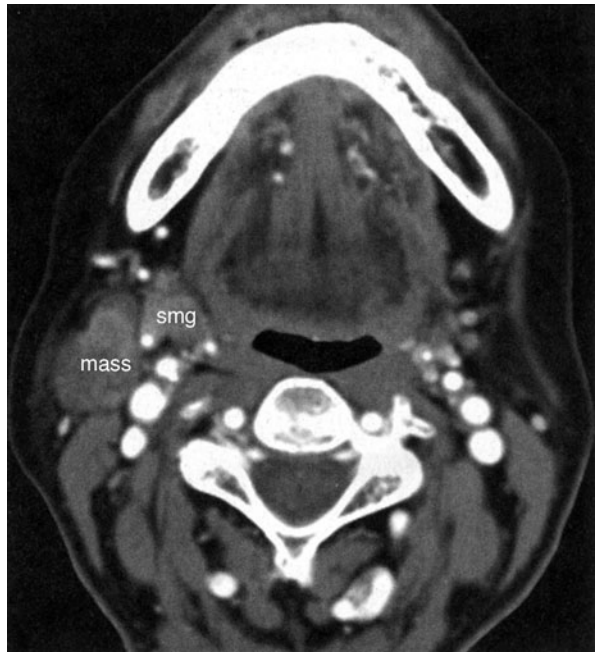
Trauma to the larynx is usually assessed clinically and endoscopically, but imaging may be useful when fracture of the laryngeal cartilages or deep tissue injury is suspected. Blunt trauma to the anterior neck compresses the larynx against the cervical spine. The thyroid cartilage most commonly fractures along its anterior margin (Figure 3–40), whereas the cricoid ring, like any complete ring, tends to fracture in two or more places.

The laryngocele results from functional obstruction (eg, increased intraglottic pressures) or true anatomic obstruction (eg, post-traumatic or postinflammatory stenosis, or neoplasm) of the laryngeal ventricle or its more distal saccule. The laryngocele may be filled with air, fluid, or pus and may be internal or external. The internal laryngocele is identified in the paraglottic space and can be followed to the level of the laryngeal ventricle. The external laryngocele has both an internal component, which may be completely collapsed, and an external component, which has penetrated the thyrohyoid membrane and often presents as an anterolateral neck mass (Figure 3–41).

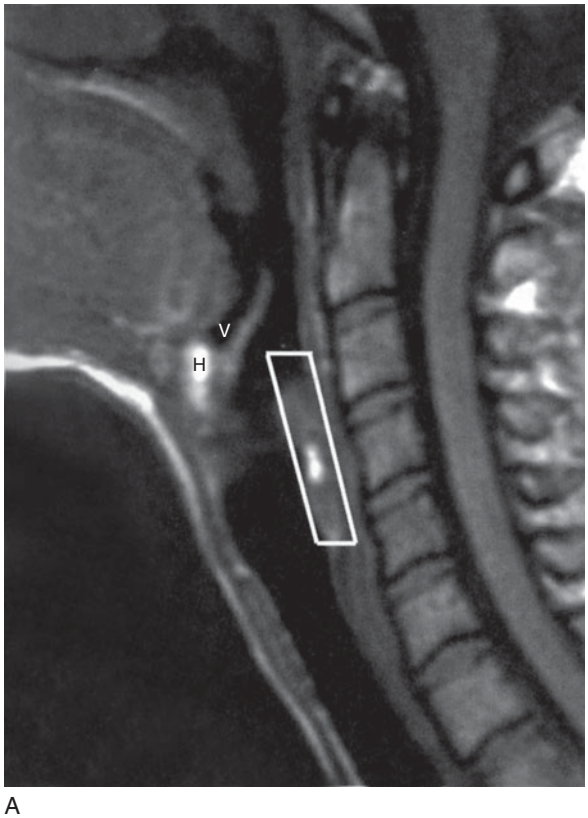


A B

▲ **Figure 3–32.** **(A)** Axial fast spin-echo T2-weighted image with fat saturation in a woman with a right CN XII palsy due to neoplastic infiltration of the skull base at the level of the hypoglossal canal (not shown) demonstrates sharply marginated hyperintensity of the right hemitongue (arrows) consistent with acute or subacute denervation change. Note that the lingual septum deviates toward the side of the "lesion," whereas a mass would be expected to push the lingual septum away. **(B)** Postgadolinium, an axial TI-weighted image with fat saturation demonstrates the enhancement of the right hemitongue as well as ptosis of the right tongue into the oropharynx, with compression of the ipsilateral right tonsil (T) compared with the left. These findings are typical of denervation change due to injury of CN XII.



▲ **Figure 3–33.** Axial postcontrast CT scan in a patient thought to have a mass arising from the submandibular gland (smg) demonstrates a well-circumscribed mass arising from the parotid tail, immediately adjacent to the submandibular gland. Fine-needle aspiration was consistent with pleomorphic adenoma.



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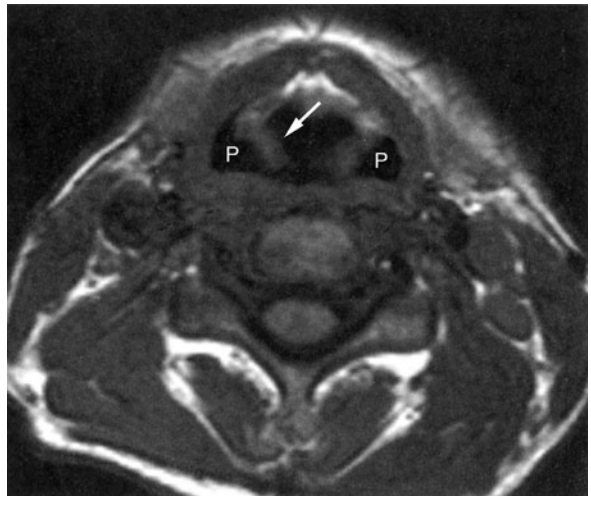

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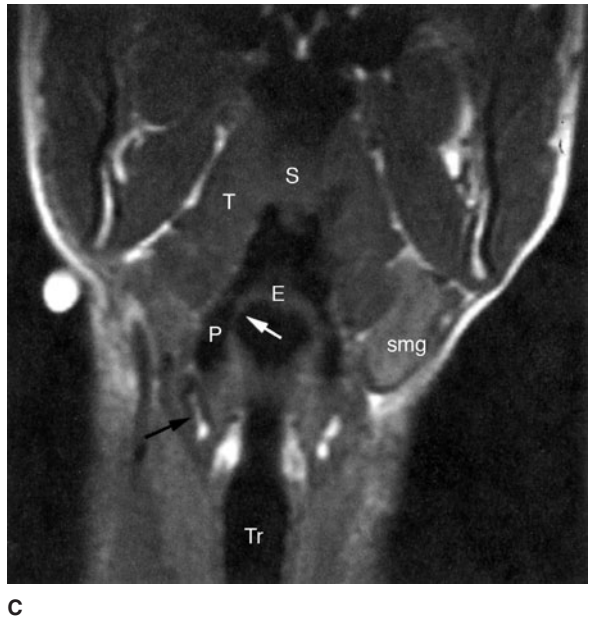
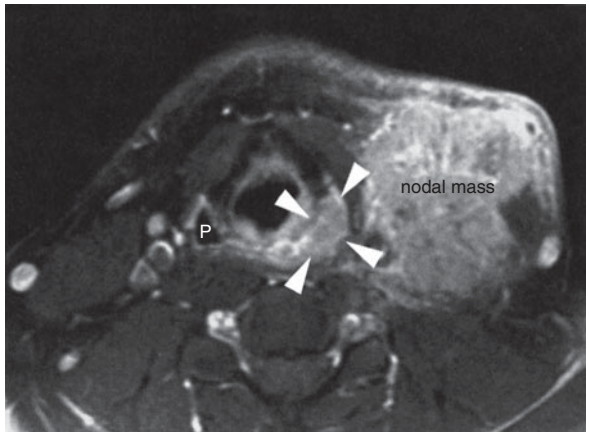


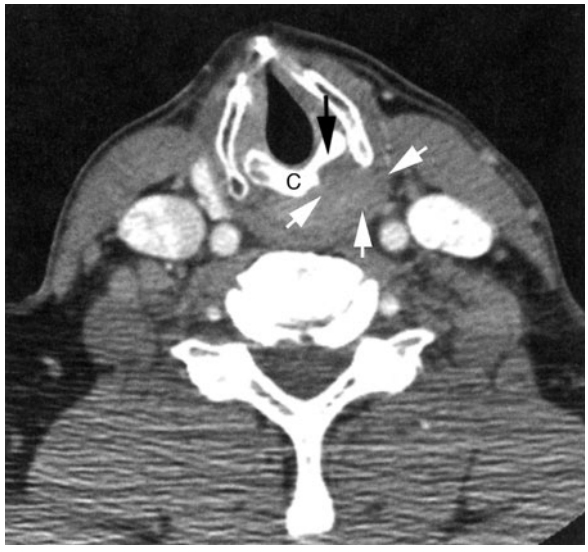
C

▲ **Figure 3–34. (A)** Sagittal Tl-weighted image demonstrates the hypopharynx (white lines) extending from the level of they hyoid bone (H) and vallecula (V) superiorly to the cricopharyngeus inferiorly, with the inferior extent approximated by the inferior margin of the cricoid cartilage. **(B)** Axial Tl-weighted image demonstrates the pyriform sinuses (P) and the right aryepiglottic fold (arrow). **(C)** Coronal Tl-weighted image demonstrates the pyriform sinus (P), epiglottis (E), aryepiglottic fold (white arrow), thyroid cartilage (black arrow), tonsil (T), trachea (Tr), soft palate (S), and submandibular gland (smg).

Hoarseness is a relatively common indication for laryngeal imaging. In the absence of a mass lesion, attention should be focused on the course of the vagus nerve (CN X). When hoarseness is present along with other symptoms of lower cranial nerve dysfunction, then MRI is the study of choice to assess for a lesion of the skull base or carotid sheath (Figure 3–42). When hoarseness is the only symptom, then CT imaging is preferred, from the skull base to the aorticopulmonary window, to assess for any anatomic abnormality or mass lesion that could affect the recurrent laryngeal nerve along its course (Figure 3–43). The normal true vocal cords are symmetrically abducted during quiet respiration, whereas the Valsalva maneuver adducts the vocal cords to an opposed, midline position. In the setting of vocal cord paralysis, the paralyzed cord is usually fixed in a paramedian position, the ipsilateral aryepiglottic fold deviates medially, the ipsilateral pyriform sinus is dilated, and the laryngeal ventricle is often patulous (Figure 3–44). Denervation atrophy of the laryngeal musculature may also be identified.



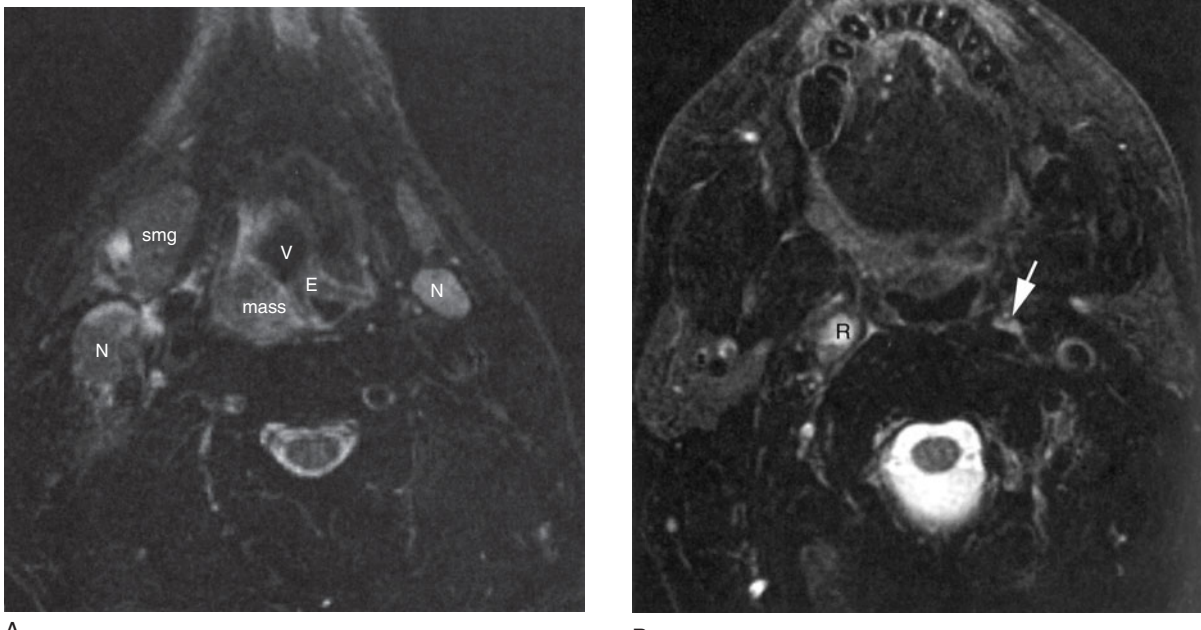
▲ **Figure 3–35.** Axial postgadolinium Tl-weighted image with fat saturation in a patient presenting with a left neck mass (nodal mass) shows a relatively small primary lesion in the left pyriform sinus (arrowheads). The normal right pyriform sinus (P) is indicated. Fine-needle aspiration of the nodal mass confirmed squamous cell carcinoma.



▲ **Figure 3–36.** Axial postcontrast CT scan in a patient with new hoarseness and throat pain demonstrates focal erosion (black arrow) of the posterolateral cricoid cartilage (C) by a mass arising from the postcricoid hypopharynx (white arrows). This lesion could probably be better delineated from adjacent soft tissues on an MRI. Biopsy demonstrated squamous cell carcinoma.

Key Imaging Points

- CT imaging is the study of choice for nonmalignant disease of the larynx (eg, trauma or laryngocele); MRI more sensitively assesses cartilage invasion and more accurately delineates the transglottic spread of tumor. However, MRI of the larynx is often compromised by patient motion; therefore, thin-section contrast-enhanced CT scanning may actually provide better depiction of the extent of disease in the majority of patients.
- The subsites of the hypopharynx are often confused with those of the larynx. It is important to distinguish among them, as SCCs in these areas behave differently.
- The paraglottic and preepiglottic spaces are fat-filled compartments that are not separated from each other by fascia, so tumor can easily spread from one space to another.
- Imaging studies of the larynx in a patient with laryngeal carcinoma should always be assessed for preepiglottic and paraglottic space involvement, as well as for the status of the laryngeal cartilages, because these areas cannot be staged clinically except in far-advanced disease.
- New hoarseness in a patient with a history of head and neck cancer should prompt careful evaluation of the course of CN X (the vagus nerve) to look for tumor recurrence and spread along the carotid sheath and to the skull base.
- It is generally best to perform imaging of the larynx in quiet respiration, during which the true vocal cords are in their relaxed, abducted state. If indicated, the scan can be repeated during a maneuver such as the Valsalva maneuver to assess for paralysis or mechanical fixation.
- The thickness of soft tissue in the anterior commissure may be as much as 2 mm in patients without disease.
- The mucosal surface of the subglottis is so closely applied to the cricoid cartilage that it is generally not appreciable on the airway side of the subglottic larynx. Visible soft tissue at this level should suggest the possible presence of tumor extension.
- A submucosal tumor of the larynx most commonly represents a chondrosarcoma or a metastatic lesion.
- In the presence of a laryngocele, the larynx should be carefully assessed clinically and radiographically for the presence of a neoplasm. Even large tumors may initially present with a neck mass secondary to a laryngocele, rather than with complaints referable to the larynx (Figure 3–45).
- In the setting of trauma to the anterior neck, particularly severe blunt trauma, CT imaging is useful to assess for fracture of the laryngeal cartilages. Because it is a complete ring, the cricoid cartilage tends to fracture in two or more places.



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▲ **Figure 3–37. (A)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates a hypopharyngeal mass with associated bilateral lymphadenopathy (N). Biopsy of the mass demonstrated squamous cell carcinoma of the posterolateral pharyngeal wall. E, epiglottis; smg, submandibular gland; V, vallecula. **(B)** A more superior image demonstrates ipsilateral pathologic retropharyngeal lymph node (R) enlargement and heterogeneity. A normal contralateral retropharyngeal node (white arrow) is shown for comparison.

Becker M. Larynx and hypopharynx. *Radiol Clin North Am* 1998;36:891 [PMID: 9747193]. (Classic review of the imaging anatomy and pathology of the larynx and hypopharynx.)

Becker M, Zbaren P, Casselman JW, Kohler R, Dulguerov P, Becker CD. Neoplastic invasion of laryngeal cartilage: reassessment of criteria for diagnosis at MR imaging. *Radiology* 2008;249:410–412 [PMID: 18936314]. (A discussion of MR imaging criteria for the diagnosis of cartilage involvement by laryngeal tumors)

Beil CM, Keberle M. Oral and oropharyngeal tumors. *Eur J Radiol* 2008;66:448–459 [PMID: 18457933]. (A detailed discussion of squamous cell carcinoma affecting these regions, but also includes non-neoplastic and pediatric lesions.)

Goh J, Lim K. Imaging of nasopharyngeal carcinoma. *Ann Acad Med Singapore* 2009;38:809–816 [PMID: 19816641]. (This MR-focused review presents the imaging features of nasopharyngeal carcinoma that are pertinent to staging and treatment planning.)

Dillon WP, Mills CM, Kjos B, DeGroot J, Brant-Zawadzki M. Magnetic resonance imaging of the nasopharynx. *Radiology* 1984;152:731 [PMID: 6463254]. (A classic introduction to the imaging anatomy of the nasopharynx.)

Laine FJ, Smoker WR. Oral cavity: anatomy and pathology. *Semin Ultrasound CT MR* 1995;16:527 [PMID: 8747416]. (The normal anatomy of the oral cavity is discussed, as is the anatomy and pathology of the sublingual and submandibular spaces.)

Pameijer FA, Mukherji SK, Balm AJ, van der Laan BF. Imaging of squamous cell carcinoma of the hypopharynx. *Semin Ultrasound CT MR* 1998;19:476 [PMID: 9861665]. (Review of imaging anatomy and pitfalls related to squamous cell carcinoma of the hypopharynx.)

Weissman JL, Carrau RL. "Puffed-cheek" CT improves evaluation of the oral cavity. *Am J Neuroradiol* 2001;22:741 [PMID: 11290490]. (Coaptation of mucosal surfaces can limit the assessment of oral cavity lesions, especially those of buccal origin. "Puffed-cheek" CT scans provide a clearer and more detailed evaluation of mucosal surfaces of the oral cavity than do conventional scans.)

Yates CB, Phillips CD. Oral cavity and oropharynx. *Curr Probl Diagn Radiol* 2001;30:38 [PMID: 11300548]. (An overview of the imaging anatomy and typical pathology of these areas.)

LYMPH NODES

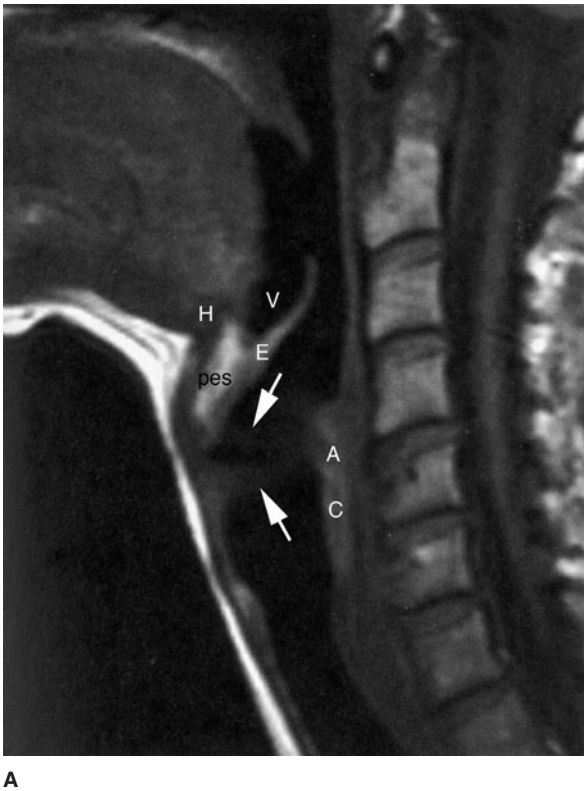
The cervical lymph nodes must always be carefully assessed in the setting of head and neck cancer, but cervical lymph nodes may also become involved by infectious, inflammatory, and granulomatous processes, as well as by systemic malignant neoplasms (eg, lymphoma or metastasis from primary sites

other than the head and neck). Before discussing the normal appearance of the cervical lymph nodes on imaging studies and the differential diagnosis of nodal abnormalities, the appropriate terminology for the cervical lymph nodes is reviewed here. Over the last decade or so, clinical terminology has evolved from being anatomically based to a simpler classification based on levels. This classification has been translated into an imaging-based classification, which is summarized in Table 3–5 and Figure 3–46.

Some nodal groups are not included in this classification scheme, notably the retropharyngeal nodes, parotid nodes, the pre- and postauricular nodes, the facial nodes, and the suboccipital nodes. These nodes are still referred to by their anatomic names. Although these nodes may certainly be involved by neoplastic and nonneoplastic processes, they do not represent the most common sites of lymphatic spread for SCC of the upper aerodigestive tract and are not included in the level classification scheme.

On noncontrast CT scans, normal lymph nodes are ovoid, homogeneous soft tissue masses with a short-axis diameter of 5–10 mm (Figure 3–47). A fatty hilum may be recognizable as an eccentric area of low density. Pathologic lymph nodes may be enlarged and focally or diffusely hypodense if there is cyst formation or necrosis. Necrotic lymphadenopathy may be seen with SCC, treated lymphoma, and other neoplastic processes, but it may also be seen with mycobacterial infection, cat-scratch disease, and other infectious processes (Figure 3–48).

Suppurative lymphadenopathy also leads to central hypodensity. In some circumstances, a lymph node may appear hyperdense before contrast administration, usually owing to partial or complete calcification (eg, old granulomatous disease, metastatic tumoral calcification, or irradiated metastatic nodes). After contrast administration, normal lymph nodes show moderate homogeneous enhancement. Areas of cyst formation or necrosis appear hypodense and are more easily appreciated than on the noncontrast scan. In some cases, a focus of tumor may appear hyperdense to normal nodal tissue after contrast administration. This is most commonly seen with vascular metastases from thyroid or renal cell carcinoma but may also be seen with inflammatory processes. If extracapsular spread of tumor has occurred, then the node will have a poorly defined border and an irregular margin with surrounding soft tissue structures.



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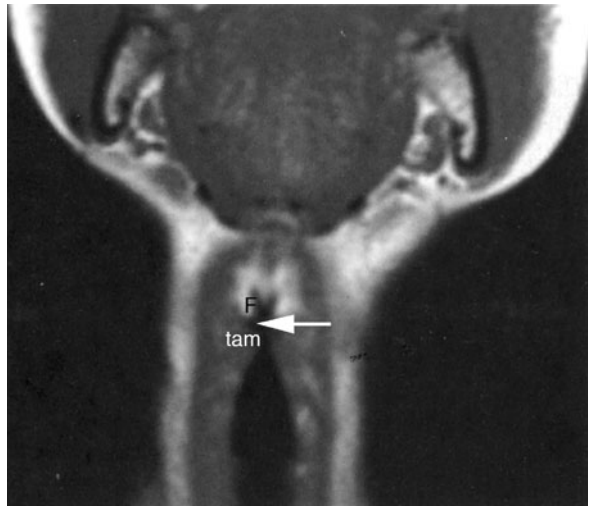

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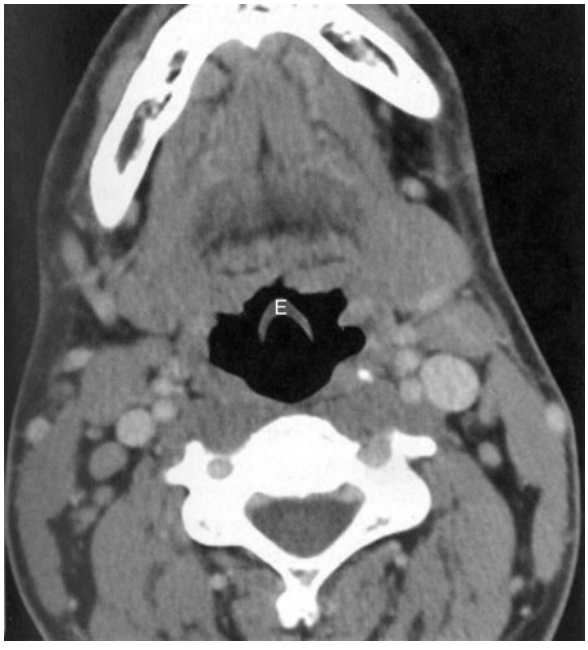
▲ **Figure 3–38. (A)** A slightly oblique sagittal T1-weighted image demonstrates the vocal ligaments (white arrows) stretching from the vocal process of the arytenoid (A) to the anterior thyroid cartilage. Also indicated are the cricoid cartilage (C), epiglottis (E), preepiglottic space (pes), vallecula (V), and hyoid bone (H). **(B)** Coronal Tl-weighted image demonstrates the thyroarytenoid muscle (tam) at the level of the true vocal cord, the laryngeal ventricle (arrow), and the fatty paraglottic space at the level of the false vocal cord (F). *(continued)*



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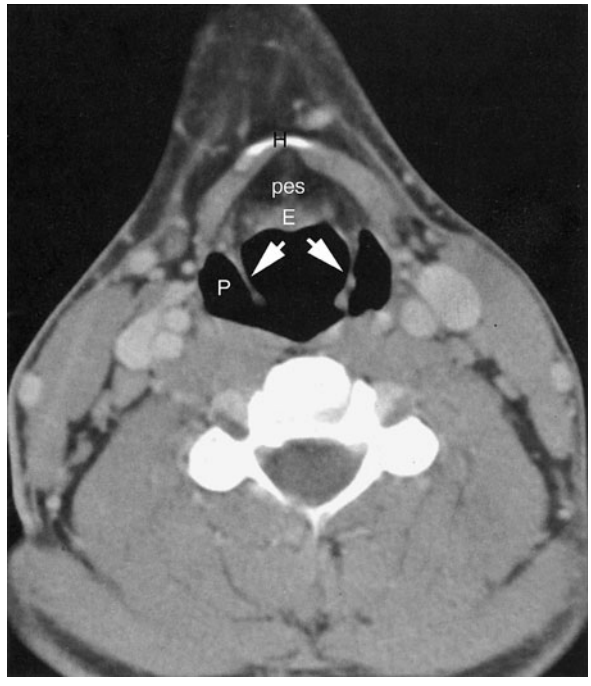

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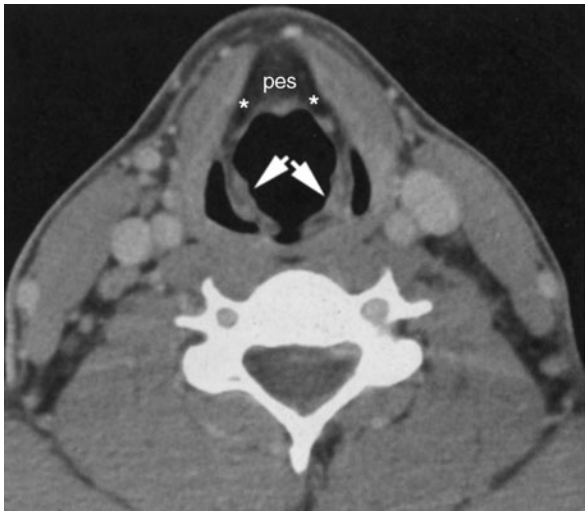

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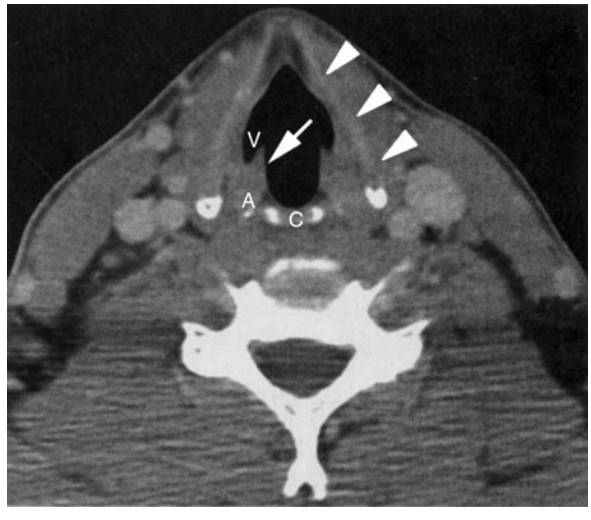


F

▲ **Figure 3–38.** *(continued)* **(C)** Axial CT scan through the supraglottis shows the free margin of the epiglottis (E). **(D)** A slightly lower scan through the supraglottis demonstrates the fixed portion of the epiglottis (E), preepiglottic space (pes), aryepiglottic folds (white arrows), hyoid bone (H), and pyriform sinuses (P). **(E)** A slightly lower scan shows the anterior preepiglottic space (pes) merging imperceptibly with the lateral paraglottic spaces (*). The aryepiglottic folds are indicated (white arrows). **(F)** Axial CT scan at the glottic level shows the true vocal cord (white arrow) and the laryngeal ventricle (V). In this young patient, the arytenoid cartilage (A), cricoid cartilage (C), and thyroid cartilage (white arrowheads) are largely nonossified and therefore poorly seen.

Table 3–4. Common Lesions of the Larynx that may be Encountered on Imaging.

Congenital/Developmental	Traumatic	Functional	Neoplastic	
			Mucosal	*Cartilaginous*
Hemangioma	Hematoma	Laryngocele	Squamous cell carcinoma	Chondroma
Venolymphatic malformation	Fracture of laryngeal cartilage			Chondrosarcoma
				Metastatic disease

On MRI, normal lymph nodes are intermediate in signal intensity on T1-weighted images and hyperintense to muscle on T2-weighted images, and they show mild or moderate homogeneous enhancement postgadolinium (Figure 3–49). Fat may be identified at the nodal hilum. If a lymph node shows high signal intensity on a T1-weighted image before the administration of gadolinium, then metastatic thyroid cancer and metastatic melanoma should be considered. A cystic-appearing node may be due to infection or to tumor and will be of low signal intensity on T1-weighted images and of high signal intensity on T2-weighted images, and will show smooth peripheral enhancement postgadolinium. The neoplasms that typically result in cystic nodal metastases are SCC and thyroid carcinoma, but many primary cancers may lead to cystic-appearing nodal disease. A potential pitfall is that a single cystic metastasis may be mistaken for a benign process such as a branchial cleft cyst. Nodal necrosis due to metastatic cancer usually leads to a thick, irregular, enhancing wall and central nonenhancement. In a patient with known head and neck cancer, the presence of necrotic lymphadenopathy is considered to represent metastatic disease. In some cases of metastatic SCC, areas of abnormally low signal intensity representing keratin pools are seen on T2-weighted images.

The assessment of the cervical lymph nodes for metastatic involvement in patients with head and neck cancer is an important role for CT and MRI. Because a non-necrotic, apparently homogeneous node may still contain foci of tumor, size criteria have been developed for predicting the likelihood of metastatic nodal involvement. These criteria represent a trade-off between sensitivity and specificity, however, and depending on what cut-off is chosen for minimal axial diameter, there may be significant numbers of false-positive or false-negative nodes. The most widely accepted cut-off for reporting metastatic lymphadenopathy is a short-axis diameter ≥10 mm, but this yields a positive predictive value of only approximately 50% and a negative predictive value of approximately 80%. The development of metabolic and functional methods such as FDG PET and iron oxide–enhanced MR lymphography shows promise in improving lymph node staging, but these techniques have significant limitations in terms of their sensitivity to small foci of tumor, and the latter technique is not widely applied at present. Diffusion-weighted MRI is also gaining acceptance as a method for detecting metastatic lymph node involvement.

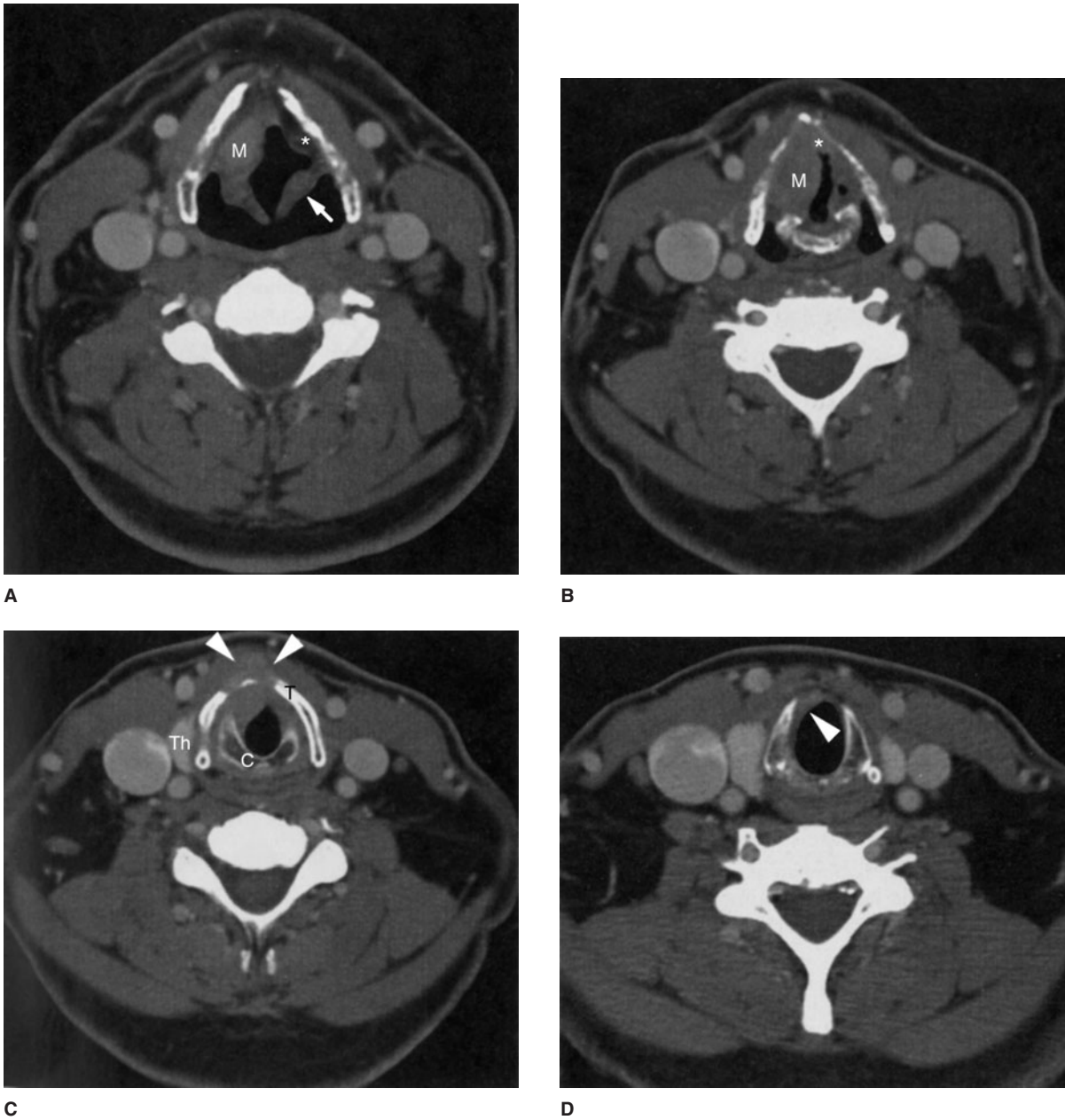
Adams S, Baum RP, Stuckensen T, Bitter K, Hor G. Prospective comparison of 18F-FDG PET with conventional imaging modalities (CT, MRI, US) in lymph node staging of head and neck cancer. *Eur J Nucl Med* 1998;25:1255 [PMID: 9724374]. (1284 lymph nodes in 60 patients were assessed. FDG PET correctly identified lymph node metastases with a sensitivity of 90% and a specificity of 94%, whereas CT and MRI visualized histologically proven lymph node metastases with a sensitivity of 82% [specificity of 85%] and 80% [specificity of 79%], respectively.)

Bellin MF, Beigelman C, Precetti-Morel S. Iron oxide-enhanced MRI lymphography: initial experience. *Eur J Radiol* 2000;34:257 [PMID: 10927166]. (Ultrasmall superparamagnetic iron oxide particles (USPIO) are novel contrast agents specifically developed for MRI lymphography. Early clinical experience suggests that USPIO-enhanced MRI lymphography improves the sensitivity and specificity for the detection of nodal metastases and suggests that micrometastases could be detected in normal-sized nodes.)

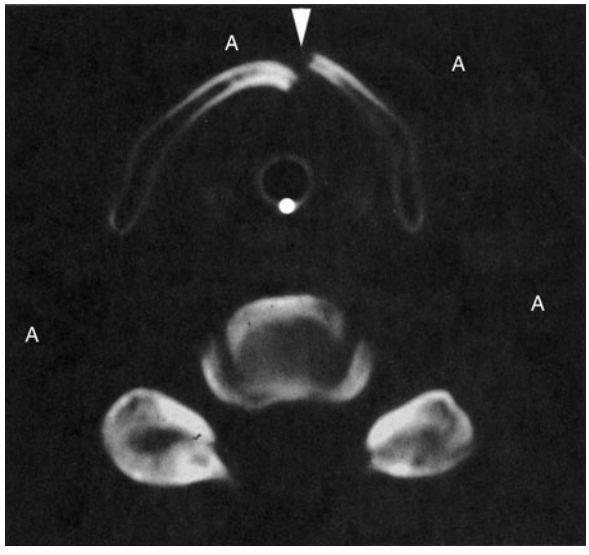
Curtin HD, Ishwaran H, Mancuso AA, Dalley RW, Caudry DJ, McNeil BJ. Comparison of CT and MR imaging in staging of neck metastases. *Radiology* 1998;207:123 [PMID: 9530307]. (With the use of a 1-cm size or an internal abnormality to indicate a positive node, CT scanning had a negative predictive value of 84% and a positive predictive value of 50%, and MRI had a negative predictive value of 79% and a positive predictive value of 52%. Overall, CT scanning performed slightly better than MRI for all interpretative criteria, but a high negative predictive value was achieved only when a low-size criterion was used and was therefore associated with a relatively low positive predictive value.)

Emonts P, Bourgeois P, Lemort M, Flamen P. Functional imaging in head and neck cancers. *Curr Opin Oncol* 2009;21:212–217 [PMID: 19370804]. (This review discusses SPECT, PET, and MR-based techniques in head and neck cancer and, specifically, nodal staging. Diffusion-weighted imaging and perfusion MR are also discussed.)

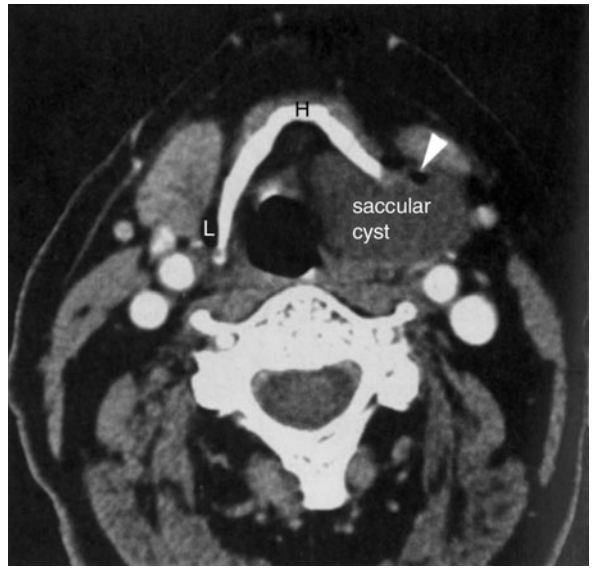
Sakai O, Curtin HD, Romo LV, Som PM. Lymph node pathology. Benign proliferative, lymphoma, and metastatic disease. *Radiol Clin North Am* 2000;38:979 [PMID: 11054964]. (CT and MR imaging characteristics of both malignant and nonmalignant nodal diseases are reviewed and the differential diagnosis of nodal pathologies based on specific imaging findings is discussed.)



▲ **Figure 3–39.** Serial axial contrast-enhanced CT images in an older man with transglottic squamous cell carcinoma with cartilage erosion. **(A)** Image through the supraglottis demonstrates a mass (M) involving the right paraglottic space and aryepiglottic fold. Normal fatty left paraglottic space (*) and aryepiglottic fold (white arrow) are indicated. **(B)** At the glottic level, the right true vocal cord is grossly enlarged by the mass (M) and the soft tissue of the anterior commissure (*) is grossly thickened. The left true vocal cord is irregular, also a consequence of tumor infiltration. **(C)** At the level of the undersurface of the vocal cords, the lesion has eroded the ventral aspect of the thyroid cartilage (T; arrowheads indicate mass) and has extended anteriorly to invade the strap muscles. **(D)** At the subglottic level, asymmetric soft tissue is seen anteriorly (arrowhead), consistent with subglottic tumor extension. Note that at the subglottic level, the air column should appear to be immediately adjacent to the cricoid cartilage with no significant intervening soft tissue.



▲ **Figure 3–40.** Axial noncontrast CT scan viewed in bone window obtained in a young man who was kicked in the neck demonstrates a vertical fracture of the anterior thyroid cartilage (arrowhead). An endotracheal tube is in place and there is extensive air (A) tracking along fascial planes. A more inferior image (not shown) demonstrated bilateral fractures through the posterior cricoid ring.



▲ **Figure 3–41.** Axial contrast-enhanced CT scan through the supraglottic larynx demonstrates a fluid-filled laryngocele (saccular) cyst protruding through the thyrohyoid membrane and demonstrating both internal and external components. A small focus of air in the cyst (arrowhead) is related to a recent aspiration. The hyoid bone (H) has been remodeled. A small air-filled external laryngocele (L) is seen on the contralateral side.

Som PM, Curtin HD, Mancuso AA. Imaging-based nodal classification for evaluation of neck metastatic adenopathy. *AJR Am J Roentgenol* 2000;174:837 [PMID: 10701636]. (Discusses the application of cross-sectional imaging to accurate and reproducible terminology for lymph node localization.)

Som PM, Curtin HD, Mancuso AA. An imaging-based classification for the cervical nodes designed as an adjunct to recent clinically based nodal classifications. *Arch Otolaryngol Head Neck Surg* 1999;125:388 [PMID: 10208676]. (A discussion of the imaging correlates to nodal levels.)

NONMUCOSAL DISEASE OF THE HEAD & NECK

SPATIAL APPROACH TO THE SUPRAHYOID & INFRAHYOID HEAD & NECK

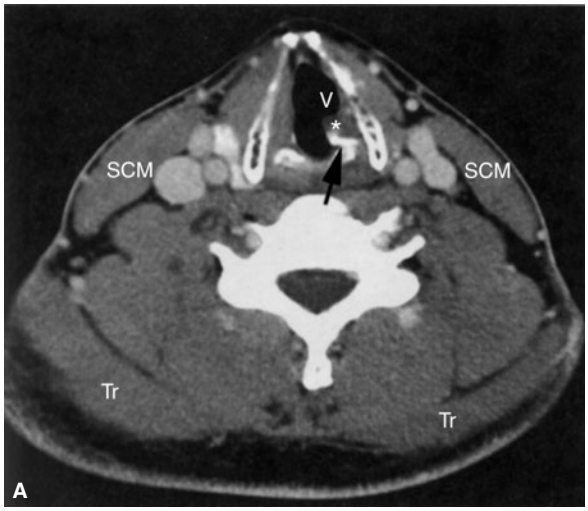
The terminology used to describe the traditional pharyngeal subdivisions of the head and neck is best suited to the assessment and staging of SCC. Because nonsquamous masses tend to spread within fascia-defined spaces, the head and neck can also be viewed as a series of deep spaces, an approach that facilitates an analysis of cross-sectional imaging of the head and neck. To simplify the discussion, the extracranial head and neck are divided into supra- and infrahyoid compartments because fascial attachments to the hyoid bone functionally cleave this region into two segments.

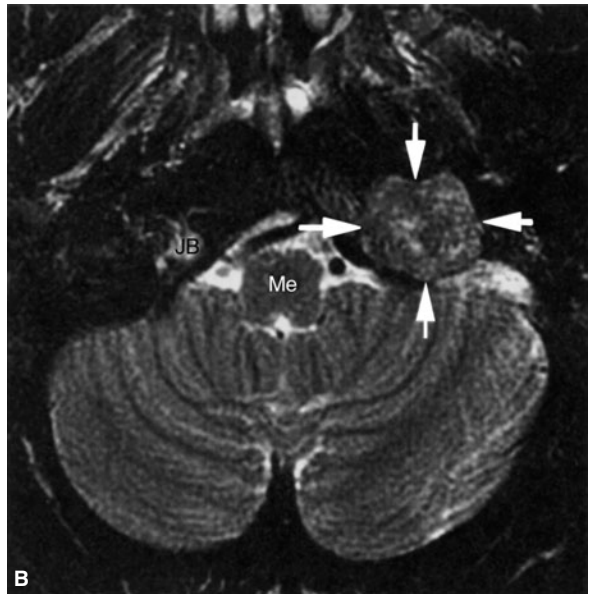
1. Suprahyoid Head & Neck

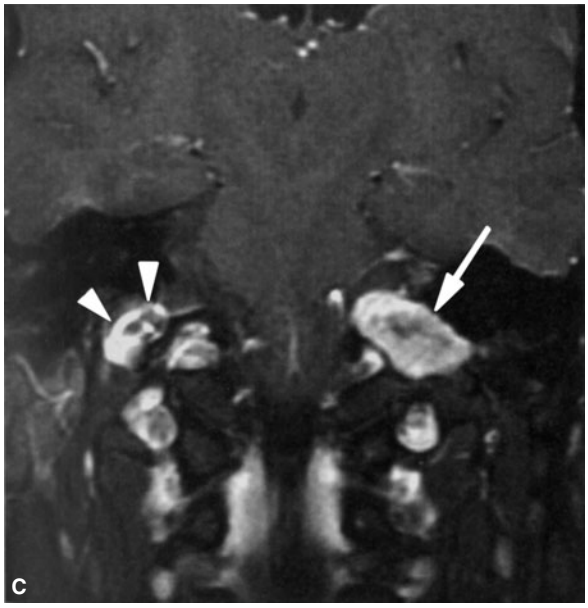
The spaces of the suprahyoid head and neck are defined by the three layers of the deep cervical fascia: superficial (investing), middle (buccopharyngeal), and deep (prevertebral). The spaces defined by these three fascial layers are shown diagrammatically in Figure 3–50.

Pharyngeal Mucosal Space

The pharyngeal mucosal space has complex fascial margins and is not completely circumscribed by the three layers of deep cervical fascia. This space is bounded by the middle layer of deep cervical fascia along its posterolateral margin, whereas on its luminal or airway side, it has no fascial boundary. The most important components of the pharyngeal mucosal space are the squamous mucosa, the lymphoid tissue of the Waldeyer ring, the minor salivary glands, and the pharyngeal constrictor muscles. The dominant pathology in this space is SCC and the pharyngeal mucosal space, divided into its traditional subdivisions of nasopharynx, oropharynx, and hypopharynx, was reviewed previously.



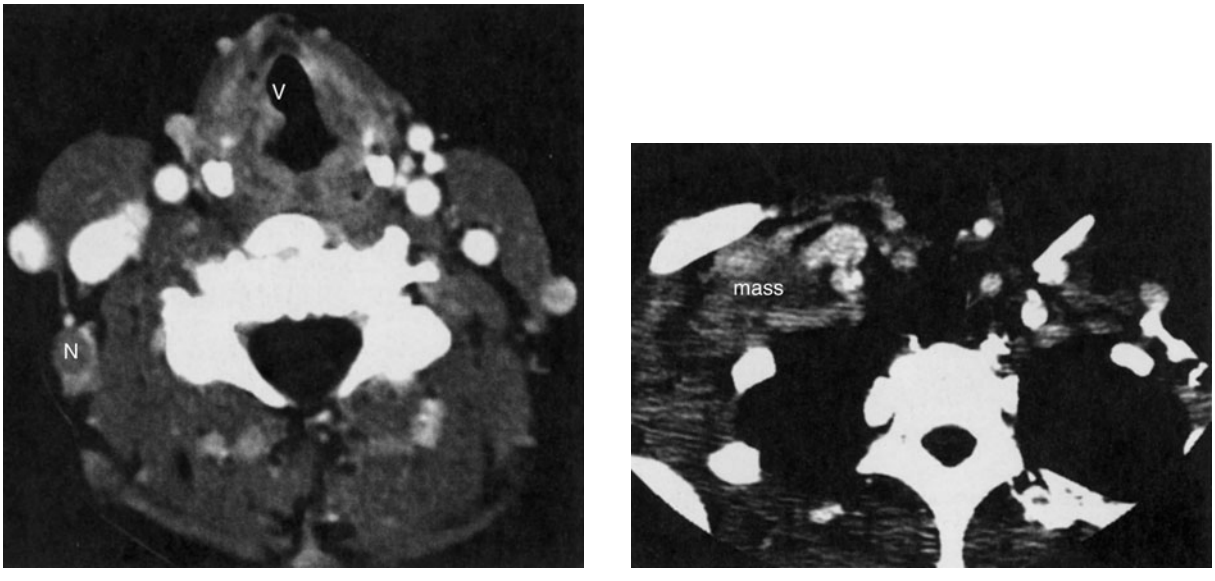




▲ **Figure 3–42. (A)** Axial contrast-enhanced CT scan of the neck in a young man with hoarseness and left vocal cord paralysis on examination. The arytenoid (black arrow) is rotated medially, the left true vocal cord and thyroarytenoid muscle (*) show fatty atrophy compared with the contralateral side, and the left laryngeal ventricle (V) is dilated, all of which are imaging features of vocal cord paralysis. In addition, the left sternocleidomastoid (SCM) and trapezius (Tr) muscles are decreased in bulk compared with the right, suggesting also dysfunction of CN XI, although this had not been noted on clinical examination. The patient was then referred for MRI to assess for a skull base lesion. **(B)** An axial fast spin-echo T2-weighted image with fat saturation demonstrates a well-circumscribed soft tissue mass (white arrows) at the level of the left jugular foramen. The right jugular bulb (JB) and the medulla (Me) are indicated. **(C)** On a postgadolinium T1-weighted image with fat saturation, the lesion (white arrow) demonstrates slightly heterogeneous but mostly intense enhancement. The diagnosis is a lower cranial nerve schwannoma. The contralateral enhancing jugular bulb (white arrowheads) is also indicated. Note that the normal jugular bulb is a "pseudomass" that can be mistaken for significant pathology.

Parapharyngeal Space

The parapharyngeal space (PPS) is a central, fat-filled space of the deep face that is frequently displaced by masses of the surrounding spaces (Figure 3–51). Assessing the center of a deep facial mass relative to the PPS and observing the direction in which this mass displaces the fat of this space indicates the space of origin of a mass of the head and neck and helps to tailor a differential diagnosis. The PPS is defined medially by the middle layer of the deep cervical fascia and borders the pharyngeal mucosal space. Laterally, it is defined by the superficial layer of deep cervical fascia and borders the masticator space and the parotid space. Posteriorly, the PPS is defined by the anterior part of the carotid sheath and is bordered



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▲ **Figure 3–43. (A)** Axial contrast-enhanced CT scan of the neck in a middle-aged woman with breast cancer and new hoarseness demonstrates a patulous right laryngeal ventricle (V) and vocal cord asymmetry consistent with a right cord paralysis. No laryngeal mass is seen. However, a metastatic node (N) is incidentally noted. **(B)** An image through the supraclavicular fossa demonstrates a metastatic nodal mass that is impinging on the course of the right recurrent laryngeal nerve.

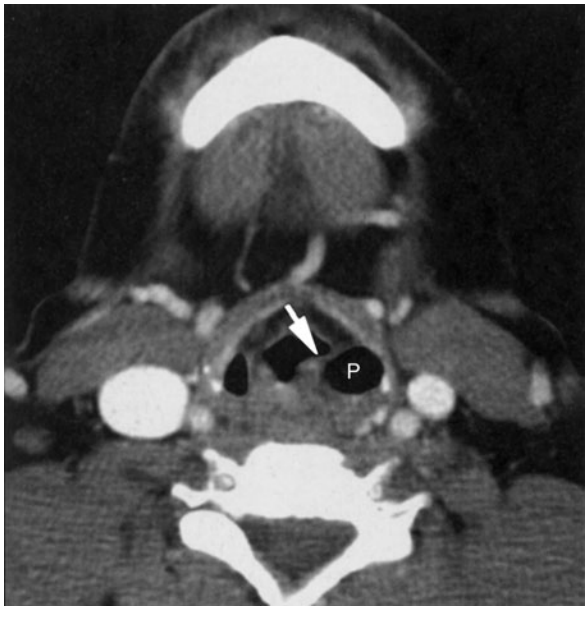
by the carotid space. Superoinferiorly, it runs from the skull base to the hyoid bone. At its inferior extent, this space is not separated by fascia from the submandibular space, and so a process in one space may extend to the other.

The PPS contains only fat, arteries, veins, and nerves; therefore, few lesions are primary to this space. Primary lesions of the parapharyngeal space include lipomas, tumors of minor salivary rests, and atypical second branchial cleft cysts (Figure 3–52). Most lesions that appear to be primary to the PPS in fact originate from adjacent spaces and compress the PPS. Therefore, fat should be identified around the circumference of a lesion before it is said to be primary to the PPS, although peripheral fat may be difficult to identify if a lesion primary to the PPS is large. Aggressive processes that are not constrained by fascial boundaries may also involve the PPS by direct spread, notably SCC, other aggressive neoplasms (eg, sarcomas, malignant neoplasms of the salivary glands, and lymphoma; Figure 3–53), and phlegmon or abscess.

Parotid Space

The parotid space is defined by a splitting of the superficial layer of the deep cervical fascia. It abuts the masticator space anteriorly, the PPS anteromedially, the carotid space posteromedially, the temporal bone posteriorly and superiorly, and the subcutaneous fat laterally (see Figure 3–51). Its contents include the parotid gland, the facial nerve, blood vessels, and the intraparotid lymph nodes. Although the intraparotid facial nerve cannot be directly identified on cross-sectional imaging studies, it is known to lie adjacent to the retromandibular vein, and this structure serves as a rough dividing point between the superficial and deep lobes of the gland. When a mass involves both the superficial and deep lobes, the distance between the mandible and the styloid process is typically widened, especially if the mass is slow growing. The parotid duct exits the anterior aspect of the parotid space, traverses the masticator space over the masseter muscle, and then pierces the buccinator muscle to enter the oral cavity at the level of the second maxillary molar.

A differential diagnosis of parotid space masses is presented in Table 3–6, and the imaging appearance of some of the more common pathologies is discussed in more detail below. It should also be noted that the presence of multiple parotid space lesions, either unilateral or bilateral, suggests a more limited differential diagnosis that includes reactive or metastatic lymphadenopathy, lymphoepithelial lesions, Warthin tumors, and recurrent pleomorphic adenoma.



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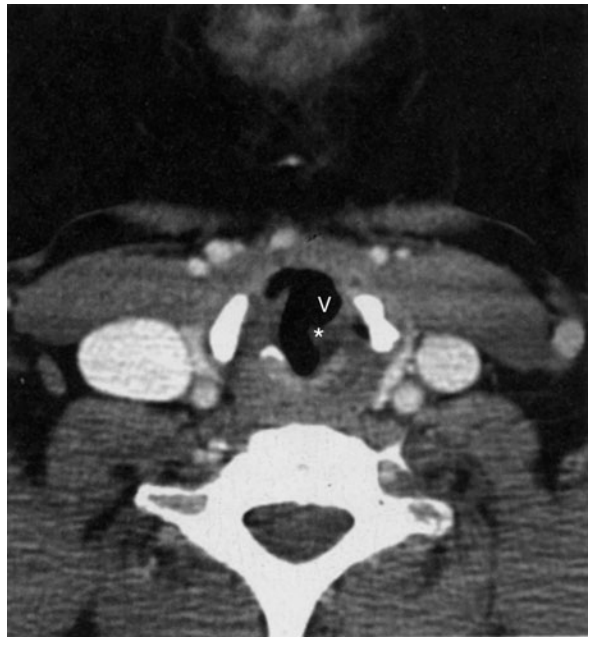

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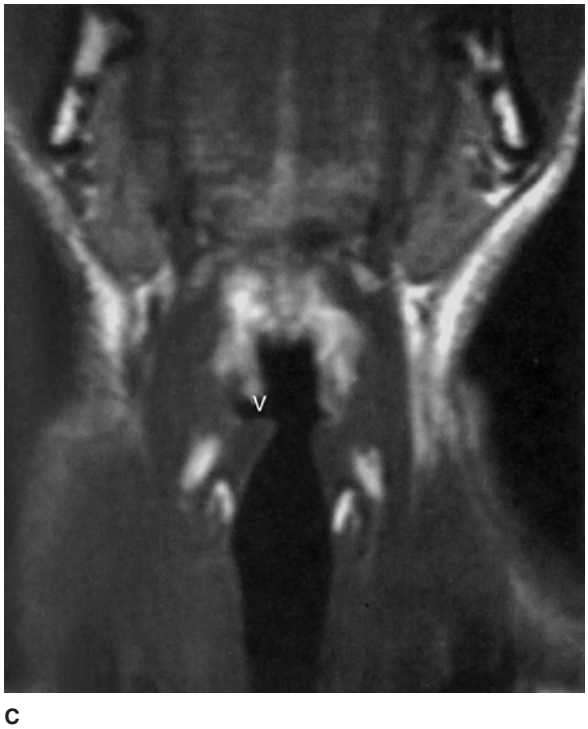
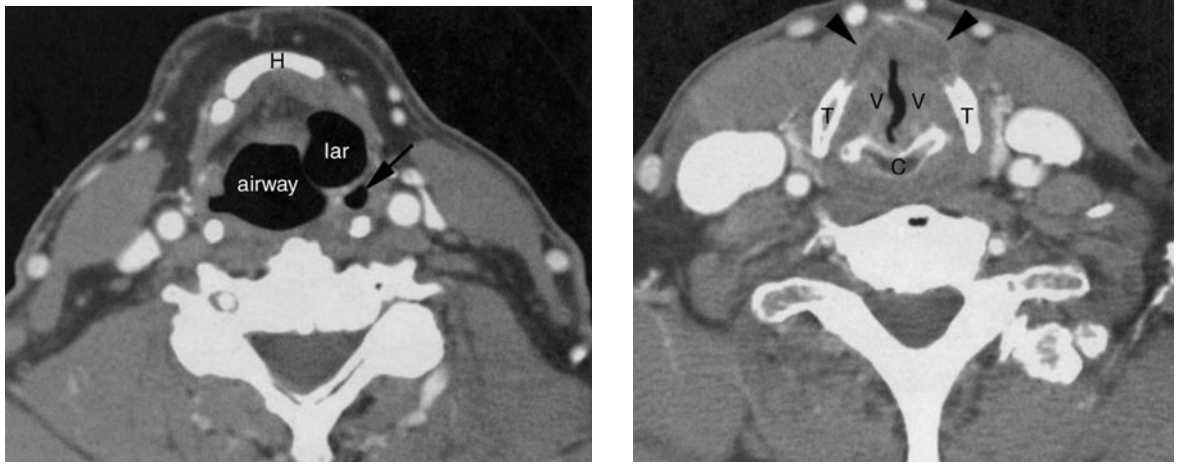


C

▲ **Figure 3–44. (A)** Axial contrast-enhanced CT scan in a patient with a left true vocal cord paralysis demonstrates dilatation of the ipsilateral pyriform sinus (P) and medial deviation of the aryepiglottic fold (arrow). **(B)** A more inferior image demonstrates asymmetric enlargement of the ipsilateral laryngeal ventricle (V) and denervation change with fatty atrophy of the thyroarytenoid muscle (*). **(C)** Coronal T1-weighted image in a different patient with right vocal cord paralysis demonstrates dilatation of the right laryngeal ventricle (V) compared with the left.



A B

▲ **Figure 3–45.** **(A)** Axial contrast-enhanced CT scan through the supraglottic larynx demonstrates an air-filled structure on the left consistent with an internal laryngocele (lar). The left pyriform sinus (black arrow) is displaced posteriorly. **(B)** A more inferior image demonstrates neoplastic infiltration of both vocal cords (V), which are irregularly thickened, as well as neoplastic erosion (black arrowheads) of the anterior thyroid cartilage (T). C, cricoid cartilage.

A. Parotid Hemangiomas

The parotid hemangioma is a vascular proliferative mass of infancy and childhood that may grow to a large size and replace the entire parotid gland before slowly involuting. The classic imaging appearance is of a multilobulated holoparotid mass that enlarges the parotid gland, is isointense to muscle on a T1-weighted image, is bright on a T2-weighted image, and enhances intensely and homogeneously postgadolinium (Figure 3–54). It usually contains prominent flow voids, and the external carotid artery and its branches are often enlarged.

B. First Branchial Cleft Cysts

Abnormalities of the first branchial apparatus account for less than 10% of branchial complex anomalies and include cysts, sinuses, and fistulas. Typically, a cystic mass is seen within or adjacent to the parotid gland (Figure 3–55), with a tract leading to the external auditory canal visible in some cases. The cyst wall may be thickened if there has been prior infection, and adjacent soft tissues may show inflammatory change if there is active infection.

C. Lymphoepithelial Cysts and Lesions

Benign lymphoepithelial lesions are seen most commonly in association with HIV, but they also occur in connective tissue disorders, notably Sjögren syndrome. In the setting of HIV, there is typically associated hypertrophy of the lymphoid tissue of Waldeyer ring (Figure 3–56) and also reactive cervical lymphadenopathy. Lesions may be purely cystic or have both cystic and solid elements, and they are typically bilateral.

D. Parotitis and Calculus Disease

Glandular enlargement, edema, and increased enhancement are seen in the setting of acute parotitis, often with inflammatory changes in adjacent fat (Figure 3–57). If the process progresses to abscess formation, a ring-enhancing mass will be present. A calculus may be identified along the parotid duct or within the gland, best detected on thin-section (1–3 mm) noncontrast CT images. The intra- or extraparotid glandular system may be dilated.

E. Pleomorphic Adenomas

The pleomorphic adenoma typically presents as a round or ovoid, well-circumscribed soft tissue mass. It may have areas of low density on CT and is typically high signal intensity on T2-weighted MRI caused by areas of mucoid matrix or cystic degeneration (Figure 3–58). Contrast enhancement is usually intense and homogeneous, and the homogeneity typically increases over time when early and delayed postcontrast CT images are compared.

F. Warthin Tumor

A Warthin tumor is typically multilobulated, well circumscribed, and heterogeneous owing to its mixed cystic and solid nature (Figure 3–59). Areas of hemorrhage may be seen as well, and bilateral lesions are not uncommon.

Table 3–5. Summary of Image-Based Nodal Classification.

Level & Subclassification	Boundaries	Previous Terminology
I	Above hyoid bone, below mylohyoid muscle, anterior to a transverse line drawn through the posterior edge of the SMG	Submental and submandibular nodes
IA	Between medial margins of anterior bellies of digastric muscles	Submental nodes
IB	Posterior and lateral to medial edge of anterior belly of digastric muscle, anterior to posterior edge of SMG	Submandibular nodes
II	From skull base to the lower body of the hyoid bone, anterior to the posterior edge of the SCM and posterior to the posterior edge of the SMG[1]	Upper internal jugular and spinal accessory nodes
IIA	Lie anterior, lateral, or medial to the IJV, or lie posterior to the IJV and are inseparable from it	Upper internal jugular nodes
IIB	Lie posterior to the IJV and have a fat plane separating the nodes and the vein	Upper spinal accessory nodes
III	Between the lower body of the hyoid bone and the lower margin of the cricoid arch; anterior to the posterior edge of the SCM and lateral to the medial margin of the CCA or ICA	Mid-jugular nodes
IV	Between the lower margin of the cricoid cartilage arch and the level of the clavicle; anterior and medial to an oblique line drawn between the posterior edge of the SCM and the posterolateral edge of the anterior scalene muscle; lateral to the medial margin of the CCA	Low jugular nodes
V	From the skull base at the posterior border of the attachment of the SCM to the clavicle; anterior to the anterior edge of the trapezius muscle and posterior to the posterior edge of the SCM (skull base to bottom of cricoid), or posterior and lateral to an oblique line through the posterior edge of the SCM and the posterolateral edge of the anterior scalene muscle (bottom of cricoid to clavicle)	Posterior cervical
VA	From skull base superiorly to lower margin of cricoid cartilage inferiorly	Upper posterior cervical
VB	From lower margin of cricoid cartilage to level of clavicle	Lower posterior cervical
VI	Inferior to body of hyoid, superior to top of manubrium, and between the medial margins of the ICAs or CCAs	Visceral nodes
VII	Caudal to the top of the manubrium in the superior mediastinum, between the medial margins of the left and right common carotid arteries and superior to the innominate vein	Superior mediastinal

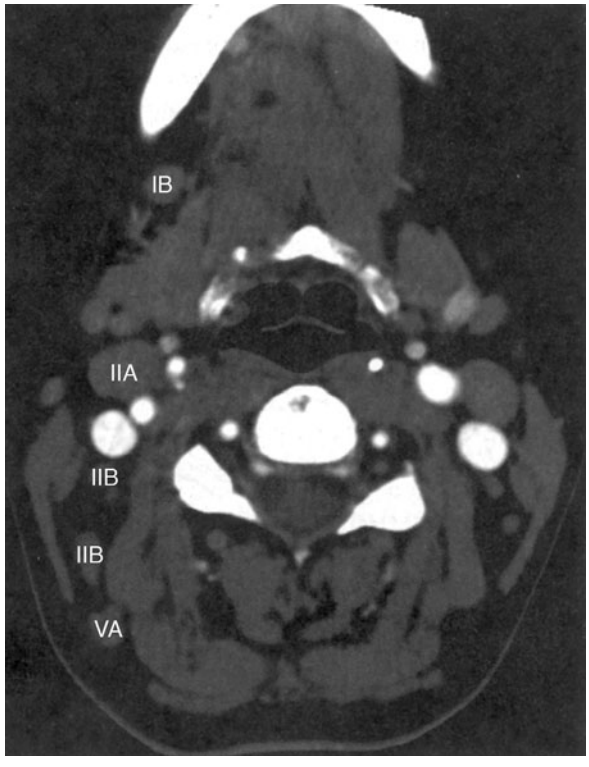
SMG, submandibular gland; SCM, sternocleidomastoid muscle; IJV, internal jugular vein; CCA, common carotid artery; ICA, internal carotid artery.
[1]A node located within 2 cm of the skull base and medial to the internal carotid arteries is classified as a retropharyngeal node. A node located within 2 cm of the skull base but anterior, lateral, or posterior to the ICA is classified as a level II node. More than 2 cm below the skull base, level II nodes can lie in any position relative to the internal jugular vein.
Data from Som PM, Curtin HD, Mancuso AA. Imaging-based nodal classification for evaluation of neck metastatic adenopathy. *AJR Am J Roentgenol* 2000;174:837.

G. Malignant Parotid Tumor

A low-grade malignant parotid tumor may appear well circumscribed and homogeneous and, based on imaging criteria, can be difficult to distinguish from a benign lesion such as a pleomorphic adenoma. Malignant tumors do, however, tend to be somewhat lower in signal intensity on T2-weighted images than benign lesions. Higher-grade lesions are often ill marginated (Figure 3–60) and invade adjacent structures such as the temporal bone, adjacent fat, and the muscles of mastication. They may also demonstrate perineural spread proximally along the facial nerve (Figure 3–61). Note that a pregadolinium T1-weighted image may be the best sequence on which to identify a parotid mass as the fatty glandular parenchyma contrasts well with the intermediate signal intensity of most parotid neoplasms (Figure 3–62).

Masticator Space

The masticator space is defined by a splitting of the superficial layer of deep cervical fascia. Its coronal extent is from the inferior surface of the mandible to the skull



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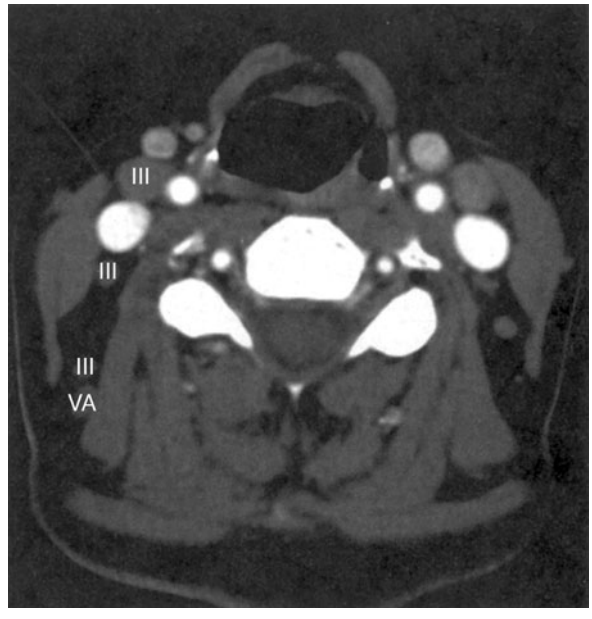

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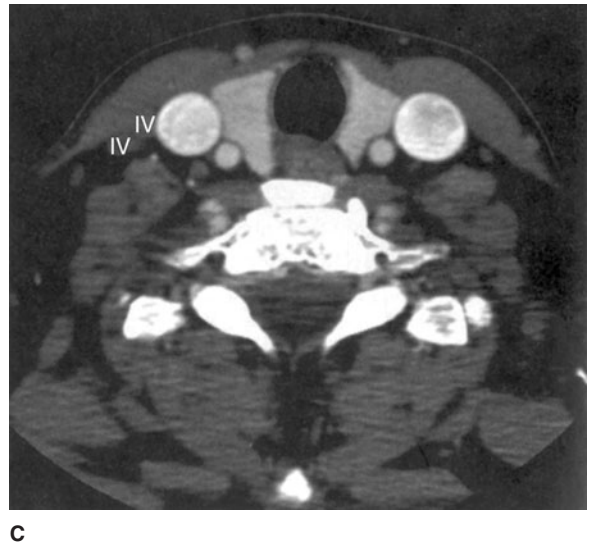
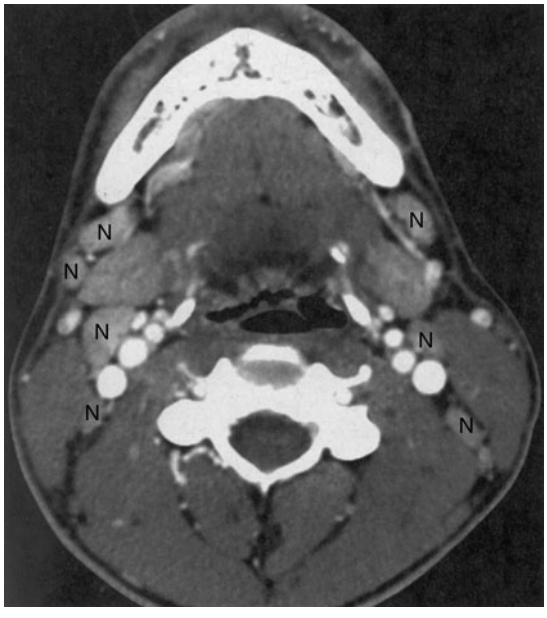


C

▲ **Figure 3–46.** (**A**, **B**, and **C**) Serial contrast-enhanced axial CT scans through the neck demonstrate the image-based nodal classification system summarized in Table 3–5. Nodes in each of the five levels commonly involved by head and neck cancer are labeled.

base medially and the calvarial convexity laterally. Superomedially, the fascia attaches to the skull base just medial to the foramen ovale; superolaterally, it attaches to the zygomatic arch and then continues superiorly over the surface of the temporalis muscle, defining the suprazygomatic masticator space (Figure 3–63). The masticator space is bordered by the parapharyngeal space medially, the parotid space posteriorly, and the subcutaneous tissues laterally. Anteriorly, it abuts the buccal space. The buccal space has no true fascial boundary and is in close proximity to the masticator space, so these two spaces are often involved together by infectious or neoplastic processes. Key contents of the masticator space include the ramus and the posterior body of the mandible, the muscles of mastication (eg, the masseter, temporalis, medial pterygoid, and lateral pterygoid muscles), the motor and sensory branches of the third division of the trigeminal nerve, and the inferior alveolar vein and artery.



▲ **Figure 3–47.** Axial contrast-enhanced CT scan of the neck in a normal young man demonstrates multiple normal-sized, homogeneously enhancing lymph nodes (N) in levels I and II.

Lesions of the masticator space (Table 3–7) are most commonly infectious (usually of odontogenic origin) or neoplastic. In all cases of neoplastic involvement of the masticator space, V3 should be carefully assessed for evidence of perineural spread of tumor. Perineural spread, when radiologically visible, may lead to the enlargement of V3 and the foramen ovale (Figure 3–64), the asymmetric enhancement of V3 (which may extend back along the main trunk of V3 to the pons), the obliteration of fat at the extracranial aperture of the foramen ovale, and possibly the replacement of CSF in Meckel cave by abnormal soft tissue. In addition, denervation change in the muscles of mastication may be seen. In the acute and subacute phases of denervation, the muscles typically demonstrate high signal intensity on T2-weighted images and enhancement on postgadolinium images, whereas in the more chronic phase, fatty atrophy sets in (Figure 3–65). Several "pseudomasses" of the masticator space should also be considered. Benign masseteric hypertrophy may be unilateral or bilateral and is generally seen in patients with bruxism. Accessory parotid tissue may also be unilateral or bilateral, is seen overlying the masseter muscle, and is isodense or isointense to a normal parotid gland on all imaging sequences. Denervation atrophy due to V3 injury or pathology may make the contralateral nonatrophic muscles appear masslike.

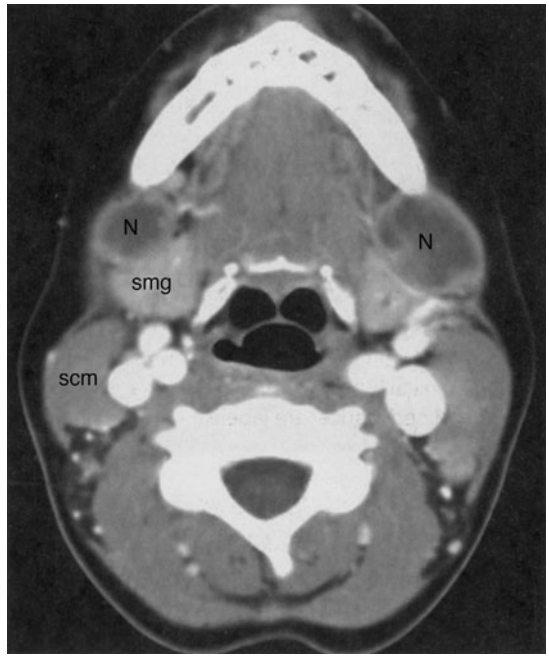
The buccal space is not a true fascia-defined compartment. It is located immediately anterior to the masticator space and is often involved by extension of neoplastic or inflammatory processes from the masticator space. Important contents include the buccal fat pad, the buccinator muscle, the distal portion of the parotid duct, and the facial artery and vein. Venous malformations of the head and neck not uncommonly involve the buccal space (Figure 3–66).

A. Odontogenic Infection

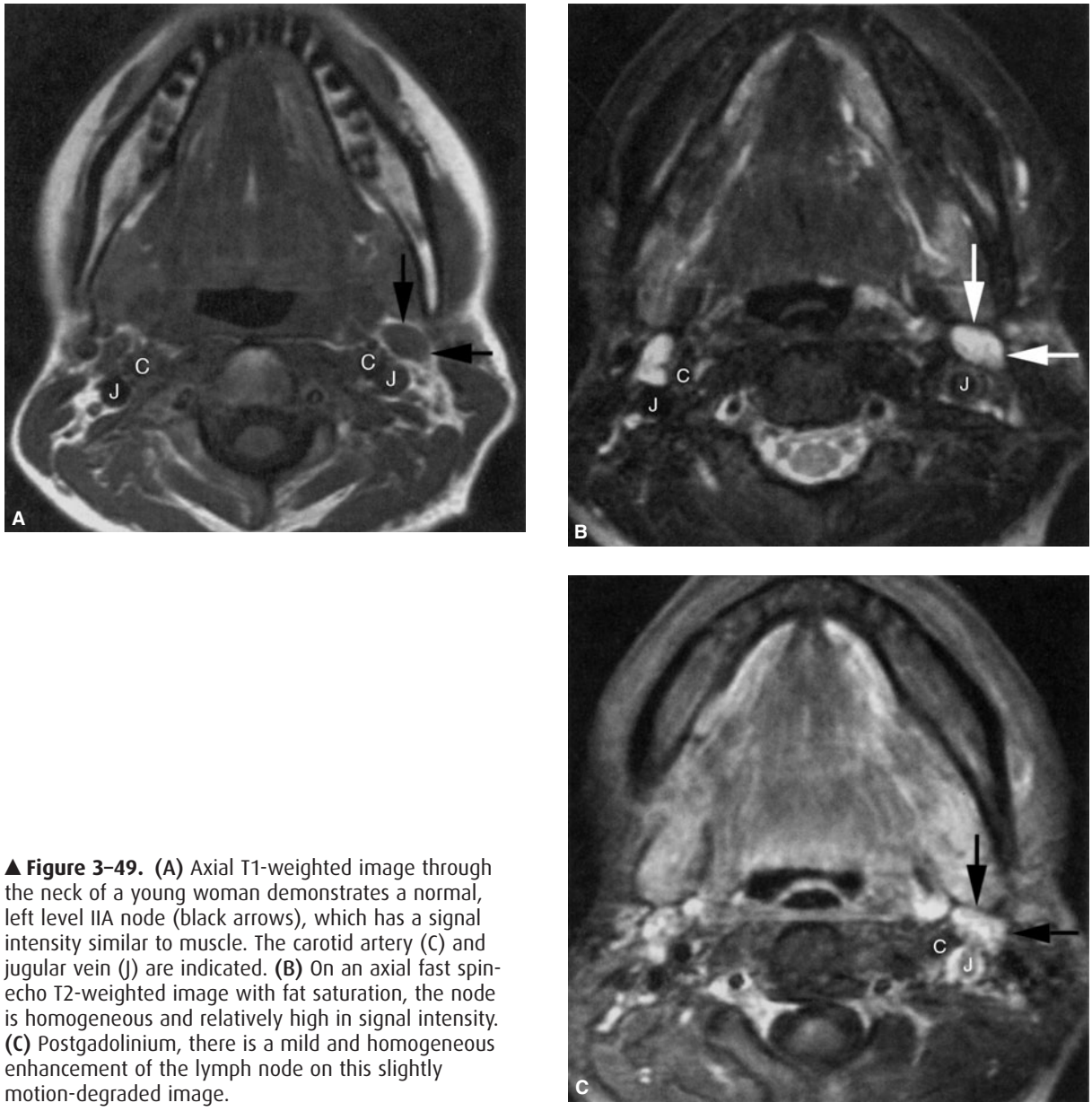
Patients with an odontogenic infection usually have a history of poor dentition or recent dental manipulation. CT scanning is the study of choice and may show changes related to periodontal disease, frank mandibular osteomyelitis, and adjacent soft tissue changes with cellulitis, phlegmon, and/or abscess formation (Figure 3–67). CT scanning is more sensitive than MRI to calculi, foreign bodies, and gas formation.

B. Rhabdomyosarcoma

A solid mass lesion arising in the masticator space of a child is considered a rhabdomyosarcoma until proven otherwise.



▲ **Figure 3–48.** Axial contrast-enhanced CT scan of the neck in a young immunosuppressed woman demonstrates large, centrally necrotic lymph nodes (N) anterior to the submandibular glands (smg) anteriorly. Needle aspiration and culture were consistent with cat-scratch disease; scm, sternocleidomastoid muscle.

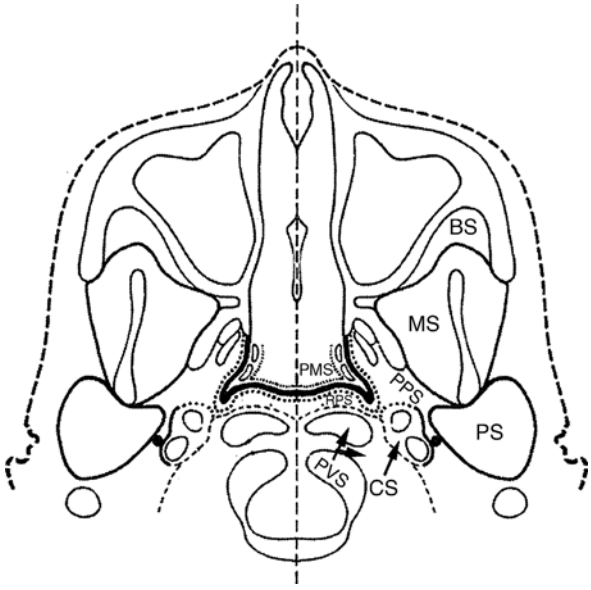


▲ **Figure 3–49.** **(A)** Axial T1-weighted image through the neck of a young woman demonstrates a normal, left level IIA node (black arrows), which has a signal intensity similar to muscle. The carotid artery (C) and jugular vein (J) are indicated. **(B)** On an axial fast spin-echo T2-weighted image with fat saturation, the node is homogeneous and relatively high in signal intensity. **(C)** Postgadolinium, there is a mild and homogeneous enhancement of the lymph node on this slightly motion-degraded image.

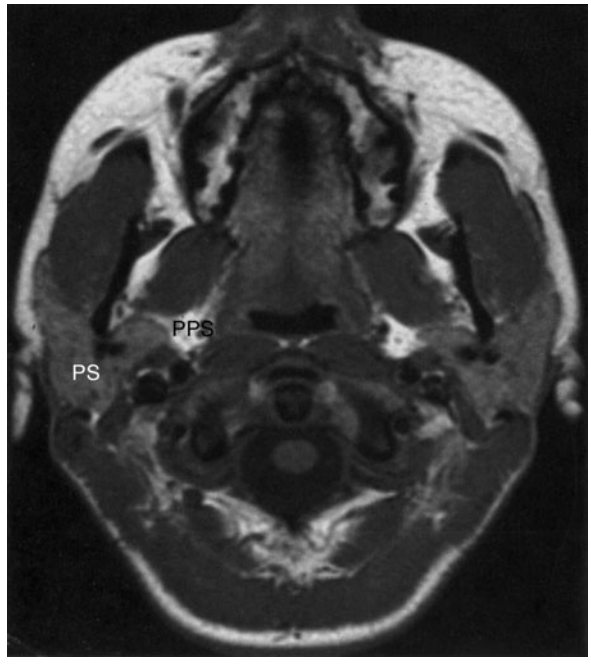
These lesions may appear fairly well circumscribed, although they are aggressive. They are typically isointense to muscle on T1-weighted images and intermediate in signal intensity on T2-weighted images, as is typical of small, round, blue-cell tumors owing to their high nuclear-to-cytoplasmic ratio. Postgadolinium, they enhance homogeneously or heterogeneously if areas of necrosis are present (Figure 3–68). There may be accompanying destruction of the mandible, and spread to the skull base and intracranial compartment may occur.

Carotid Space

All three layers of the deep cervical fascia contribute to the fascial boundary of the carotid space, known as the carotid sheath. The carotid space extends from the skull base to the aortic arch, and therefore spans both the supra- and the infrahyoid neck. At the level of the skull base, the carotid space communicates directly with the carotid canal and jugular foramen. The suprahyoid carotid space relates laterally to the parotid space, anteriorly to the parapharyngeal space,



▲ **Figure 3–50.** Diagrammatic representation of the fascia-defined spaces of the suprahyoid neck at the level of the nasopharynx. The dashed line represents the deep layer of deep cervical fascia, also known as the prevertebral fascia. The dotted line represents the middle layer of deep cervical fascia, and the thick solid line represents the superficial layer of deep cervical fascia, also known as the investing fascia. The heavy solid line outlining the pharyngeal mucosal space represents the pharyngobasilar fascia, which connects the superior constrictor muscle to the skull base. PMS, pharyngeal mucosal space; PPS, parapharyngeal space; MS, masticator space; PS, parotid space; CS, carotid space; RPS, retropharyngeal space; PVS, perivertebral space; BS, buccal space. (Note that the buccal space does not represent a true fascia-defined space, but is often considered as a distinct space for the purposes of anatomic localization and differential diagnosis.) (Modified and reproduced, with permission, from Harnsberger HR. CT and MRI of masses of the deep face. *Curr Probl Diagn Radiol* 1987;16:141.)



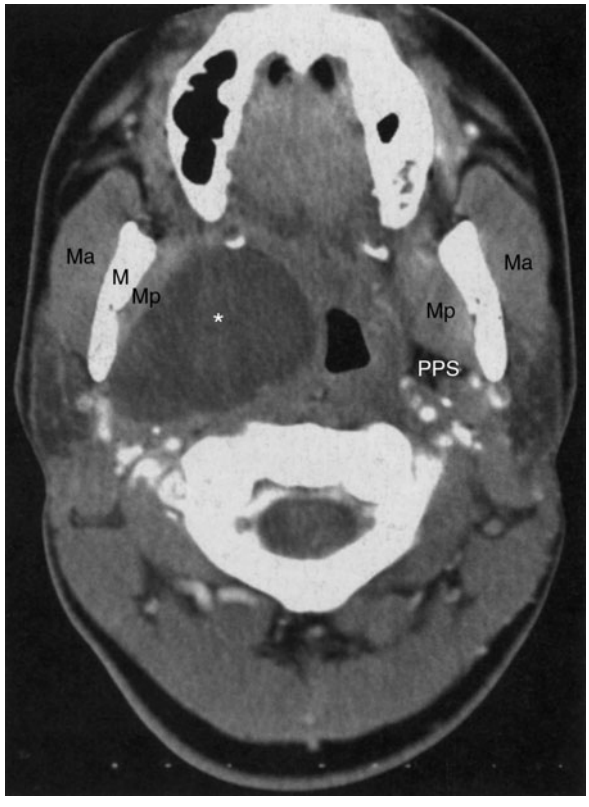
▲ **Figure 3–51.** Axial T1-weighted image demonstrates high signal intensity fat in the centrally located parapharyngeal space (PPS). Also indicated is the parotid space (PS).

and medially to the retropharyngeal space. Posteriorly, it borders the vertebral bodies of the cervical spine.

The contents of the carotid space include the carotid artery (common or internal, depending on the level), the internal jugular vein, the sympathetic plexus, and cranial nerves (Figure 3–69). The upper (nasopharyngeal) carotid space contains CN IX (the glossopharyngeal nerve), X (the vagus nerve), XI (the accessory nerve), and XII (the hypoglossal nerve). Only CN X traverses the oropharyngeal and infrahyoid carotid space, since the other lower cranial nerves have already exited the carotid space. CN X is typically located posteriorly between the carotid artery and the internal jugular vein, whereas the sympathetic plexus runs along the medial aspect of the carotid space. Lymph nodes are also present in the carotid space, with the highest carotid space nodes constituting the jugulodigastric nodes—or, more correctly, the upper level IIA nodes. The most common lesions of the carotid space are vascular or neoplastic. "Pseudomasses" are typically vascular in origin and relate to the asymmetry or tortuosity of the carotid artery or the asymmetry of the jugular veins. Common lesions of the carotid space are indicated in Table 3–8.

A. Paragangliomas

Paragangliomas arise from neuroendocrine cells of the autonomic nervous system. In the head and neck, subtypes include the carotid body tumor, the glomus vagale (arising from the nodose ganglion of the vagus nerve), the glomus jugulare (arising from the jugular ganglion), and the glomus tympanicum (arising in association with the Jacobsen nerve along the cochlear promontory). These lesions may present as a palpable neck mass or with lower cranial neuropathy, pulsatile tinnitus, or both. On CT scans, these lesions enhance intensely postcontrast. The glomus jugulare typically causes irregular erosion of adjacent bone. On MRI,

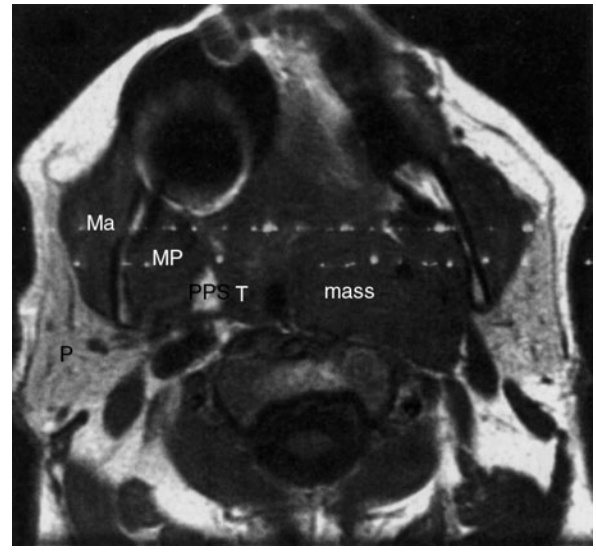


▲ **Figure 3–52.** Axial contrast-enhanced CT scan demonstrates a well-circumscribed cystic lesion (*) centered on the right parapharyngeal space, deviating the airway and the pharyngeal mucosal space medially and displacing the muscles of mastication laterally. The normal left parapharyngeal space is indicated. The pathology was most consistent with a branchial cleft cyst. Ma, masseter; M, mandible; Mp, medial pterygoid; PPS, parapharyngeal space.

paragangliomas typically show macroscopic flow voids when they are >2 cm and also show intense enhancement. The carotid body tumor classically splays the internal and external carotid arteries (Figure 3–70), whereas the glomus vagale displaces the internal carotid artery anteriorly (Figure 3–71). MRA and catheter angiography demonstrate a hypervascular mass, with the usual vascular supply being the ascending pharyngeal artery.

B. Schwannomas

Schwannomas of the lower cranial nerves may be asymptomatic and present as a neck mass or incidental finding on an imaging study obtained for another purpose, or may present with lower cranial neuropathy. On imaging, these



▲ **Figure 3–53.** Axial T1-weighted image in a patient with lymphoma demonstrates a left oropharyngeal mass with lateral extension to obliterate the parapharyngeal fat. The normal right tonsil (T) and right parapharyngeal space (PPS) are shown for comparison. Masseter (Ma), medial pterygoid muscle (MP), and parotid gland (P) are indicated.

lesions are typically round or ovoid and well circumscribed (Figure 3–72). Adjacent bony structures may be smoothly remodeled but do not show infiltrative or permeative changes. Schwannomas may be homogeneous or heterogeneous owing to cyst formation and hemorrhage. They are typically moderately and homogeneously enhancing. Rarely, macroscopic flow voids may be seen in "hypervascular" schwannomas, making them difficult to distinguish from paragangliomas.

C. Squamous Cell Carcinoma

SCC may access the carotid space via direct invasion from the primary site or via nodal metastases. A primary squamous carcinoma of the upper aerodigestive tract may be deeply infiltrative at the time of the first diagnosis, extending to involve the carotid artery and thereby rendering the tumor unresectable without carotid sacrifice; more commonly, recurrent disease at the primary site may infiltrate adjacent deep tissues and extend back to the carotid space. Metastases to the lymph nodes along the jugular vein (levels II, III, and IV) are common with mucosal SCCs, and if there is extracapsular extension, then the metastatic tumor may extend all the way to the skull base along the carotid sheath (Figure 3–73). New hoarseness or difficulty with articulation may be seen if CN X or XII is affected by metastatic tumor in the carotid space, and these symptoms should raise concern for recurrent disease in a patient previously treated for SCC.

Table 3–6. Lesions of the Parotid Space.

Congenital/Developmental	Inflammatory/Infectious	Neoplastic	
		Benign	*Malignant*
Hemangioma	Parotitis or parotid abscess	Pleomorphic adenoma	Mucoepidermoid carcinoma
Venolymphatic malformation	Reactive lymphadenopathy	Warthin tumor	Adenoid cystic carcinoma
First branchial cleft cyst	Lymphoepithelial cysts or lesions	Lipoma	Acinic cell carcinoma
		Facial nerve schwannoma	Carcinoma ex pleomorphic adenoma
		Oncocytoma	Salivary ductal carcinoma
			Squamous cell carcinoma
			Extranodal or nodal non-Hodgkin lymphoma
			Nodal metastases

D. Lesions of the Sympathetic Chain

The cervical segment of the sympathetic trunk extends from the base of the skull down to the first rib, where it becomes continuous with the thoracic segment. The cervical sympathetic chain lays posteromedial to the internal and common carotid arteries and is embedded in the deep fascia between the carotid sheath and the prevertebral fascia. Neuroblastic tumors are the third most common cause of early childhood neoplasia, and lesions originating from the cervical sympathetic chain account for 2–5% of neuroblastic lesions. There are three histologic subgroups, neuroblastoma, ganglioneuroblastoma, and ganglioneuroma, with neuroblastoma being the least differentiated and most malignant form. A helpful diagnostic clinical feature may be the presence of Horner syndrome (Figure 3–74).

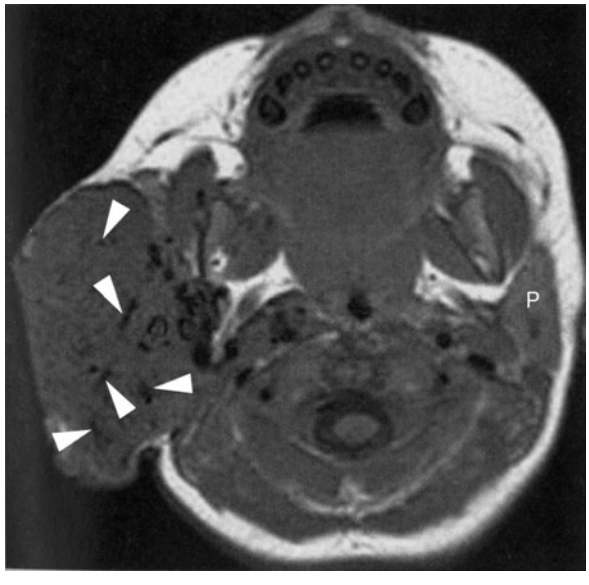
Retropharyngeal Space

The retropharyngeal space is a potential space between the middle and deep layers of the deep cervical fascia that extends from the skull base to the T4 level (Figure 3–75). Anatomically, a slip of deep cervical fascia separates the retropharyngeal space from a more posterior potential space known as the "danger space," which extends more caudally into the mediastinum and provides a conduit to this space for disease processes, notably infection. For practical purposes, however, the retropharyngeal and danger spaces are indistinguishable on imaging studies of the neck, and both are included when the retropharyngeal space is discussed. The retropharyngeal space is bordered by the pharyngeal mucosal space anteriorly, the carotid space laterally, and the danger space and prevertebral space posteriorly. The only notable contents of the retropharyngeal space are fat and lymph nodes; therefore, the retropharyngeal space is usually affected by the direct spread of tumor or infection or by the spread of tumor or infection to retropharyngeal lymph nodes. The extension of tumor beyond the confines of a retropharyngeal node may lead to skull base invasion and lower cranial nerve dysfunction, whereas the extension of infection beyond the nodal capsule may lead to retropharyngeal abscess formation.

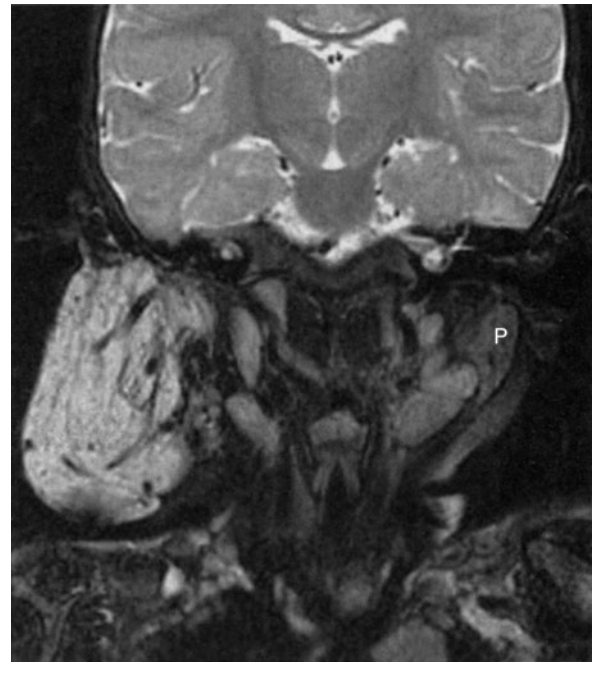
The lateral retropharyngeal nodes are present at the level of the nasopharynx and upper oropharynx and are seen well on MRI even when nondiseased (Figure 3–76). The medial retropharyngeal nodes are present from the nasopharynx to the hypopharynx, but retropharyngeal nodes are not usually found below the level of the hyoid bone. Retropharyngeal lymph nodes are normally quite prominent in children and gradually decrease in size. In adults, normal retropharyngeal nodes are typically <6 mm in short-axis dimension.

A. Pyogenic Infection

Retropharyngeal nodes are commonly involved with infection in the context of pharyngitis in children and spine infections in adults. With infection, the nodes initially enlarge and may eventually suppurate. As the infection progresses, the retropharyngeal fat becomes edematous because of retropharyngeal cellulitis, and if the nodal capsule ruptures, then a retropharyngeal abscess develops (Figure 3–77). A CT scan should be performed if there is concern for a retropharyngeal abscess, since these patients generally require surgical drainage and intravenous antibiotics. In some cases, the retropharyngeal space may simply be filled with noninfected fluid (retropharyngeal edema) owing to jugular venous or lymphatic obstruction, prior radiation therapy, or noninfectious inflammatory processes; it is therefore important to distinguish retropharyngeal edema from retropharyngeal infection (Figure 3–78), as this will influence patient management.



A



B

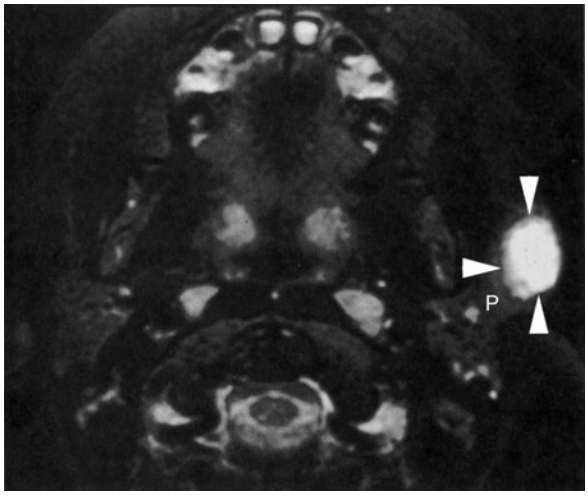
▲ **Figure 3–54.** **(A)** Axial T1-weighted image in a 13-month-old female with a parotid region mass and overlying skin discoloration demonstrates a large, multilobulated, well-circumscribed mass centered on the parotid gland. Internal serpiginous hypointensities (arrowheads) are consistent with vessels. The contralateral parotid gland (P) is shown for comparison; note that the parotid gland in an infant and young child is not as fatty as in an adult and therefore not as bright on a T1-weighted image. **(B)** The mass is high in signal intensity on a T2-weighted image. Again, note the prominent vessels within the lesion. Postgadolinium (not shown), the lesion demonstrated intense and homogeneous enhancement. These imaging features are diagnostic of a parotid hemangioma.

B. Neoplasms

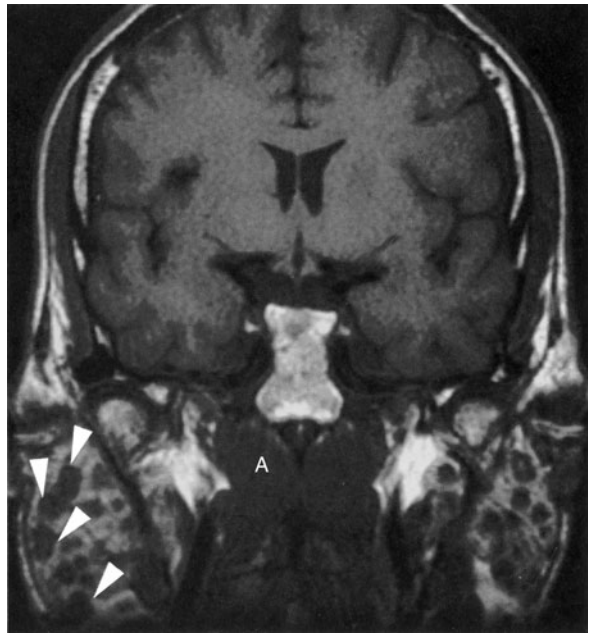
Retropharyngeal nodal metastases are most commonly seen with nasopharyngeal carcinoma and with SCC of the posterior oropharyngeal wall and hypopharynx. Non-Hodgkin lymphoma of the Waldeyer ring also commonly leads to neoplastic enlargement of the retropharyngeal nodes. The retropharyngeal space may also be involved with direct extension of a primary tumor from the pharyngeal mucosal space, the carotid space, or the vertebral column and perivertebral space.

Perivertebral Space

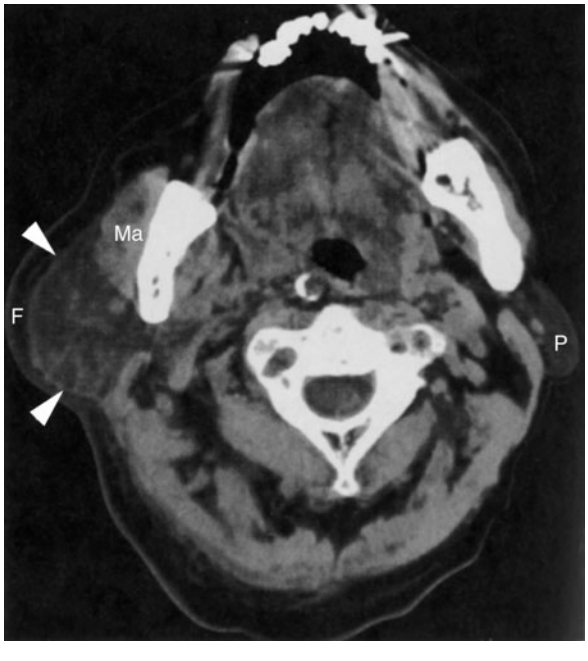
The space around the spinal column has generally been referred to as the prevertebral space, but an argument has been made to adopt the more encompassing term perivertebral space. Within the perivertebral space, enclosed and defined by the deep layer of deep cervical fascia, two regions can be recognized: the prevertebral and the paraspinal portions of the perivertebral space. The prevertebral portion is defined by the deep layer of the deep cervical fascia as it arches from one transverse process to the other transverse process in front of the vertebral body, enclosing the prevertebral muscles as well as the vertebral artery, the vertebral vein, and the vertebral body. The paraspinal portion is defined by the deep layer of deep cervical fascia, extending back on each side from the transverse process to the nuchal ligament in the midline; it therefore includes only the paraspinal muscles, the posterior elements of the vertebra, and fat. The prevertebral portion of the perivertebral space is bordered by the retropharyngeal and danger spaces anteriorly and the carotid space anterolaterally. A mass in the prevertebral portion of the perivertebral space displaces the retropharyngeal space anteriorly; if the lesion is primary to the vertebral body, it also displaces the prevertebral muscles anteriorly, confirming its localization to the prevertebral portion of the perivertebral space.



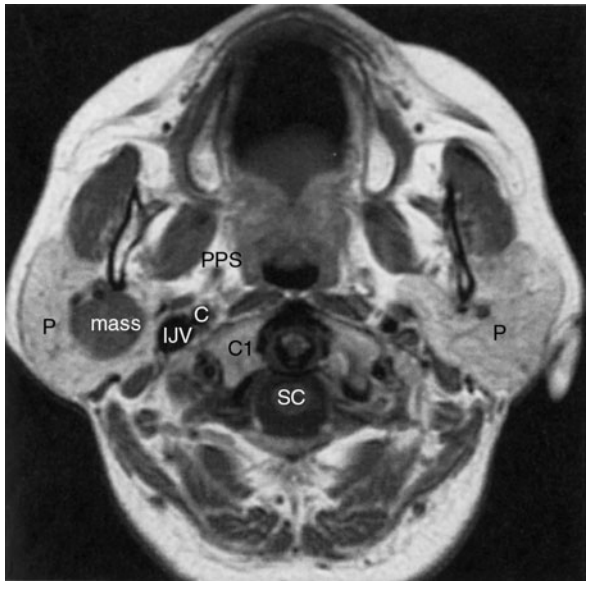
▲ **Figure 3–55.** A 3-year-old girl with a left parotid-region mass and slight drainage from her external ear canal. Axial fast spin-echo T2-weighted image with fat saturation demonstrates a well-circumscribed, very high signal intensity mass (arrowheads) in the left parotid gland (P). Other images (not shown) confirmed the cystic nature of the lesion and a first branchial cleft cyst was found at surgery.



▲ **Figure 3–56.** Coronal T1-weighted image in an HIV-positive patient with bilateral parotid gland enlargement demonstrates multiple small cysts (arrowheads) in both parotid glands as well as adenoidal hypertrophy (A). Findings are consistent with multiple lymphoepithelial cysts.



▲ **Figure 3–57.** Contrast-enhanced CT scan of the neck in a patient with clinical acute parotitis demonstrates marked enlargement and irregular enhancement of the left parotid gland as compared to the right (P, parotid glands); there is also enlargement of the ipsilateral masseter muscle as compared to the contralateral masseter muscle (Ma, masseter muscles) due to inflammatory myositis. Infiltration of the overlying subcutaneous fat on the left is due to associated cellulitis (thin white arrows show subcutaneous fat of the fact); there is also stranding and infiltration of fat in the left parapharyngeal space as compared with the right (large white arrows indicate parapharyngeal spaces). No calculi were identified, and no abscess was present. The patient responded to intravenous antibiotic therapy.



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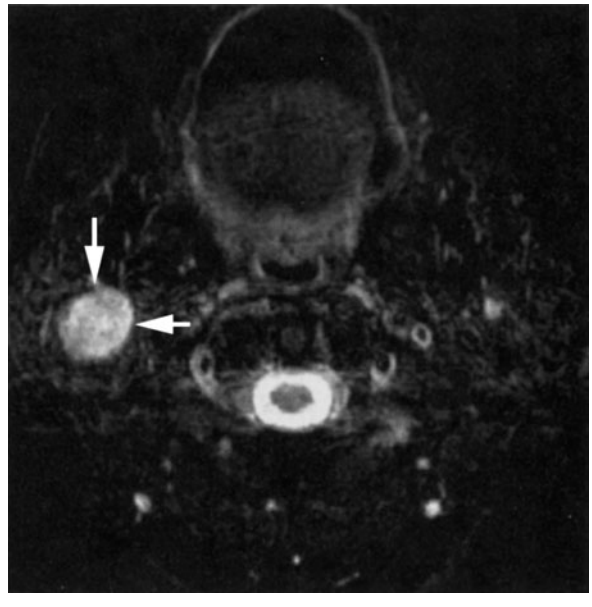

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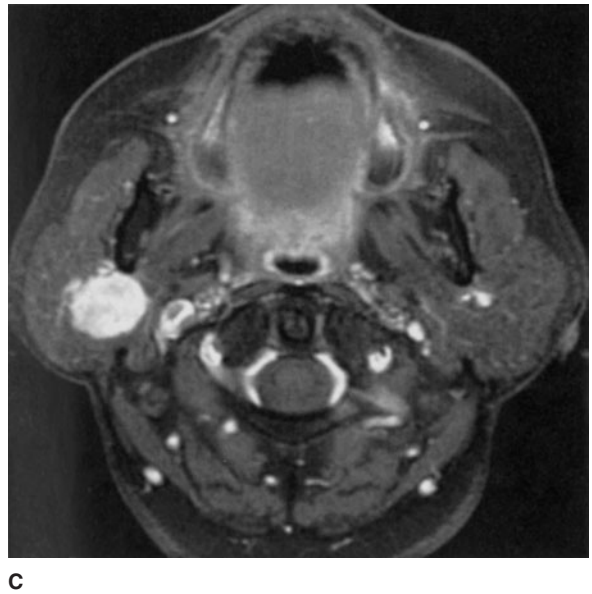


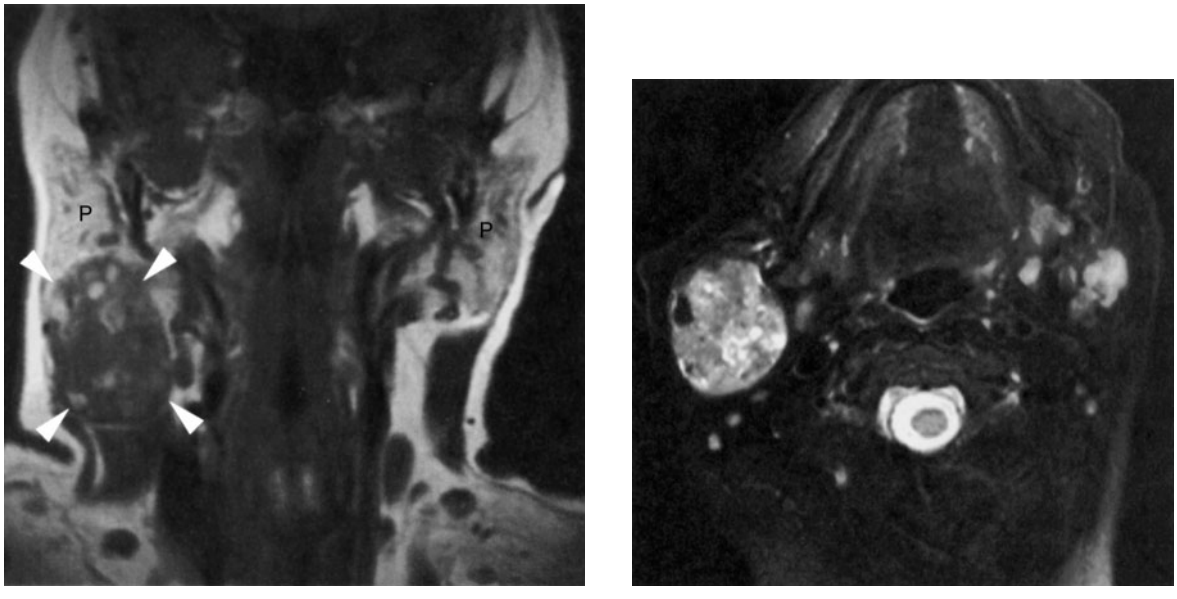
C

▲ **Figure 3–58.** **(A)** Axial T1-weighted image in a young patient with a slowly enlarging right parotid mass shows a round, well-circumscribed lesion of intermediate signal intensity. Also indicated are the parotid glands (P), parapharyngeal space (PPS), internal jugular vein (IJV), internal carotid artery (C), lateral mass of C1 (C1), and the spinal cord (SC). **(B)** The mass is very bright on a fast spin-echo T2-weighted image with fat saturation. **(C)** Following gadolinium, the lesion enhances intensely and homogeneously. These are the typical imaging features of a pleomorphic adenoma and this diagnosis was confirmed pathologically.

The perivertebral space is most commonly involved by infectious processes originating from the vertebral bodies and the intervertebral discs (Figure 3–79), and neoplasia of the spinal column—most commonly metastatic disease, but also primary bone tumors and hematologic processes such as leukemia and myeloma (Figure 3–80). Because the deep layer of the deep cervical fascia is very tough and resists violation by tumor and infection, it is unusual for retropharyngeal space processes to extend into the perivertebral space, and vice versa.

The Posterior Cervical Space

The posterior cervical space has complex fascial margins and is defined by both superficial and deep layers of the deep cervical fascia. It extends from the skull base to the clavicle, spanning the supra- and infrahyoid neck, but having a relatively small suprahyoid segment. It abuts the carotid space anteriorly, the perivertebral space medially, and the sternocleidomastoid muscle and subcutaneous fat laterally. Its suprahyoid contents include fat, CN XI, and



A B

▲ **Figure 3–59. (A)** Coronal Tl-weighted image in a 55-year-old woman with a mass (arrowheads) arising from the inferior aspect of the right parotid gland (P). The lesion is well circumscribed but quite heterogeneous, with internal areas of high signal intensity representing areas of hemorrhage or proteinaceous cysts. **(B)** The lesion is hyperintense on an axial fast spin-echo T2-weighted image with fat saturation, but also somewhat heterogeneous. The heterogeneity of the lesion and the areas of intrinsic T1 shortening are suggestive of a Warthin tumor, which was confirmed pathologically.

lymph nodes in levels II and V. Pathology in the posterior cervical space is most commonly nodal (Figure 3–81).

Babbel RW, Harnsberger HR. The parapharyngeal space: the key to unlocking the suprahyoid neck. *Semin Ultrasound CT MR* 1990;11:444 [PMID: 2275807]. (Reviews important anatomic relationships of this centrally located space.)

Chong VF, Fan YF. Pictorial review: radiology of the carotid space. *Clin Radiol* 1996;51:762 [PMID: 8937318]. (Illustrates the imaging features of carotid space lesions.)

Davis WL, Harnsberger HR, Smoker WR, Watanabe AS. Retropharyngeal space: evaluation of normal anatomy and diseases with CT and MR imaging. *Radiology* 1990;174:59 [PMID: 2294573]. (The review addresses the spectrum of lesions of the retropharyngeal space, the imaging features that mark a lesion as originating in this space, and whether there is a difference between the radiologic pattern of the suprahyoid and infrahyoid portions of the neck.)

Davis WL, Harnsberger HR. CT and MRI of the normal and diseased perivertebral space. *Neuroradiology* 1995;37:388 [PMID: 7477840]. (A retrospective analysis of patients with lesions in the perivertebral space to identify the imaging features that mark a lesion as originating in the perivertebral space and to define the spectrum of pathology that occurs in this space.)

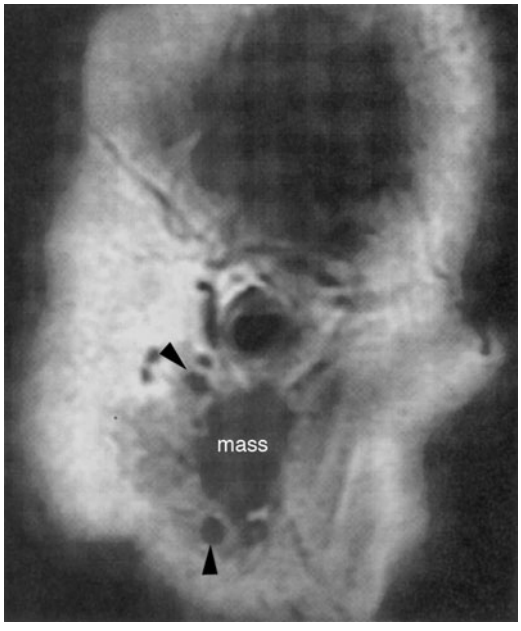
Moukheiber AK, Nicollas R, Roman S, Coze C, Triglia JM. Primary pediatric neuroblastic tumors of the neck. *Int J Pediatr Otorhinolaryngol* 2001;60:155 [PMID: 11518594]. (Reviews clinical, imaging, and management issues related to pediatric cervical neuroblastic tumors.)

Mukherji SK, Castillo M. A simplified approach to the spaces of the suprahyoid neck. *Radiol Clin North Am* 1998;36:761 [PMID: 9747188]. (This article presents a simplified approach to the various spaces of the suprahyoid neck and their anatomic components. Each space is discussed separately and is accompanied by a table that lists a differential diagnosis based primarily on the normal anatomic contents of the space.)

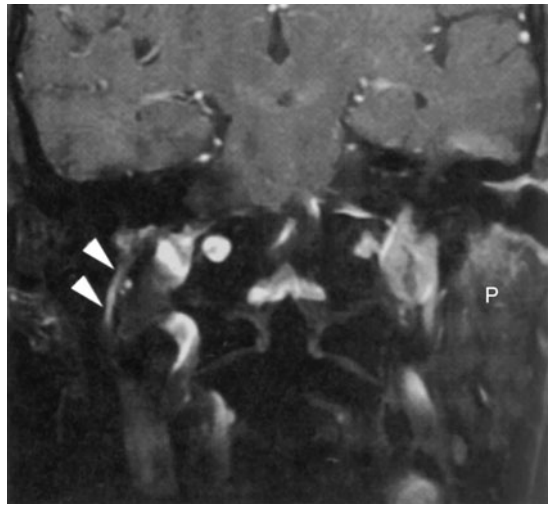
Pollei SR, Harnsberger HR. The radiologic evaluation of the parotid space. *Semin Ultrasound CT MR* 1990;11:486 [PMID: 2275810]. (Reviews the radiologic anatomy and appearance of pathology of the parotid space.)

Tart RP, Kotzur IM, Mancuso AA, Glantz MS, Mukherji SK. CT and MR imaging of the buccal space and buccal space masses. *Radiographics* 1995;15:531 [PMID: 7624561]. (Reviews the imaging anatomy and pathology of the buccal space.)

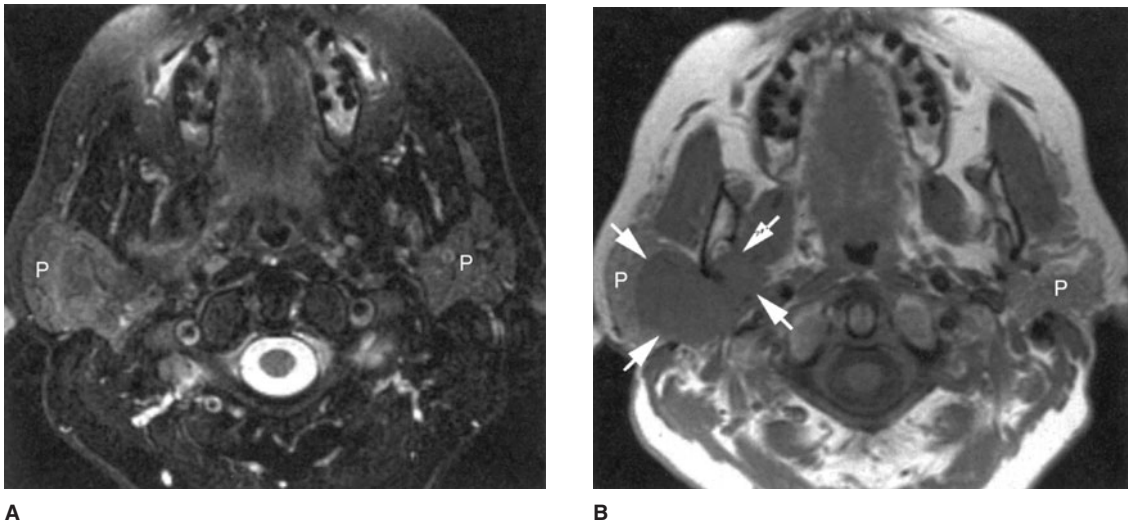
Tryhus MR, Smoker WR, Harnsberger HR. The normal and diseased masticator space. *Semin Ultrasound CT MR* 1990;11:476 [PMID: 2275809]. (Reviews the radiologic anatomy and pathology of the masticator space.)



▲ **Figure 3–60.** Sagittal T1-weighted image in a patient with a mucoepidermoid carcinoma of the parotid. The mass has an irregular, spiculated margin. In addition, two parotid lymph nodes (black arrowheads) are seen, which are suggestive of local metastases.

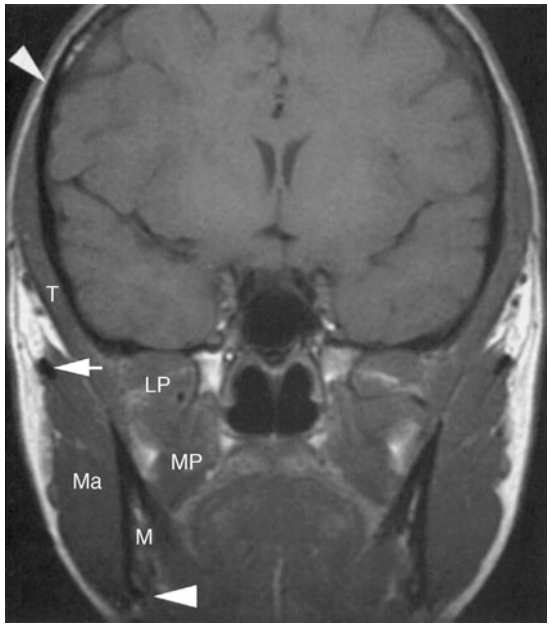


▲ **Figure 3–61.** Coronal postgadolinium T1-weighted image with fat saturation in an older man who had undergone a prior right parotidectomy for carcinoma ex pleomorphic adenoma demonstrates abnormal thickening and intense enhancement of the descending mastoid segment of the right facial nerve (arrowheads), consistent with the perineural spread of disease. The normal left parotid gland (P) is indicated. The patient had a progressive right facial palsy.



A **B**

▲ **Figure 3–62.** **(A)** Axial fast spin-echo T2-weighted image with fat saturation in a 60-year-old woman who has noted fullness in her right parotid region. Both parotid glands (P) are indicated, but the large right parotid mass is difficult to detect on this sequence. **(B)** Axial T1-weighted image demonstrates a large right parotid mass (arrows), which is easy to identify in contrast to the fatty glandular parenchyma. The low signal intensity on the T2-weighted image is suggestive of a malignant histology, and squamous cell carcinoma of the parotid gland was pathologically confirmed.



▲ **Figure 3–63.** The masticator space demonstrated on a coronal T1-weighted image. The space extends from the inferior edge of the mandible below (lower white arrowhead) to the superior attachment of the temporalis muscle above (upper white arrowhead); the zygoma (white arrow) represents the inferior margin of the suprazygomatic masticator space. The mandible (M) is indicated, as are the muscles of mastication: temporalis (T), masseter (Ma), medial pterygoid (MP), and lateral pterygoid (LP).

2. Infrahyoid Neck

As in the suprahyoid neck, the infrahyoid neck is cleaved into a series of spaces by the three layers of the deep cervical fascia. These spaces are illustrated in Figure 3–82. There are five major spaces of the infrahyoid neck, four of which also traverse the suprahyoid neck, and their suprahyoid segments have already been discussed: the carotid space, the retropharyngeal space, the perivertebral space, and the posterior cervical space. Only the visceral space is unique to the infrahyoid neck.

Visceral Space

The visceral space extends from the hyoid bone to the mediastinum, and its circumference is defined by the middle layer of deep cervical fascia. This complex space contains the thyroid and parathyroid glands, the larynx and trachea, the hypopharynx and esophagus, the recurrent laryngeal nerves, and visceral (level VI) lymph nodes.

Infrahyoid Carotid Space

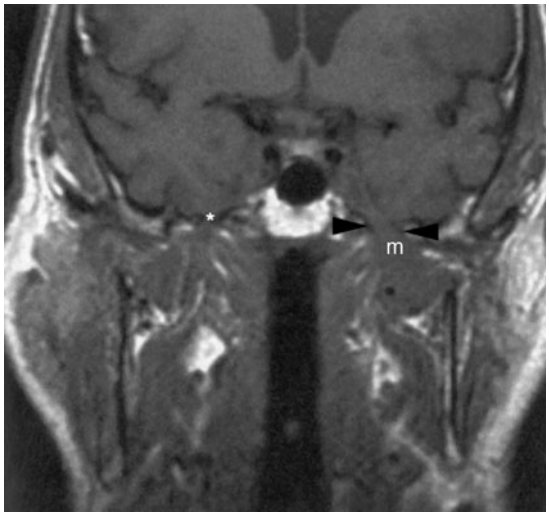
The infrahyoid carotid space includes the common carotid artery, the internal jugular vein, the vagus nerve, and the sympathetic chain. Level III and IV lymph nodes are intimately associated with the infrahyoid carotid space, although they do not lie within the fascial boundaries of this space. The infrahyoid carotid space apposes the visceral space anteromedially, the perivertebral space posteromedially, and the posterior cervical space posterolaterally.

Infrahyoid Posterior Cervical Space

As in the suprahyoid neck, the infrahyoid posterior cervical space has complex fascial boundaries derived from the superficial and deep layers of the deep cervical fascia, as well as the posterior aspect of the carotid sheath. It contains primarily fat and lymph nodes, but the trunks of the brachial plexus also traverse the posterior cervical space. This space is most commonly involved with nodal pathology.

Table 3–7. Lesions of the Masticator Space.

Congenital/Developmental	Inflammatory/Infectious	Neoplastic	
		Benign	*Malignant*
Hemangioma	Odontogenic infection: —Abscess —Cellulitis	Benign tumor of muscle or bone	Osteosarcoma
Venolymphatic malformation	Myositis	Nerve sheath tumor	Rhabdomyosarcoma
Masseteric hypertrophy			Non-Hodgkin lymphoma
			Deep extension of mucosal squamous cell carcinoma
			Metastatic disease



▲ **Figure 3–64.** Coronal T1-weighted image in a patient with a history of carcinoma involving the left masticator space and new lower facial numbness demonstrates marked enlargement of the foramen ovale on the left (arrowheads) and a masslike enlargement of V3 (m) due to the perineural spread of tumor. The normal right foramen ovale (*) is shown for comparison.

Infrahyoid Retropharyngeal Space

The only significant difference between the supra- and infrahyoid retropharyngeal space is that the infrahyoid retropharyngeal space contains only fat, whereas the suprahyoid retropharyngeal space also contains lymph nodes. There are, therefore, almost no processes that are primary to the infrahyoid retropharyngeal space, except, occasionally, lipoma. Pathology in the retropharyngeal space, whether inflammatory, infectious, or neoplastic, accesses this space either by direct extension from adjacent spaces across fascial boundaries or by inferior extension of a process centered in the suprahyoid retropharyngeal space.

Infrahyoid Perivertebral Space

The infrahyoid perivertebral space also occurs as two distinct areas, the prevertebral and the paraspinal portions of the perivertebral space, which are enclosed by the deep layer of deep cervical fascia. In the infrahyoid neck, in addition to the prevertebral muscles and vertebral vessels, the prevertebral portion of the perivertebral space contains the phrenic nerve, the scalene muscles, and the roots of the brachial plexus. The roots of the brachial plexus actually pierce the deep layer of deep cervical fascia on their way to the posterior cervical space.

Babbel RW, Smoker WR, Harnsberger HR. The visceral space: the unique infrahyoid space. *Semin Ultrasound CT MR* 1991;12:204 [PMID: 1892686]. (Reviews the anatomy and pathology of the visceral space.)

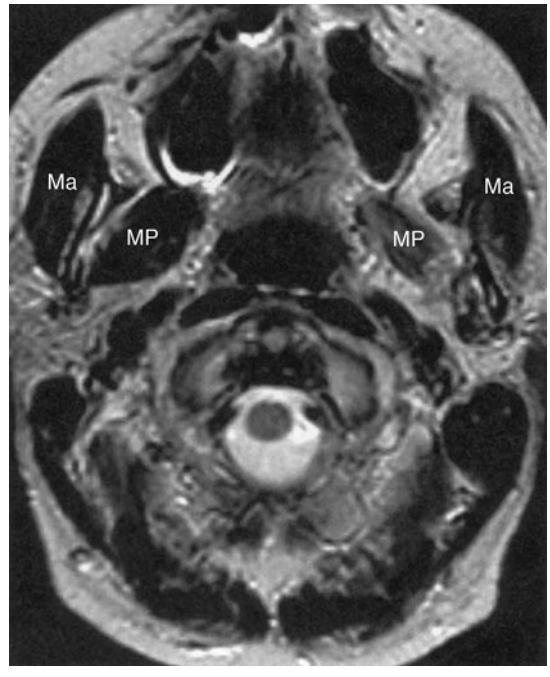
Fruin ME, Smoker WR, Harnsberger HR. The carotid space of the infrahyoid neck. *Semin Ultrasound CT MR* 1991;12:224 [PMID: 1892687]. (Reviews the anatomy and pathology of the infrahyoid carotid space.)

Shah RR, Lewin JS. Imaging of the infrahyoid neck. *Neuroimaging Clin N Am* 1998;8:219 [PMID: 9449762]. (Reviews the complex anatomy and pathology of the infrahyoid neck with updated imaging techniques.)

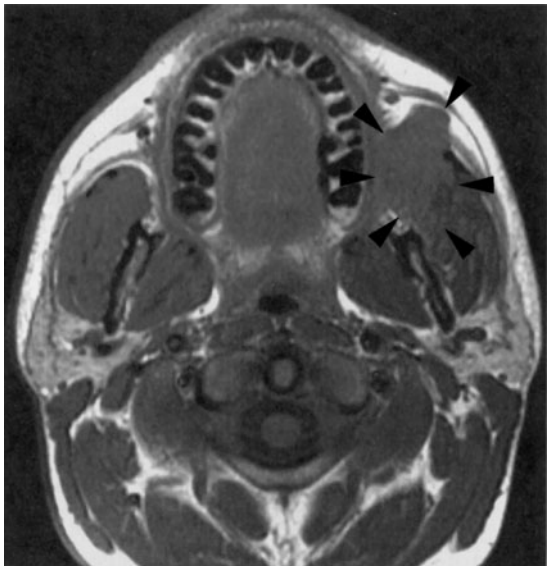
Smoker WR. Normal anatomy of the infrahyoid neck: an overview. *Semin Ultrasound CT MR* 1991;12:192 [PMID: 1892685]. (Reviews the complex anatomy and pathology of the infrahyoid neck.)

3. Trans-Spatial Masses

Some pathologies classically involve multiple spaces and can be considered within a unique group of multispatial or "trans-spatial" processes. These are typically lesions of structures that normally pass from one space to another, such as



▲ **Figure 3–65.** Axial fast spin-echo T2-weighted image (no fat saturation) in a patient with left-sided perineural spread of squamous cell carcinoma along V3 demonstrates marked asymmetry of the masseter (Ma) and medial pterygoid (MP) muscles, consistent with longstanding denervation atrophy on the left.



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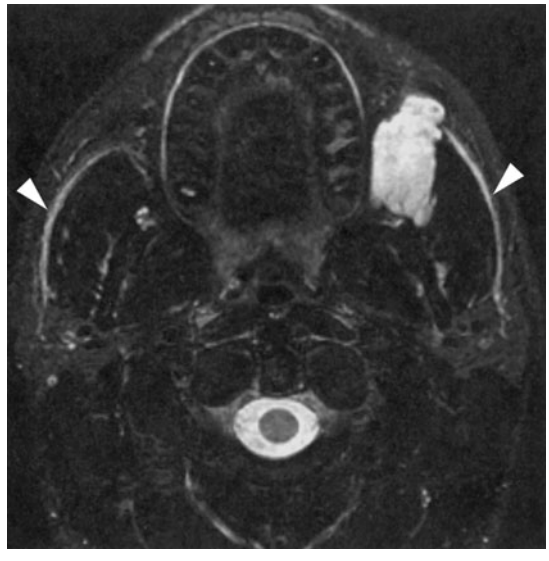

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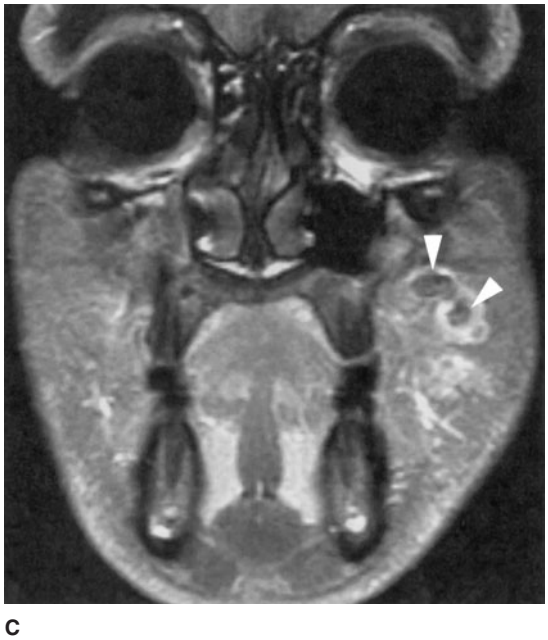
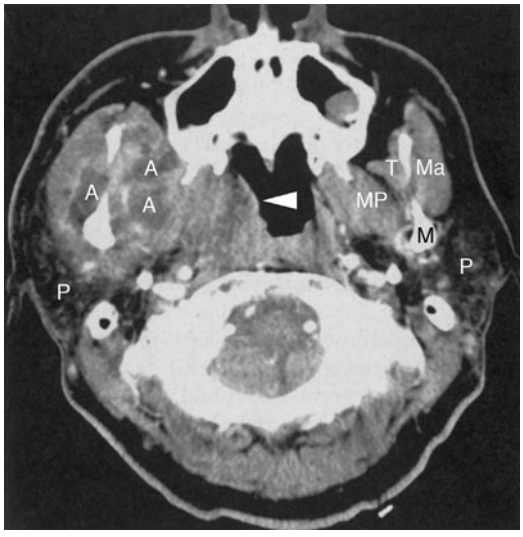


C

▲ **Figure 3–66.** **(A)** Axial T1-weighted image in a young man with a soft, slowly enlarging mass of the left buccal region demonstrates a well-circumscribed, slightly lobulated soft tissue intensity mass (black arrowheads). **(B)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates the lesion to be very bright. Also demonstrated are the parotid ducts bilaterally (arrowheads), running over the surface of the masseter muscles toward the buccal space. **(C)** Coronal postgadolinium T1-weighted image with fat saturation through the most anterior aspect of the lesion demonstrates two low signal intensity, rounded masses (arrowheads) within what was otherwise a homogeneously and intensely enhancing lesion. These are consistent with phleboliths, confirming the diagnosis of a venous malformation.

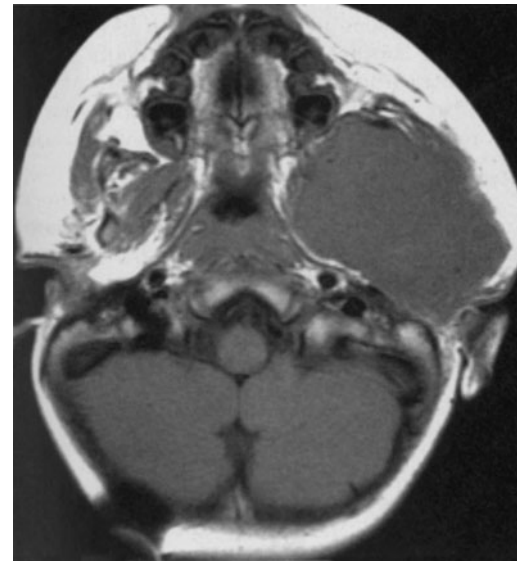
blood vessels, lymphatics, and nerves. Although aggressive infectious or neoplastic processes may also traverse spatial boundaries, they do so by virtue of their destructive nature rather than as a consequence of the tissue of origin. The entities that commonly present as trans-spatial processes include capillary hemangiomas, vascular malformations (venous or arteriovenous), lymphatic malformations, and plexiform neurofibromas. The latter are typically seen in patients with neurofibromatosis type I.

The soft tissue vascular lesions of the head and neck fall into two categories: hemangiomas and vascular malformations. The term hemangioma should be limited to vascular lesions of infancy, which grow rapidly in early infancy and then undergo fatty replacement and involution by adolescence. Vascular malformations result from abnormal blood or lymphatic vessel morphogenesis and are classified by the predominant type of vessel involved (ie, capillary, venous, lymphatic, or arteriovenous malformations).



▲ **Figure 3–67.** Axial contrast-enhanced CT scan of the neck in a patient with poor dentition, fever, pain, and facial swelling. Extensive abscess formation (A) is seen in the right masticator space. The normal left masticator space (M, mandible; MP, medial pterygoid; Ma, masseter; T, temporalis) is shown for comparison. The right pharyngeal wall is bowed medially, the parapharyngeal fat is obliterated, and the right parotid gland (P) is displaced posteriorly.

Hemangiomas are typically intermediate signal intensity on T1-weighted images and bright on T2-weighted images, and enhance intensely postgadolinium (see Figure 3–54, parotid hemangioma). Flow voids may be seen within larger lesions, and feeding arteries may be enlarged. As hemangiomas involute, they may show an increasingly high signal on T1-weighted images due to fatty replacement. In patients with a large, segmental, plaque-type facial hemangiomas, PHACES syndrome should be considered. PHACES is an acronym coined to describe a neurocutaneous syndrome that encompasses the following features: **p**osterior fossa brain malformations, large facial **h**emangiomas, **a**rterial cerebrovascular anomalies, **c**ardiac anomalies and aortic **c**oarctation, **e**ye anomalies, and ventral developmental defects (**s**ternal defects or **s**upraumbilical raphe). Children at risk should receive careful ophthalmologic, cardiac, and neurologic assessments. Venous malformations have signal characteristics similar to hemangiomas, but they are typically multilobulated and contain venous lakes and also rounded calcifications (phleboliths). (See Figure 3–66, venous malformation of the buccal space.) Venous malformations are not high-flow lesions and do not demonstrate enlargement of feeding vessels or draining veins, or internal flow voids. Lymphatic malformations are discussed later in this



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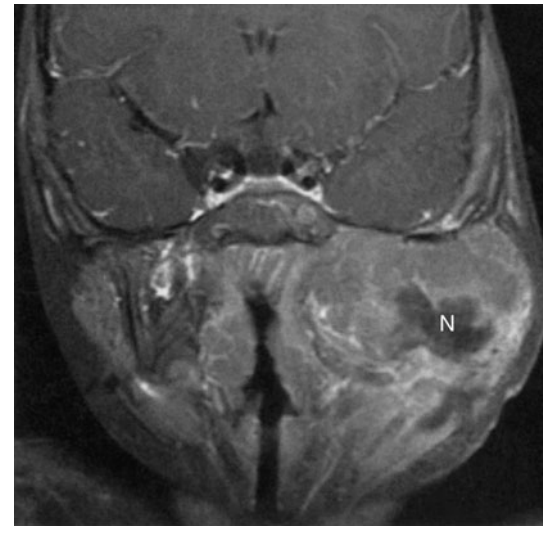
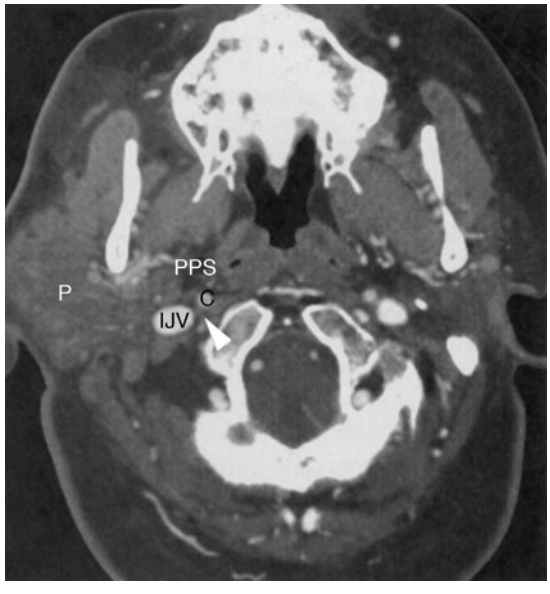


B

▲ **Figure 3–68.** **(A)** Axial T1-weighted image demonstrates a large, homogeneous mass, which is isointense to muscle and centered on the left masticator space. The mandible has been largely destroyed. **(B)** Postgadolinium, a coronal T1-weighted image with fat saturation demonstrates an area of irregular central nonenhancement, consistent with necrosis (N). The lesion abuts and erodes the floor of the left middle cranial fossa, but no gross intracranial extension is seen. A rhabdomyosarcoma was confirmed pathologically.



▲ **Figure 3–69.** Axial contrast-enhanced CT scan of the neck demonstrates the contents of the carotid space: the internal jugular vein (IJV), carotid artery (C), and cranial nerves (arrowhead). Note that the cranial nerves cannot be individually resolved and appear as a focal soft tissue density posterior and slightly lateral to the carotid artery. Also indicated are the bordering parotid (P) and parapharyngeal (PPS) spaces.

chapter in Cystic Neck Masses. Arteriovenous malformations have serpiginous signal voids and lack a dominant mass (Figure 3–83).

Baker LL, Dillon WP, Hieshima GB, Dowd CF, Frieden IJ. Hemangiomas and vascular malformations of the head and neck: MRI characterization. *Am J Neuroradiol* 1993;14:307 [PMID: 8456703]. (Characterizes the MRI appearance of a common hemangioma of infancy as well as the low- and high-flow vascular malformations of the head and neck.)

Hartemink DA, Chiu YE, Drolet BA, Kerschner JE. PHACES syndrome: a review. *Int J Pediatr Otorhinolaryngol* 2009;73:181–187 [PMID: 19101041]. (The spectrum of PHACES is reviewed.)

Mulliken JB, Glowacki J. Hemangiomas and vascular malformations in infants and children: a classification based on endothelial characteristics. *Plast Reconstr Surg* 1982;69:412 [PMID: 7063565]. (A classic paper that clarifies the categorization of hemangiomas versus vascular malformations. This analysis provides a useful classification of vascular lesions of infancy and childhood and serves as a guide for the diagnosis, management, and further research.)

Vogelzang P, Harnsberger HR, Smoker WR. Multispatial and trans-spatial diseases of the extracranial head and neck. *Semin Ultrasound CT MR* 1991;12:274 [PMID: 1892690]. (Reviews the imaging and differential diagnosis of multispatial processes of the head and neck.)

4. Thyroid & Parathyroid

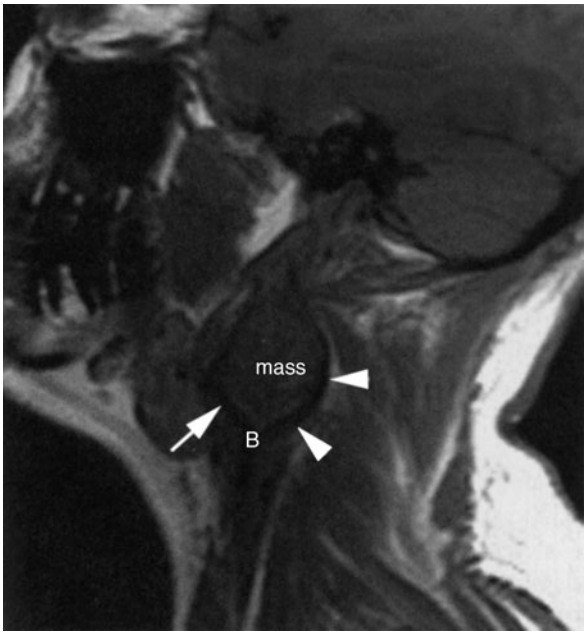
Thyroid

The thyroid gland consists of right and left lobes connected across the midline by a narrow isthmus. A pyramidal lobe is frequently present, projecting upward from the isthmus and in some cases connecting to the hyoid bone via a fibrous or muscular band. The thyroid is a highly vascular organ that is supplied mainly by the superior and inferior thyroid arteries, the former being a branch of the external carotid artery and the latter a branch of the thyrocervical trunk. Because of its high iodine concentration, the thyroid gland is intrinsically dense on a noncontrast CT scan (Figure 3–84). Following the administration of iodinated contrast material or gadolinium, the normal thyroid gland enhances homogeneously (Figure 3–85).

Nonspecific, incidental thyroid lesions such as cysts and adenomas are very commonly seen on cross-sectional imaging studies. The primary evaluation of a thyroid mass is typically done with ultrasound and nuclear medicine scanning, with CT scanning or MRI reserved to assess the extent of a process and evaluate the rest of the neck. If there is a concern about possible thyroid carcinoma, then the cross-sectional imaging evaluation should be done with a noncontrast CT scan or, ideally, gadolinium-enhanced MRI. Because the thyroid gland concentrates iodine, the bolus of

Table 3–8. Lesions of the Carotid Space.

Vascular	Inflammatory/Infectious	Neoplastic	
		Benign	***Malignant***
Internal jugular vein thrombosis	Abscess	Paraganglioma	Neuroblastoma
Carotid artery thrombosis		Schwannoma	Non-Hodgkin lymphoma
Carotid artery aneurysm or pseudoaneurysm		Meningioma (from posterior fossa via the jugular foramen)	Direct extension of mucosal squamous cell carcinoma
			Nodal metastases



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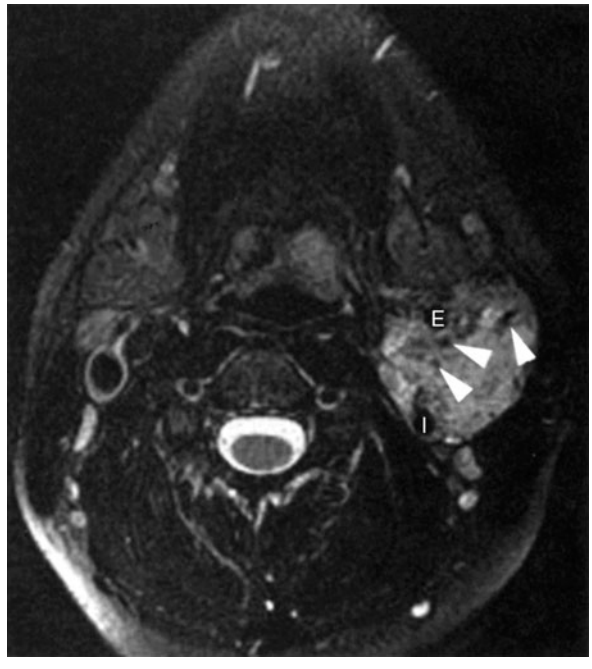

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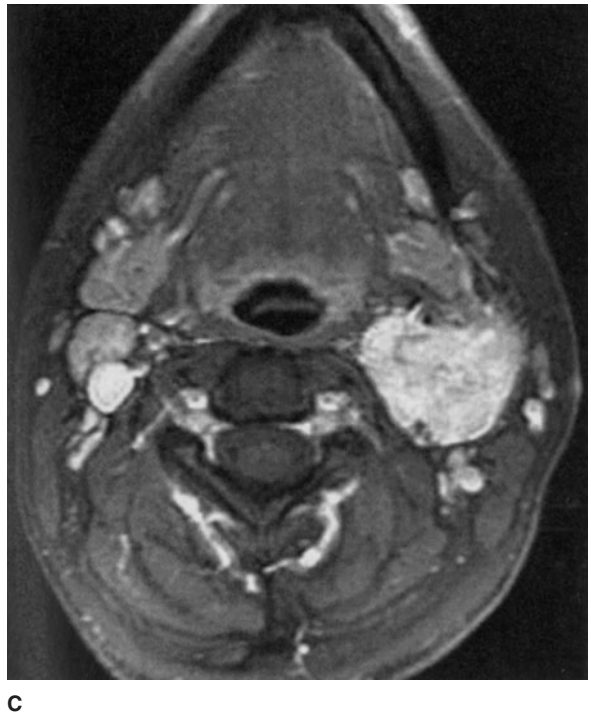
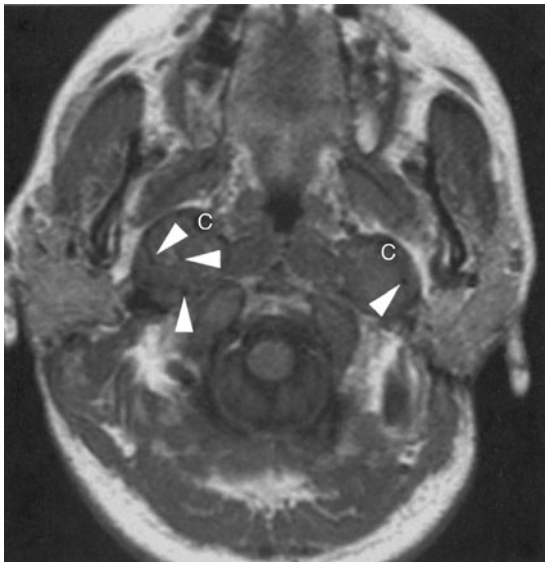


C

▲ **Figure 3–70.** **(A)** Sagittal T1-weighted image demonstrates a soft tissue mass arising at the level of the carotid bifurcation (B) and displacing the internal carotid artery posteriorly (arrowheads) and the external carotid artery anteriorly (arrow). **(B)** The mass is mildly bright on an axial fast spin-echo T2-weighted image with fat saturation and also demonstrates prominent vessels (arrowheads). The internal carotid artery (I) is displaced posteriorly and the external carotid artery (E) is displaced anteriorly. **(C)** Postgadolinium, the mass enhances intensely and homogeneously. These findings are classic for a carotid body tumor.



▲ **Figure 3–71.** Axial T1-weighted image in a patient with bilateral glomus vagale tumors demonstrates round, well-circumscribed soft tissue masses displacing the internal carotid arteries (C) anteriorly. Prominent flow voids (arrowheads) are seen within both lesions.

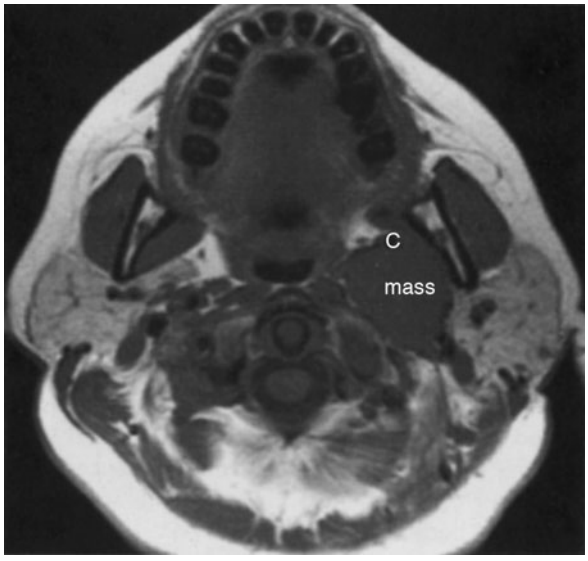
iodinated contrast material that is given during a CT scan of the neck can take many months to clear from a patient's system and can delay radioiodine therapy for as long as 6 months.

A. Benign Thyroid Lesions

Benign thyroid lesions include goiter, colloid cyst, and adenoma. The goiter appears on the CT scan or MRI as a diffuse or multinodular enlargement of the gland, often with areas of heterogeneous density on CT scan and intensity on MRI. Dramatic enlargement of the gland may result in the displacement and compression of vital structures such as the trachea (Figure 3–86). A colloid cyst is a well-circumscribed cystic lesion that may appear bright on a pregadolinium T1-weighted image owing to an elevated protein content or hemorrhagic contents. A thyroid adenoma is a generally well-circumscribed mass that may have areas of calcification, hemorrhage, or cystic degeneration within it; adenomas are indistinguishable from low-grade thyroid carcinomas on the basis of imaging alone.

B. Thyroid Carcinoma

Thyroid carcinoma has a number of pathologic subtypes that are generally not distinguishable from one another on imaging studies (Figure 3–87). Less aggressive carcinomas



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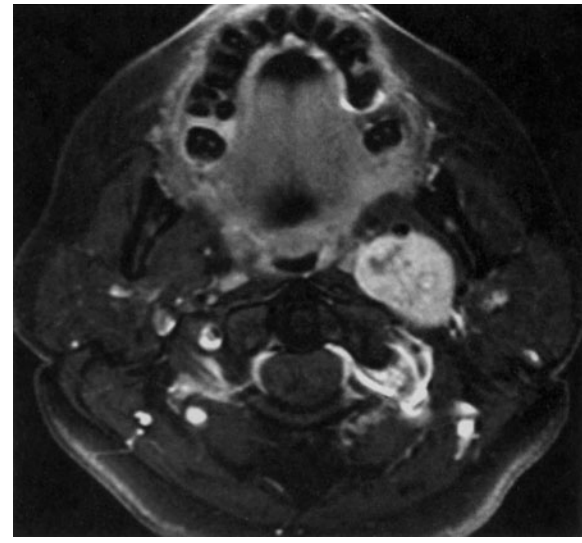
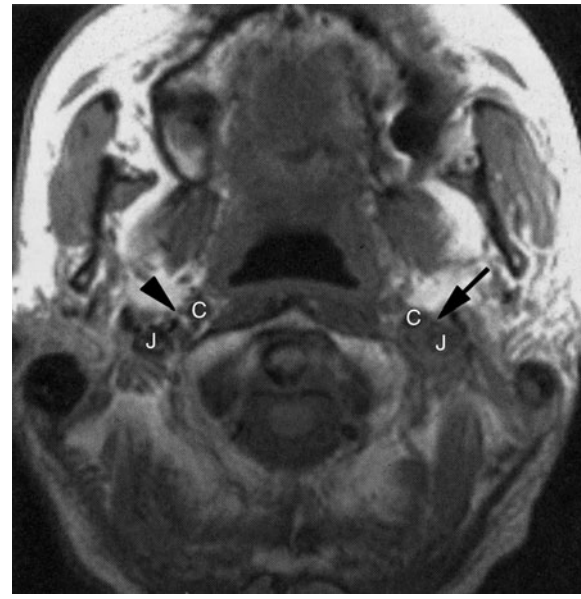
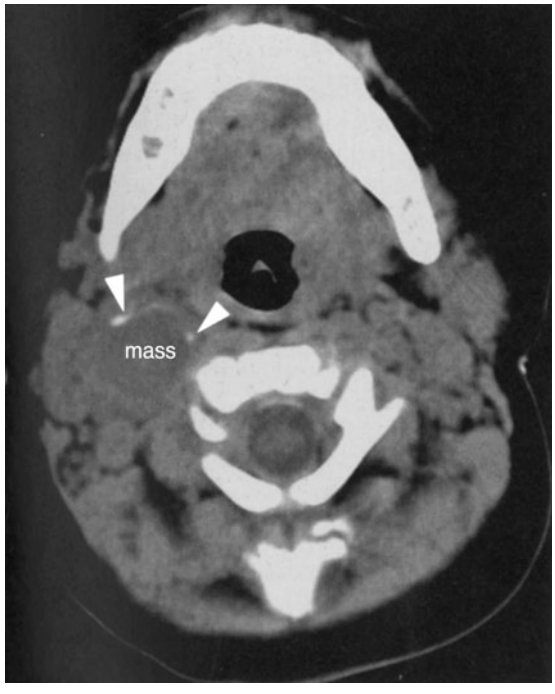


B

▲ **Figure 3–72.** **(A)** Axial T1-weighted image demonstrates a well-circumscribed, homogeneous mass arising from the left carotid space, displacing the left internal carotid artery (C) anteriorly. No vessels are seen within the lesion. **(B)** Postgadolinium, the lesion enhances intensely. A few small areas of nonenhancement most likely represent small areas of cystic degeneration, as flow voids should have been seen on the T1-weighted image. The diagnosis of schwannoma was favored and was confirmed pathologically.



▲ **Figure 3–73.** Axial T1-weighted image in a patient with recurrent squamous cell carcinoma and new cranial neuropathy demonstrates abnormal soft tissue (black arrow) infiltrating the left carotid space between the internal carotid artery (C) and a thrombosed jugular vein (J). Normal fat between the vessels (arrowhead) is demonstrated on the contralateral side. Fine-needle aspiration confirmed squamous cell carcinoma in the carotid sheath.



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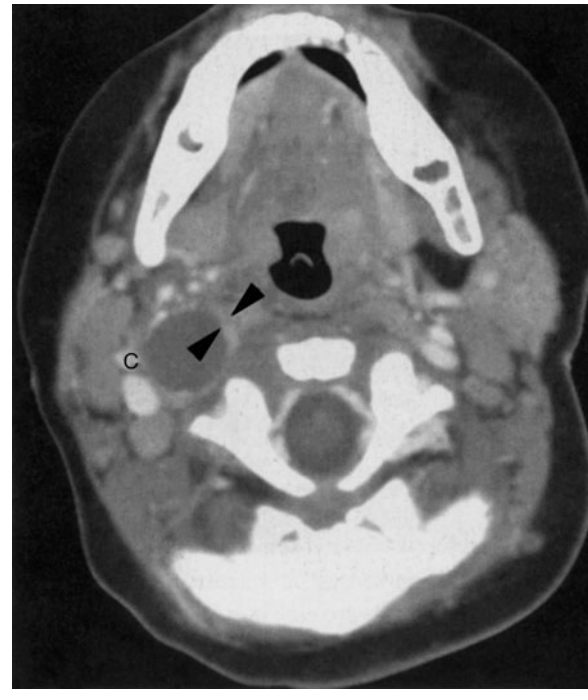
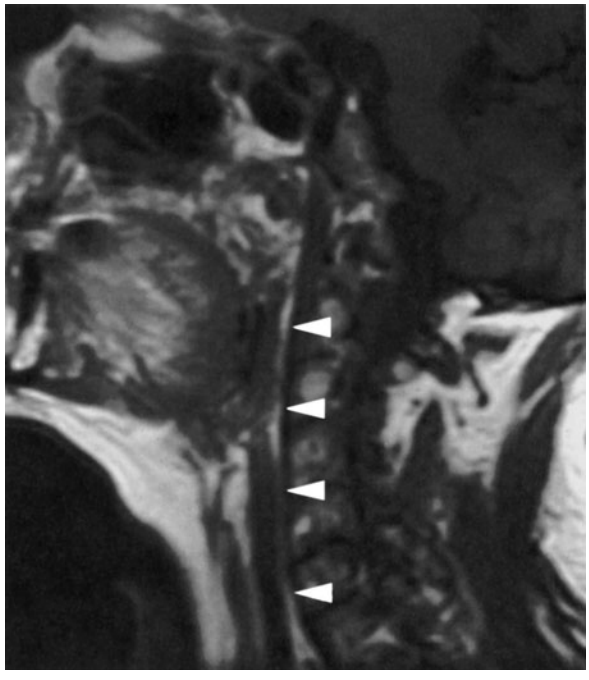


B

▲ **Figure 3–74.** **(A)** A noncontrast CT scan of the neck in a 9-month-old girl with a neck mass and Horner syndrome demonstrates a relatively low-density lesion with some peripheral calcification (arrowheads). **(B)** Postcontrast, the mass is seen to be located medial to the internal carotid artery (C) in the right carotid space. The mass appears of low density and possibly cystic, but with some irregular thickness to its wall (black arrowheads). Fine-needle aspiration confirmed neuroblastoma.



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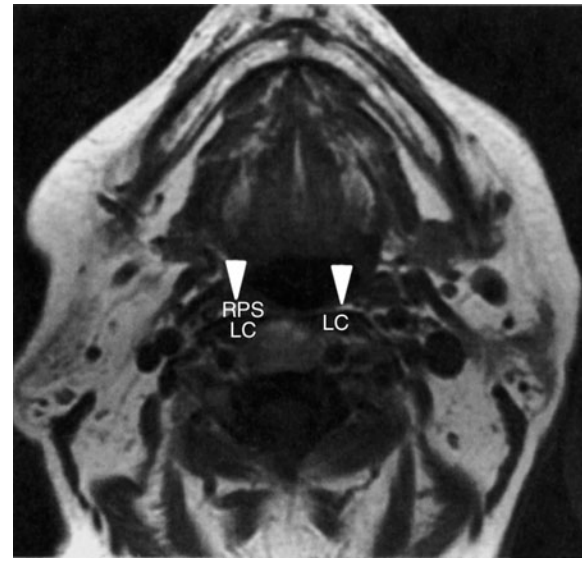
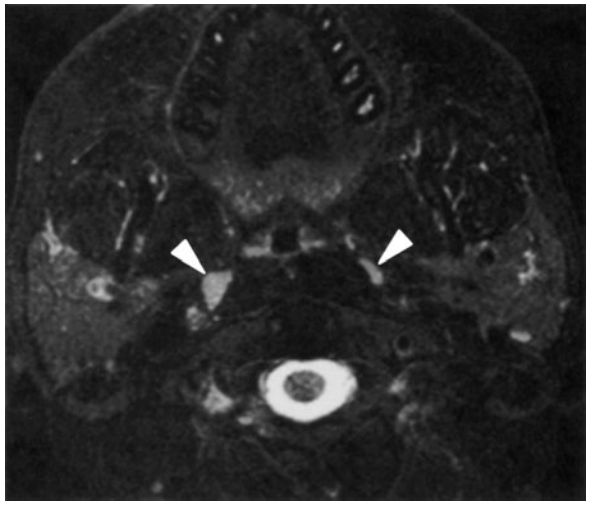


B

▲ **Figure 3–75.** **(A)** Sagittal T1-weighted image demonstrates a hyperintense stripe of retropharyngeal fat in this slightly off-midline image. **(B)** Axial T1-weighted image demonstrates fat in the retropharyngeal space (RPS, arrowheads), which lies just anterior to the prevertebral muscles (longus colli [LC]).

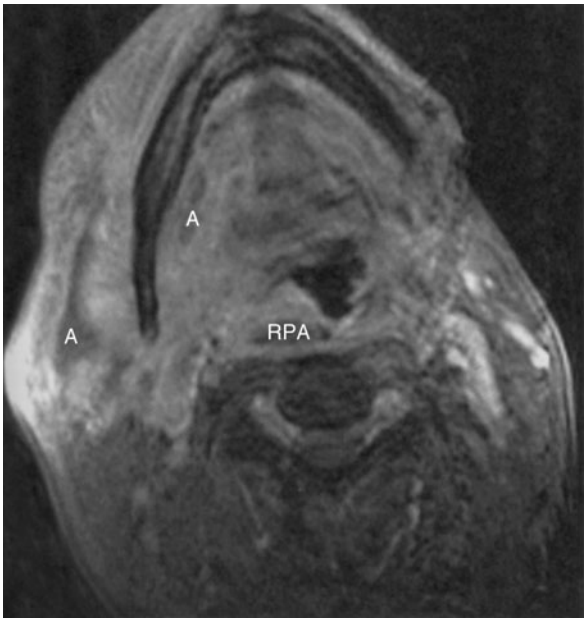


▲ **Figure 3–76.** Normal, nonenlarged lateral retropharyngeal lymph nodes (arrowheads) are well seen on this axial fast spin-echo T2-weighted image with fat saturation.

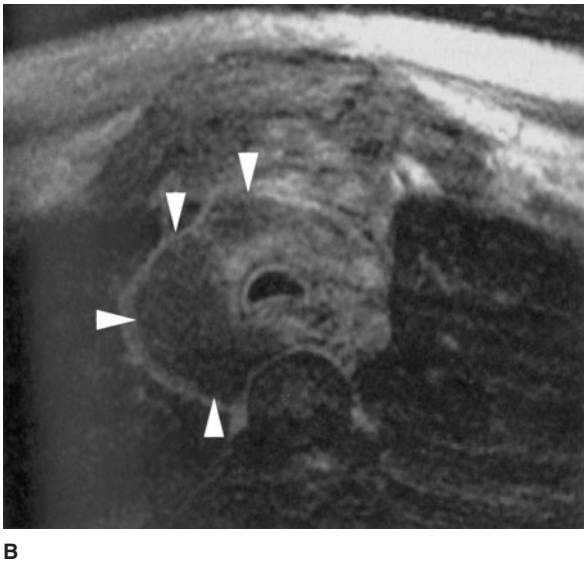
generally present as well-circumscribed masses, whereas more aggressive lesions such as anaplastic carcinomas are highly invasive and destructive of adjacent tissues. Of note, the nodal metastases of thyroid carcinoma may appear cystic, and metastatic thyroid cancer should be included in the differential diagnosis of a cystic neck mass. Because these nodal metastases may be either hemorrhagic because of the highly vascular nature of thyroid cancer or highly proteinaceous because of their thyroglobulin content, they may show a high signal intensity on a pregadolinium T1-weighted image (Figure 3–88). This appearance is highly suggestive of metastatic thyroid cancer.

Parathyroid

The parathyroid glands are ovoid bodies measuring approximately 6 mm in length that are intimately related to the posterior border of the thyroid gland and lie within its fascial capsule. There are typically two superior and two inferior parathyroid glands, but in some cases, a parathyroid gland may be found some distance caudal to the gland, in association with the inferior thyroid veins or even in the superior mediastinum. Parathyroid pathology

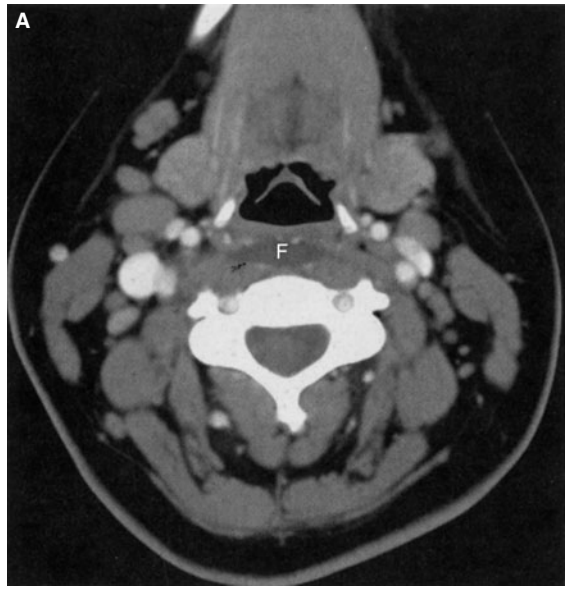


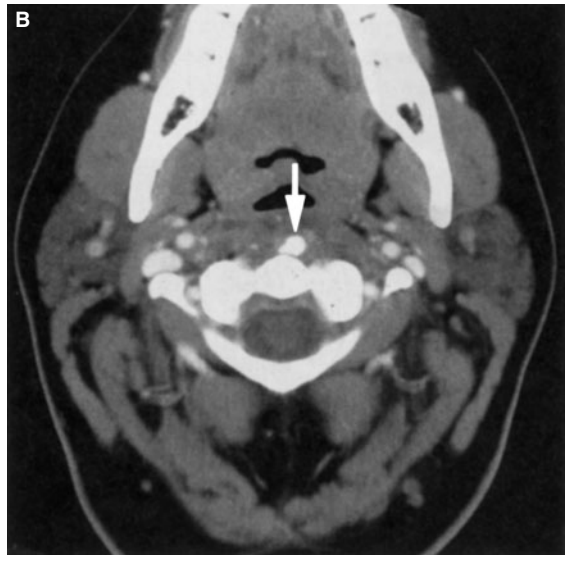
A



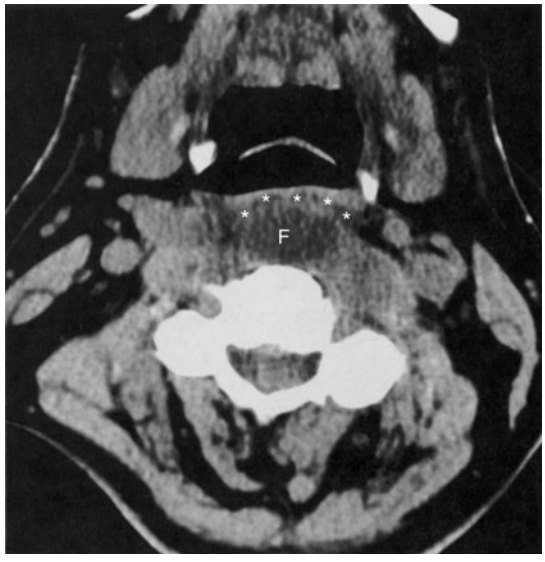
B

▲ **Figure 3–77. (A)** Axial postgadolinium T1-weighted image with fat saturation in a young male with diabetes and extensive neck infection shows abnormal enhancement throughout the right masticator space, oral cavity, and parapharyngeal space. Focal areas of abscess formation are present (A), including in the retropharyngeal space (RPA). **(B)** Postgadolinium image through the upper mediastinum demonstrates the inferior extension of the process and a large mediastinal abscess (arrowheads).

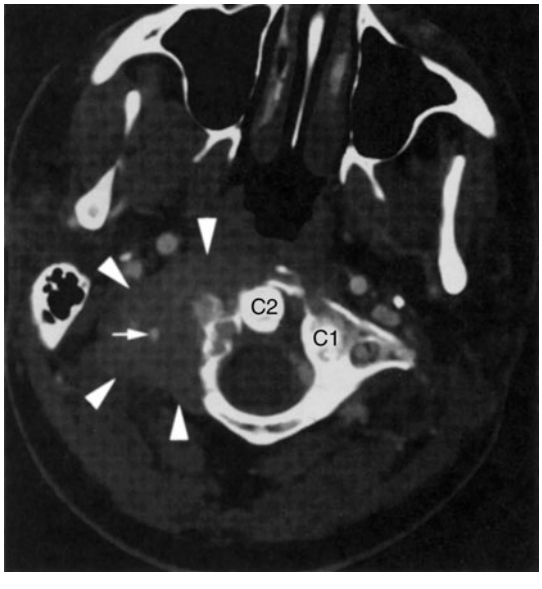




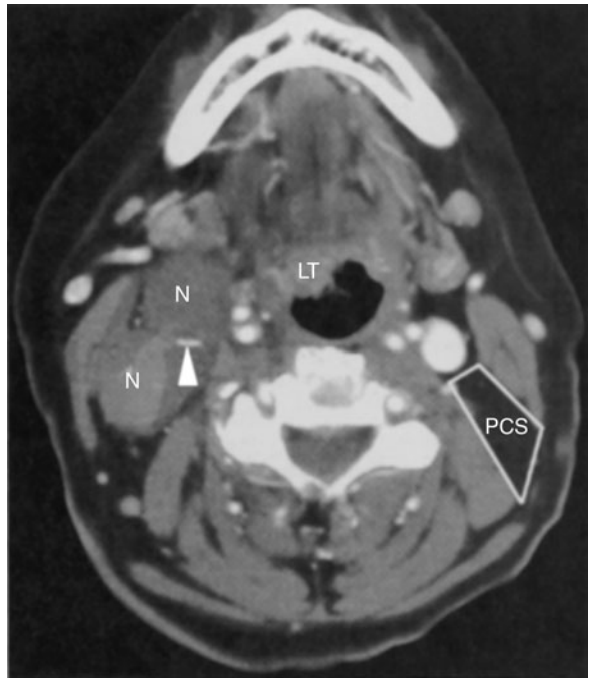
▲ **Figure 3–78. (A)** Axial contrast-enhanced CT scan of the neck in a young woman with 5 days of torticollis, odynophagia, a low-grade fever, and a slightly elevated white blood cell count demonstrates a fluid collection (F) in the retropharyngeal space. A few displaced contrast-enhancing vessels are seen around the collection, but the peripheral enhancement that might be expected with a retropharyngeal abscess is not present. **(B)** Axial image at a more cephalad level demonstrates an irregular calcification anterior to the C2 vertebral body, consistent with calcific tendinitis of the longus colli muscle. The fluid collection seen in part A represents an associated retropharyngeal effusion.



▲ **Figure 3–79.** Axial noncontrast CT scan of the neck in a patient with known cervical vertebral diskitis and osteomyelitis demonstrates a prevertebral fluid collection (F) displacing the retropharyngeal fat stripe (*) anteriorly. A prevertebral abscess was drained transcervically.



▲ **Figure 3–80.** Axial contrast-enhanced CT scan of the neck demonstrates a large soft tissue mass (arrowheads) arising from and destroying the right lateral mass of the C1 vertebral body. The mass encases the right vertebral artery (small white arrow) and displaces the right prevertebral muscle and retropharyngeal fat anteriorly. The pathology demonstrated a plasmacytoma.



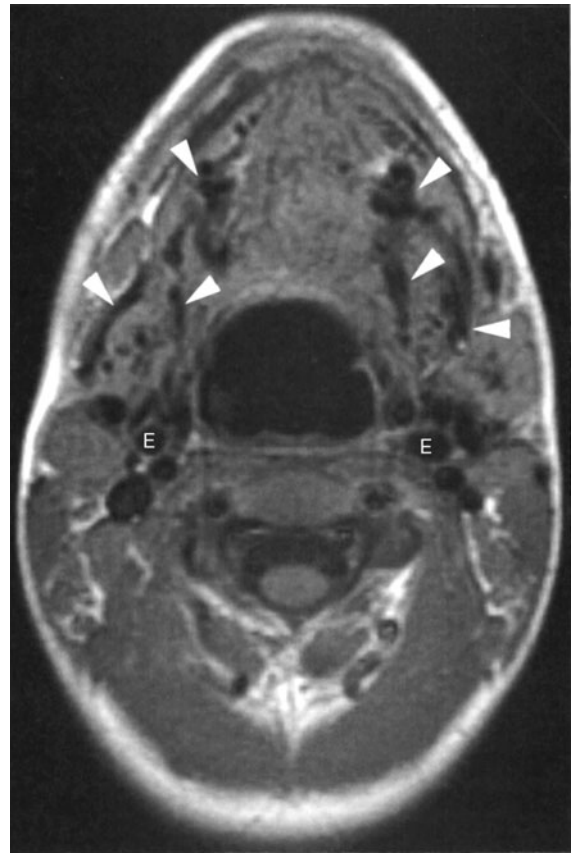
▲ **Figure 3–81.** Axial contrast-enhanced CT scan of the neck in a patient with lymphoma and multiple enlarged cervical lymph nodes (N) in the right neck. The right lingual tonsil (LT) is also somewhat prominent. The right jugular vein (arrowhead) is severely compressed. The normal fat-filled posterior cervical space (PCS) is outlined on the left.

is most commonly assessed with ultrasound and with nuclear medicine scanning (sestamibi). The normal glands are usually not identified on a CT scan or MRI and are identified only when pathologically enlarged, typically by parathyroid adenoma. A pathologically enlarged parathyroid gland may look very similar to a lymph node on a CT scan, but on MRI, the parathyroid adenoma is typically high in signal on T2-weighted images, which is a helpful feature.

Loevner LA. Imaging of the thyroid gland. *Semin Ultrasound CT MR* 1996;17:539 [PMID: 9023867]. (The embryology, anatomy, and physiology of the thyroid are discussed; congenital, autoimmune, inflammatory, metabolic, and neoplastic diseases are reviewed; and the diagnostic utility of various radiologic imaging modalities is addressed.)

Loevner LA. Imaging of the parathyroid glands. *Semin Ultrasound CT MR* 1996;17:563 [PMID: 9023868]. (The embryology, anatomy, and physiology of the parathyroid glands are reviewed. The diagnostic utility of radiologic imaging is discussed, particularly as it pertains to the evaluation of primary hyperparathyroidism.)

▲ **Figure 3–82.** Major spaces of the infrahyoid neck. Visceral space (VS; black arrows), retropharyngeal space (RPS), perivertebral space with prevertebral (PVS) and paraspinal (PSS) compartments, and posterior cervical space (PCS). Also indicated are two minor spaces, the fat-filled anterior cervical space (ACS) and the fat-filled superficial space (SS). (Modified and borrowed, with permission, from Smoker WR, Harnsberger HR. Differential diagnosis of head and neck lesions based on their space of origin. 2. The infrahyoid portion of the neck. AJR Am J Roentgenol 1991;157:155.)



▲ **Figure 3–83.** Axial T1-weighted image in a 6-year-old girl with a submental vascular malformation demonstrates marked enlargement of the external carotid arteries (E) bilaterally, as well as multiple large flow voids (arrowheads) throughout the submandibular and sublingual spaces bilaterally. No associated soft tissue mass was seen and angiography (not shown) confirmed extensive arteriovenous malformation.

Yousem DM, Huang T, Loevner LA, Langlotz CP. Clinical and economic impact of incidental thyroid lesions found with CT and *MR*. *Am J Neuroradiol* 1997;18:1423 [PMID: 9296181]. (Incidental thyroid lesions are frequently present and often overlooked on cross-sectional images of the neck in patients being examined for other reasons. The cost of pursuing a workup of these lesions and their high prevalence in the population raise questions regarding appropriate management strategies.)

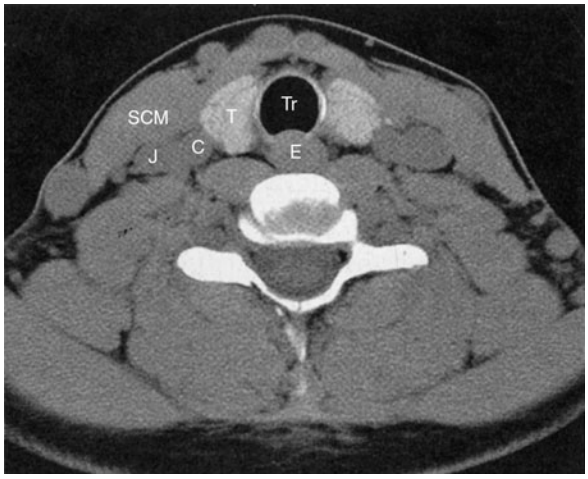
5. Cystic Neck Masses

The identification of a neck mass as cystic presents a limited differential diagnosis and often permits the differential considerations to be narrowed to a list of one or several entities when the specific clinical, CT, and/or MRI features are taken into consideration. A list of the more common cystic neck masses is presented in Table 3–9. To be considered in this differential, a mass should be of fluid density or intensity and lack enhancement. The mass should have a thin, regular rim, although prior infection may lead to thickening of the wall and the presence of enhancement. It is important to note that hemorrhage into a cyst or increased protein content within a cyst may affect its density or intensity. Some lesions that are not truly cystic may mimic a cystic neck mass because of central nonenhancement—notably, a thrombosed jugular vein, a thrombosed aneurysm or pseudoaneurysm, or a necrotic mass with a nonenhancing center.

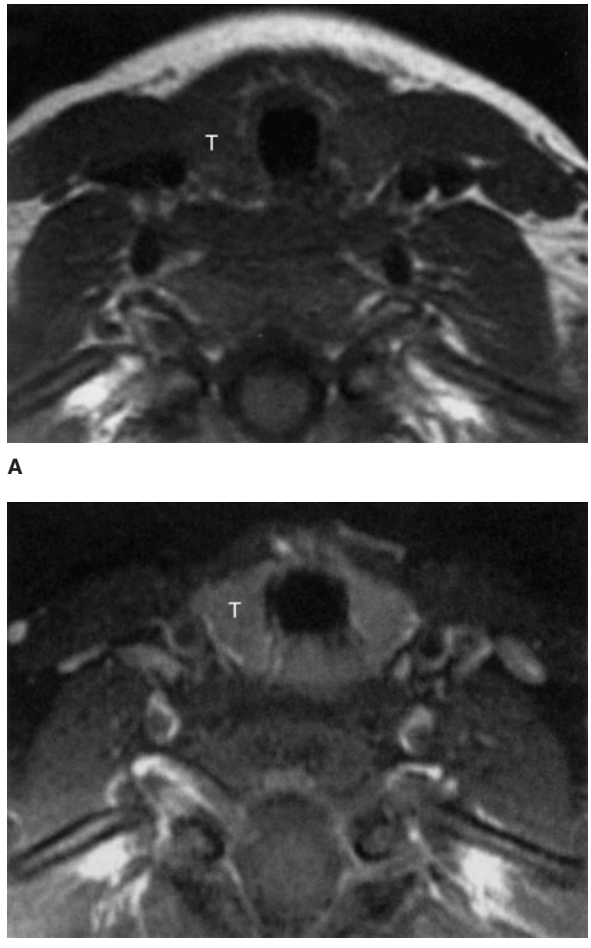
Pathology

A. Branchial Cleft Cysts

The second branchial apparatus accounts for ~90% of all branchial cleft anomalies. On a CT scan or MRI, a unilocular cystic mass is seen displacing the submandibular gland anteromedially and the sternocleidomastoid muscle



▲ **Figure 3–84.** Axial noncontrast CT scan of the neck demonstrates the intrinsic high density of the thyroid gland (T). Also shown are the esophagus (E), trachea (Tr), common carotid artery (C), internal jugular vein (J), and sternocleidomastoid muscle (SCM).



▲ **Figure 3–85.** Axial T1-weighted image of the neck before **(A)** and after **(B)** the administration of gadolinium demonstrates homogeneous enhancement of the thyroid gland (T) following contrast administration.

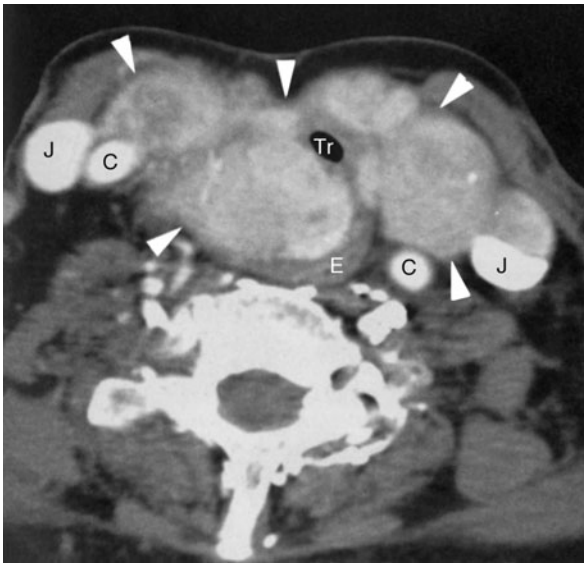
posterolaterally (Figure 3–89). In some cases, a "beak" pointing between the internal and external carotid arteries will be identified, and very rarely, a tract leading to the tonsillar fossa will also be identified. A sinus tract or fistula extending inferiorly in the neck to drain just above the clavicle may also be identified (Figure 3–90). If infection has occurred in the past, the cyst wall may show thickening and enhancement. If the infection is active, there may also be inflammatory changes in adjacent soft tissues.

B. Thyroglossal Duct Cysts

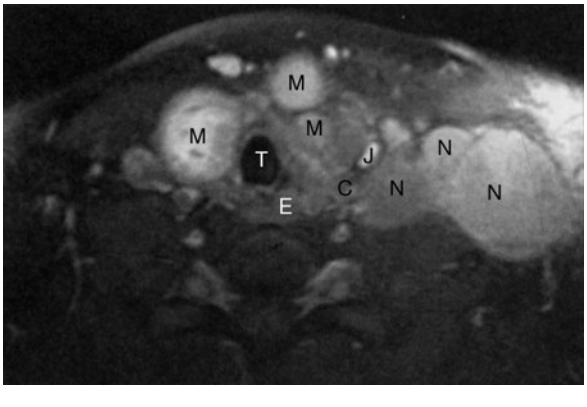
During embryogenesis, the thyroid anlage descends from the level of the foramen cecum at the tongue base to its normal position in the infrahyoid neck. Thyroid elements may remain at any level along this pathway (the thyroglossal duct) and may give rise to cysts, fistulas, or solid nodules of thyroid tissue. Thyroglossal duct cysts are usually located at or just below the hyoid bone, in which case a midline or paramedian cystic mass that is embedded in the strap muscles is seen (Figure 3–91). There is typically no associated enhancement unless prior or active infection has occurred. In some cases, carcinoma may arise within a thyroglossal duct cyst; clues to this include the presence of calcification and solid tissue components.

C. Lymphatic Malformations

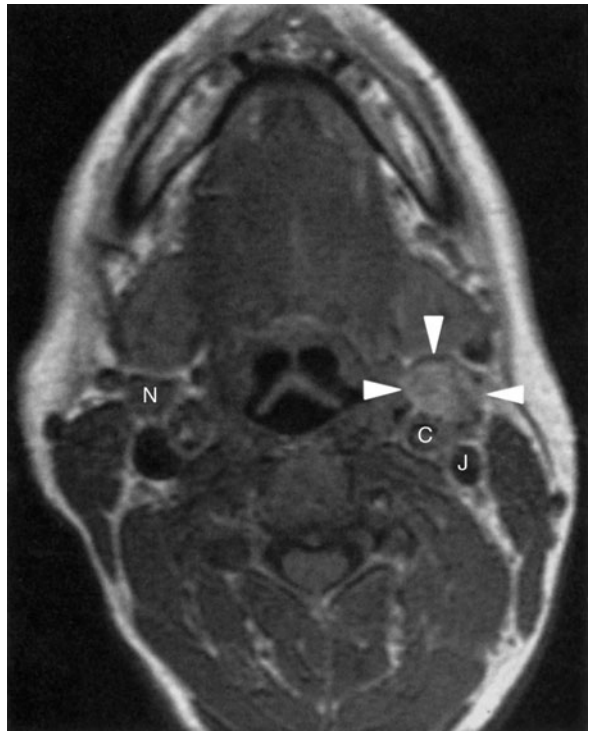
Lymphatic malformations, also known as cystic hygromas or lymphangiomas, result from the maldevelopment of lymphatic vessels and the failure of these abnormal vessels to communicate with normal lymphatic drainage channels. This leads to a fluid-filled mass that is characteristically multilobulated and multiloculated. The lymphatic malformation may involve multiple spaces, but most commonly involves the posterior cervical space. These lesions are typically of low density on CT scans, but are often heterogeneous in signal intensity on T1- and T2-weighted MRI sequences because of their variable protein content and their propensity to hemorrhage. In fact, fluid–fluid levels due to hemorrhage are characteristic of lymphatic malformations (Figure 3–92). Lymphatic malformations do not enhance postcontrast, although fibrous septa separating fluid spaces may normally enhance and the lesion may demonstrate peripheral enhancement if infection has occurred.



▲ **Figure 3–86.** Axial contrast-enhanced CT scan of the neck in an elderly woman with a gradually enlarging neck mass demonstrates massive enlargement of a heterogeneously enhancing thyroid gland (arrowheads). There is maintenance of a smooth margin, however, and no evidence of any invasion of adjacent structures. No abnormal lymph nodes are identified. Adjacent structures are displaced and compressed by this large mass, notably, the trachea (Tr), esophagus (E), and carotid (C) and jugular (J) vessels. The surgical pathology confirmed diffuse goiter.



▲ **Figure 3–87.** Axial postgadolinium T1-weighted image with fat saturation demonstrates multiple lobulated enhancing masses (M) in the thyroid gland and multiple nodal masses (N) lateral to the carotid artery (C) and jugular vein (J). No invasion of the trachea (T) or esophagus (E) is seen. Fine-needle aspiration confirmed papillary carcinoma of the thyroid with multiple nodal metastases.



▲ **Figure 3–88.** Axial T1-weighted image in a young woman who presented with an enlarged left level IIA lymph node (arrowheads) demonstrates that the node is intrinsically bright. Compare a normal intermediate signal intensity node on the right (N). Fine-needle aspiration confirmed metastatic papillary carcinoma of the thyroid. Also shown are the carotid artery (C) and jugular vein (J).

D. Epidermoid and Dermoid Lesions

Dermoid and epidermoid lesions result from the sequestration of ectodermal tissue. In the head and neck, they most commonly occur in the floor of mouth (Figure 3–93). Both are lined by squamous epithelium, but the dermoid also contains skin appendages (eg, sebaceous glands and hair follicles) within its wall. These lesions are typically midline, unilocular, and slowly growing. Both contain cheesy material due to desquamated keratin, but the dermoid may contain fatty material as well. Epidermoids are typically low density on CT scans, low signal intensity on T1-weighted images, and high signal intensity on T2-weighted images—hence, their "fluidlike" appearance. The rim of the lesion may enhance postcontrast. Dermoids are similar in appearance except that their fatty contents may result in a very low density on CT scans and a high signal on T1-weighted MRI.

Table 3–9. Cystic Lesions of the Neck.

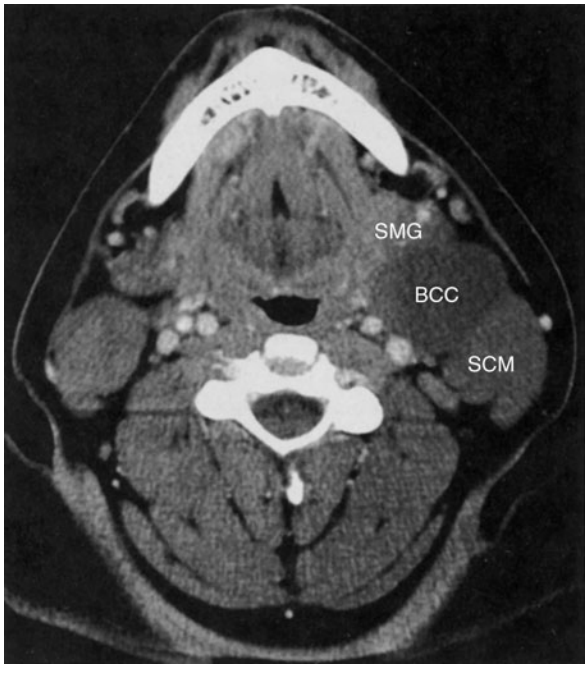
Congenital/Developmental	Infectious/Inflammatory	Neoplastic		Miscellaneous
		Benign	*Malignant*	
Branchial cleft cyst	Ranula	Cystic schwannoma	Cystic nodal metastases	Saccular cyst
Thyroglossal duct cyst	Necrotic lymphadenopathy		Cystic thyroid carcinoma	
Lymphatic malformation	Abscess			
Epidermoid or dermoid				
Foregut cyst				

E. Foregut Cysts

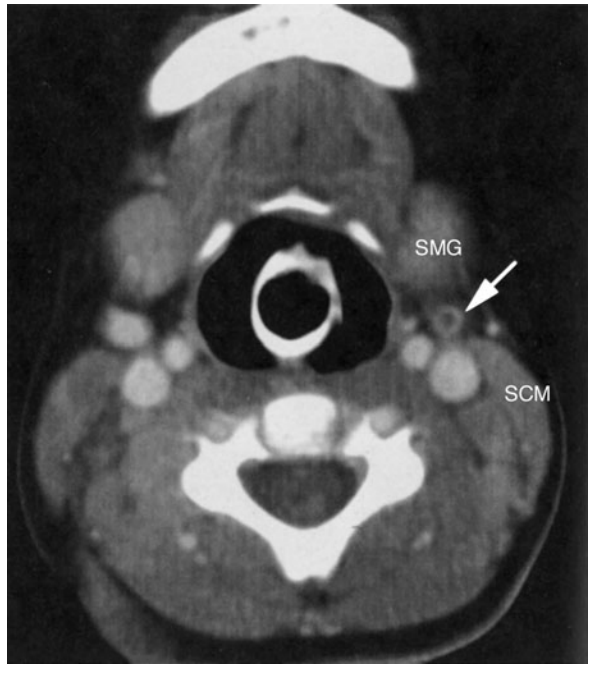
Foregut cysts are uncommon congenital defects of the developing airway and gut that may occur anywhere from the mouth to the anus. They are relatively rare in the neck, but may present with a neck mass or, if large, with airway obstruction or compression of other vital structures. The imaging is nonspecific (Figure 3–94), although there is often high signal within the cyst fluid on a T1-weighted image owing to an elevated protein content. These lesions tend to be located in the low neck and may extend into the superior mediastinum.

F. Ranulas

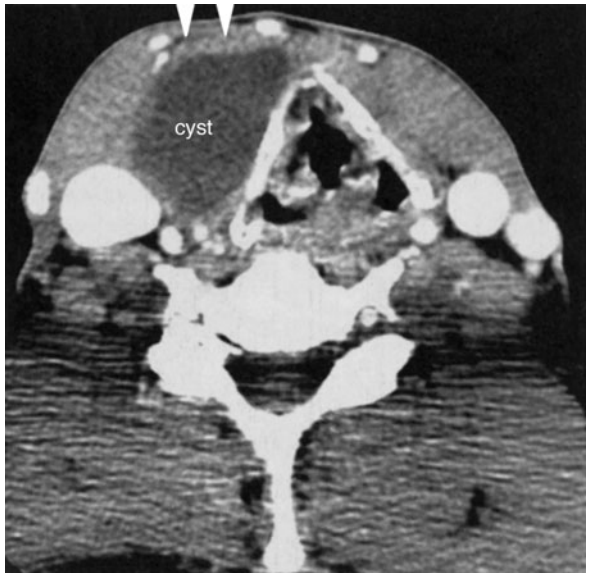
The simple ranula is a mucous retention cyst that is confined to the floor of mouth and is presumed to be caused by the



▲ **Figure 3–89.** Axial contrast-enhanced CT scan of the neck demonstrates a unilocular, well-circumscribed cystic mass (BCC) between the submandibular gland (SMG) and the sternocleidomastoid (SCM) muscle, anterolateral to the carotid space. This appearance is characteristic of a second branchial cleft cyst.



▲ **Figure 3–90.** Axial contrast-enhanced CT scan of a 14-month-old girl with recurrent redness and swelling of her left neck, as well as a draining pit just above her left clavicle. A peripherally enhancing tubular structure (arrow) could be followed from the upper neck down to the level of the clavicle, representing a second branchial apparatus sinus tract. Note its location between the submandibular gland (SMG) and the sternocleidomastoid (SCM) muscle.



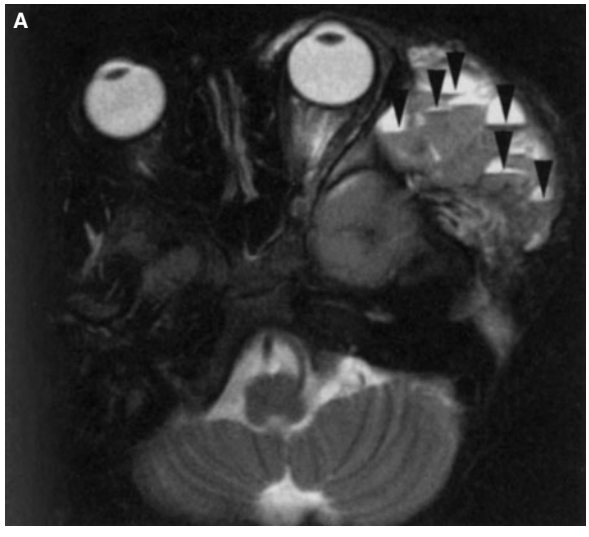
▲ **Figure 3–91.** Axial contrast-enhanced CT scan of a young man with right anterior neck swelling demonstrates a well-circumscribed cystic mass adjacent to the right thyroid lamina, embedded in the strap muscles, which are displaced around the periphery of the lesion (arrowheads). Surgical excision confirmed a thyroglossal duct cyst.

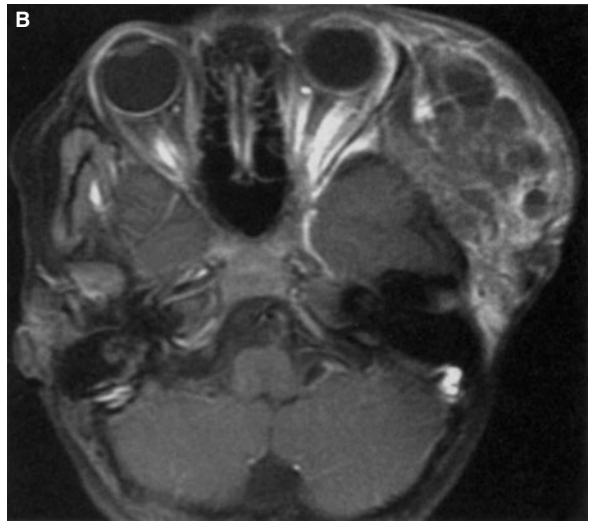
obstruction of a sublingual gland. In some cases, there is a rupture of the capsule or pseudocapsule and extension into the neck, and the lesion is then referred to as a plunging or diving ranula. This extension to the neck may occur along the deep lobe of the submandibular gland, between the mylohyoid and hyoglossus muscles, or via a congenital dehiscence in the mylohyoid muscle itself. A simple ranula appears as a unilocular cyst in the floor of mouth on both CT scans (see Figure 3–26) and MRI and may be difficult to distinguish on imaging from an epidermoid or a lymphangioma. A plunging ranula usually shows a "tail" leading back to the sublingual space, which is very suggestive of the diagnosis.

G. Laryngoceles

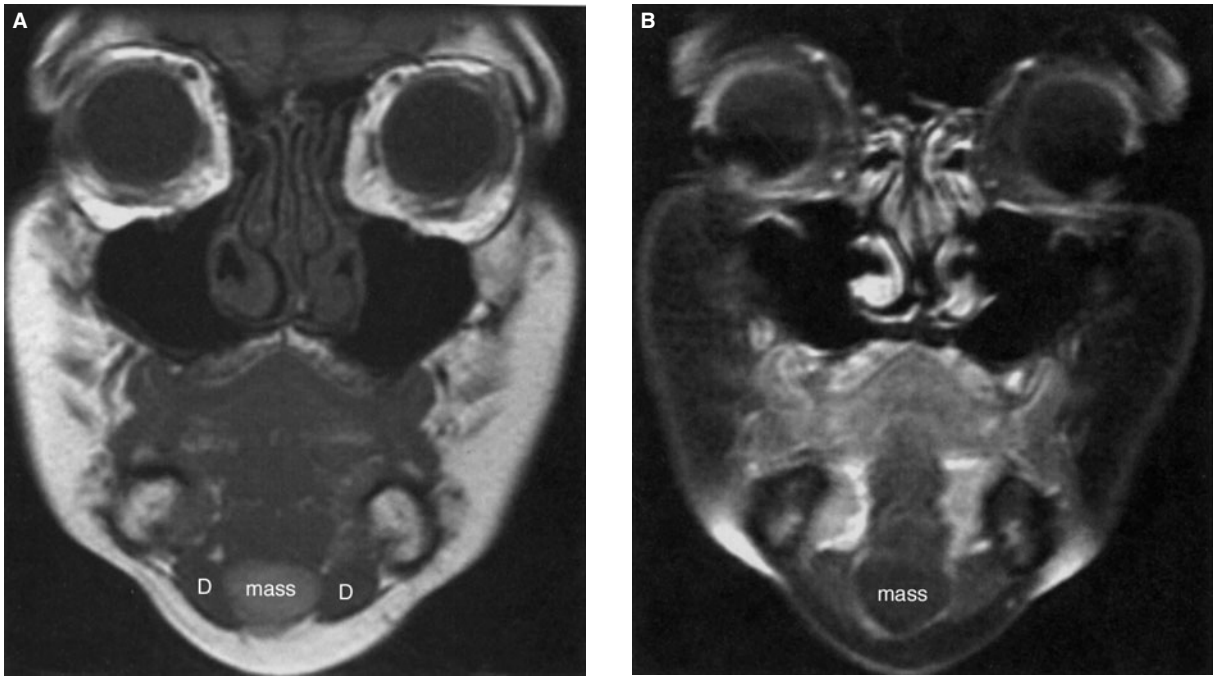
A laryngocele develops when the laryngeal ventricle or its appendix is functionally or anatomically obstructed. The mass that develops may be filled with air, fluid, or pus. The internal laryngocele is confined to the paralaryngeal space, whereas the external laryngocele penetrates the thyrohyoid membrane and may present as a neck mass. The imaging characteristics depend on the laryngocele contents (see Figures 3–41 and 3–45). In all cases, the larynx should be closely inspected clinically and on imaging studies to assess for a causative obstructing lesion.

Cohen SR, Thompson JW, Brennan LP. Foregut cysts presenting as neck masses. A report on three children. *Ann Otol Rhinol Laryngol* 1985;94:433 [PMID: 4051397]. (Three patients are





▲ **Figure 3–92.** **(A)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates a lobulated lesion of the left face with evidence of prior internal hemorrhage and multiple fluid-fluid levels (arrowheads) in its multiple cystic spaces. This is a typical appearance for a lymphangioma. **(B)** Postgadolinium, there is linear enhancement of the fibrous septa bordering some of these cystic spaces, which is often present in lymphangiomas. Some ill-defined enhancement more posteriorly and laterally is likely related to inflammation as this patient had a prior infection of the lesion as well as prior hemorrhage into it.



▲ **Figure 3–93.** **(A)** Coronal T1-weighted image in a 55-year-old woman with a submental mass demonstrates a rounded, well-circumscribed mass located in the midline between the anterior bellies of the digastric muscles (D). The lesion is somewhat bright on the T1-weighted image, suggesting fatty, proteinaceous, or hemorrhagic content. **(B)** On a postgadolinium coronal T1-weighted image with fat saturation, the lesion is seen to decrease in signal intensity. Hemorrhagic or proteinaceous material would not be expected to lose signal on a fat saturation image, but fatty material does. This suggests the diagnosis of dermoid cyst, which was confirmed surgically.

presented in detail, and the histopathology and differential diagnosis are discussed. Surgical extirpation of the cyst should be curative.)

Davison MJ, Morton RP, McIvor NP. Plunging ranula: clinical observations. *Head Neck* 1998;20:63 [PMID: 9464954]. (Reviews the etiology, clinical presentation, imaging, and surgical management of plunging ranulas.)

Glastonbury CM, Davidson HC, Haller JR, Harnsberger HR. The CT and MR imaging features of carcinoma arising in thyroglossal duct remnants. *Am J Neuroradiol* 2000;21(4):770 [PMID: 10782794]. (The presence of a solid nodule or invasive features in association with a thyroglossal duct lesion visible on CT scans or MRI raises the question of thyroglossal duct carcinoma. Calcification is also associated with carcinoma.)

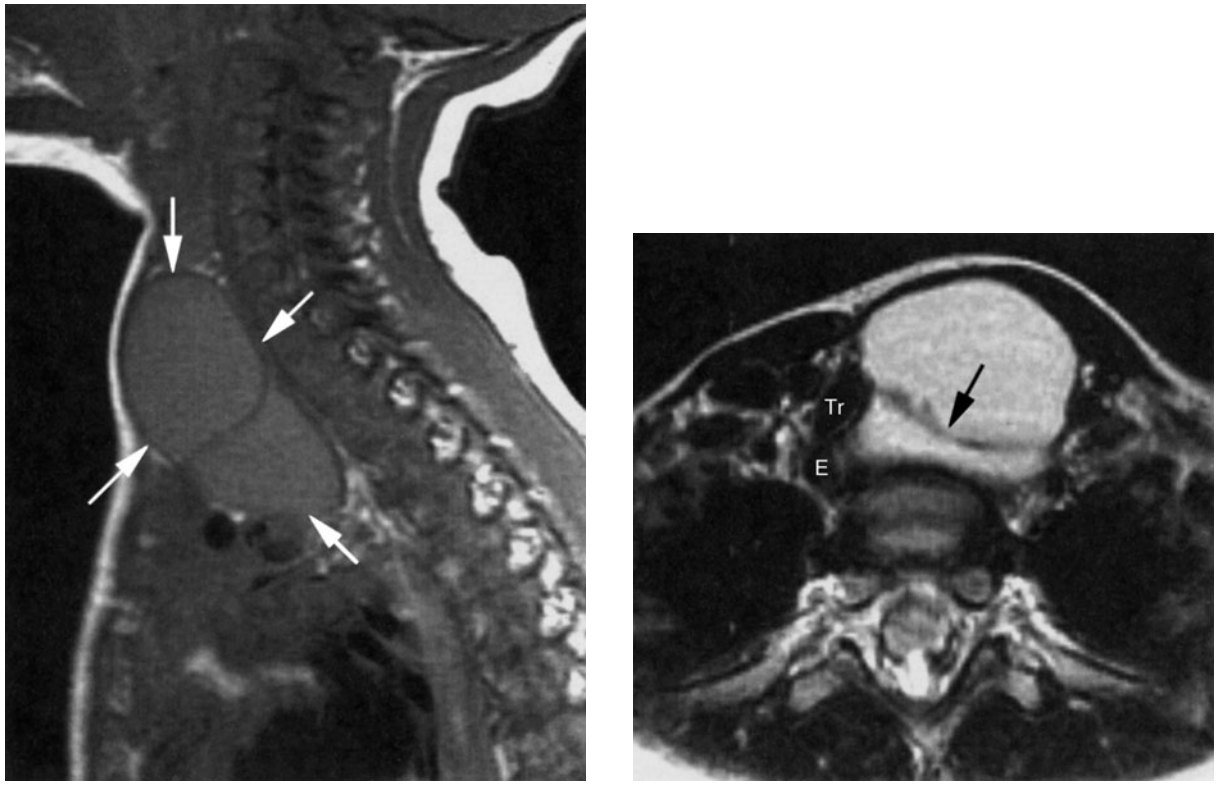
Koeller KK, Alamo L, Adair CF, Smirniotopoulos JG. Congenital cystic masses of the neck: radiologic-pathologic correlation. *Radiographics* 1999;19:121 [PMID: 9925396]. (Reviews the clinical and radiologic features of cervical congenital cystic masses.)

6. The Pediatric Neck

The imaging evaluation of the pediatric neck raises a limited differential diagnosis, which is heavily weighted toward congenital-developmental and infectious-inflammatory processes, but also includes a limited list of neoplastic or neoplasm-like considerations. A differential diagnosis of the more common pediatric neck masses is presented in Table 3–10. The appropriate imaging workup of neck masses depends on the category of disease. Infectious-inflammatory processes are typically evaluated with CT scanning, with MRI reserved to assess complications such as spinal epidural or intracranial extension. Congenital and neoplastic processes are most completely assessed with MRI, which may also provide more specificity regarding a particular diagnosis; however, a good-quality, thin-section, contrast-enhanced CT scan may also be adequate for many of these lesions. In general, a child under the age of 5 requires monitored anesthesia care or general anesthesia for CT scanning or MRI to obtain a high-quality study. Over the age of 5, many CT studies can be done without sedation, but most children are not able to cooperate with a more lengthy MRI study without sedation until at least age 8 or 10.

▶ Fibromatosis Colli

This benign disorder presents as torticollis or as a palpable neck mass in neonates and young infants. Because of its association with traumatic delivery, it is thought to be



▲ **Figure 3–94.** **(A)** Sagittal T1-weighted image of the neck in a 22-month-old boy with a gradually increasing neck mass demonstrates a well-circumscribed, bilobed mass that is slightly bright on the T1-weighted image and extends inferiorly into the superior mediastinum. **(B)** Axial fast spin-echo T2-weighted image with fat saturation shows that the mass is extremely bright and has a slightly irregular internal septation (black arrow). It displaces the trachea (Tr) and esophagus (E) to the right. The mild hyperintensity on T1-weighted image is likely due to elevated protein content of the cyst fluid. On a postgadolinium image (not shown) there was mild enhancement of the internal septation, but no other enhancement. A foregut cyst was diagnosed at surgery.

Table 3–10. Limited Differential Diagnosis for More Common Pediatric Neck Masses.

		Neoplastic	
Congenital/Developmental	**Infectious/Inflammatory**	***Benign or Neoplasm-like***	***Malignant***
Lymphatic malformation	Suppurative lymphadenopathy	Fibromatosis colli	Neuroblastoma
Venous malformation	Abscess	Neurofibroma	Rhabdomyosarcoma
Branchial cleft cyst		Hemangioma	Lymphoma
Thyroglossal duct cyst			
Epidermoid or dermoid			

related to perinatal muscle trauma with a fibroinflammatory response within the sternocleidomastoid muscle. Imaging features are nonspecific but characteristic. On ultrasound, the mass is fusiform, expanding the belly of the sternocleidomastoid muscle and tapering at the ends; it is noncalcified and varied in its echogenicity. On MRI, the mass is similarly fusiform and oriented along the course of the sternocleidomastoid muscle. It is intermediate in signal intensity on T1-weighted images and heterogeneous on T2-weighted images, and it demonstrates enhancement postgadolinium (Figure 3–95). The adjacent soft tissues are normal, and there is no associated lymphadenopathy. Its appearance is characteristic, but the clinical and imaging differential diagnosis of fibromatosis colli includes rhabdomyosarcoma.

Jaber MR, Goldsmith AJ. Sternocleidomastoid tumor of infancy: two cases of an interesting entity. *Int J Pediatr Otorhinolaryngol* 1999;47:269 [PMID: 10321783]. (Reviews the diagnostic modalities and treatment options for this entity.)

Koch BL. Imaging extracranial masses of the pediatric head and neck. *Neuroimaging Clin N Am* 2000;10:193 [PMID: 10658162]. (A thorough review that emphasizes the imaging characteristics of lesions by location: the orbit, the sinonasal cavity, the nasopharynx, the face and jaw, and the neck.)

PARANASAL SINUSES & NASAL CAVITY

Paranasal Sinuses

The paranasal sinuses and nasal cavity are well suited to assessment by thin-section (≤3 mm) coronal CT imaging, which clearly delineates the delicate bony anatomy of this region (Figure 3–96). The paired maxillary sinuses lie on either side of the nasal cavity, with the orbit above, the maxillary alveolus below, and the pterygopalatine fossa behind. Drainage is via the maxillary ostium into the infundibulum. The ethmoid sinus is a series of air cells, usually divided into anterior, middle, and posterior air cells, which are intimately related to the orbit laterally and the anterior cranial fossa superiorly. The roof of the ethmoid, also known as the fovea ethmoidalis, forms part of the floor of the anterior cranial fossa and lies just lateral and superior to the cribriform plate (the roof of the nasal cavity). Drainage of the anterior and middle ethmoid air cells is into the middle meatus, whereas the posterior ethmoid air cells drain via the sphenoethmoidal recess. The frontal sinuses abut the orbit inferiorly and the anterior cranial fossa posteriorly. They drain via the nasofrontal "duct" into the frontal recess of the middle meatus. The sphenoid sinuses arise from the body of the sphenoid bone and are intimately associated with the structures of the central skull base: the sella turcica above, the cavernous sinuses laterally, and the nasopharynx inferiorly. Drainage is via the sphenoethmoidal recess into the superior meatus (Figure 3–97).

Ostiomeatal Unit of the Nasal Cavity

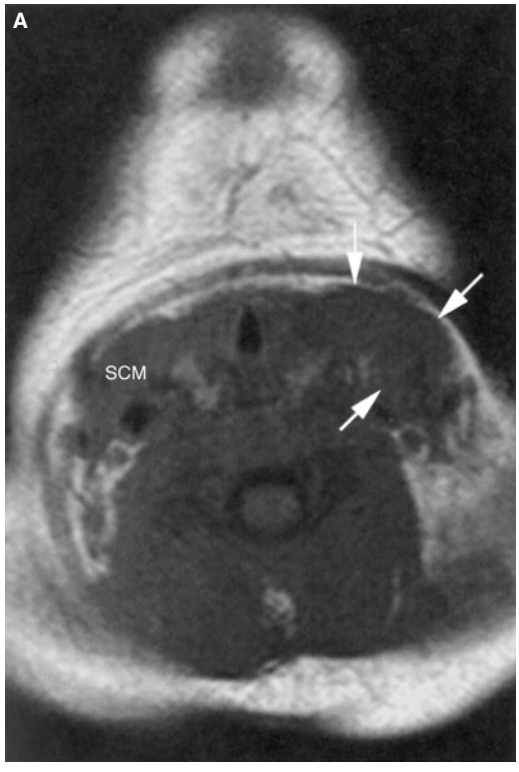
The lateral nasal wall is anatomically complex. The superior, middle, and inferior turbinates project from the lateral nasal wall, and each overlies its respective meatus (Figure 3–98). The inferior turbinate arises from the junction of the uncinate process and the medial wall of the maxillary sinus, and the inferior meatus lies medial to it. The ostium of the nasolacrimal duct opens into the inferior meatus. The middle turbinate has more complex attachments, with a superior attachment to the cribriform plate, a lateral attachment to the lamina papyracea, and a posterior attachment to the ethmoid crest of the palatine bone. The maxillary sinuses, anterior and middle ethmoid air cells, and frontal sinuses drain into the middle meatus. The superior turbinate attaches to the skull base superiorly (often merging with the attachment of the middle turbinate), the lamina papyracea laterally, and the inferior portion of the anterior wall of the sphenoid sinus posteriorly. The superior meatus receives drainage from the posterior ethmoid air cells.

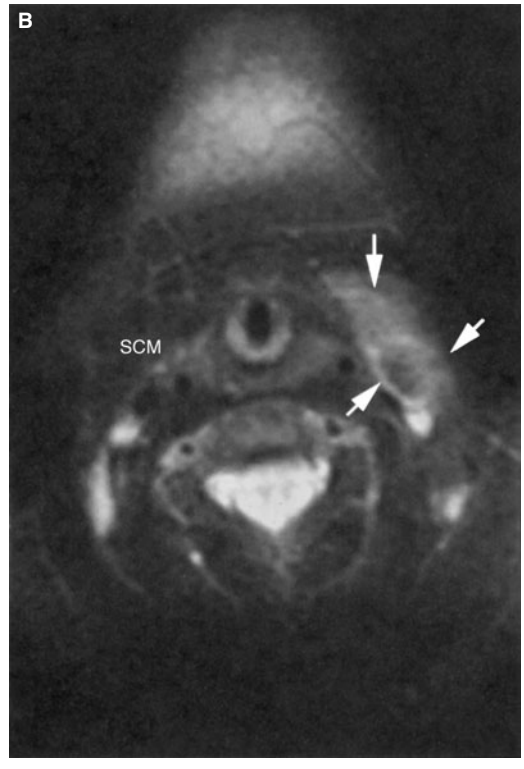
The ostiomeatal unit includes the maxillary ostium and the structures of the middle meatus, and defines the region into which the frontal, anterior, and middle ethmoid and maxillary sinuses drain. When the ostiomeatal unit is diseased, a characteristic pattern of obstructive sinus disease is present, with involvement of the aforementioned areas.

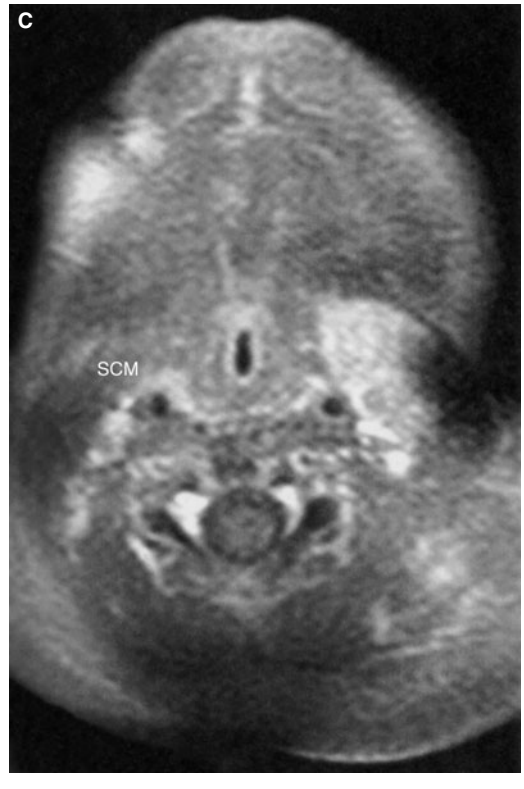
Important components of the ostiomeatal unit that are well visualized on coronal CT scans include the infundibulum, the uncinate process, and the ethmoid bulla (Figure 3–99). The infundibulum is a channel defined by the orbital wall laterally, the uncinate process medially, and the ethmoid bulla superiorly; it connects superomedially to the hiatus semilunaris and functions as the conduit for secretions from the maxillary and ethmoid sinuses. The uncinate process is the thin, hook-shaped bony process that forms the medial wall of the infundibulum. The ethmoid bulla receives drainage from the middle ethmoid air cells.

Anatomic Variations

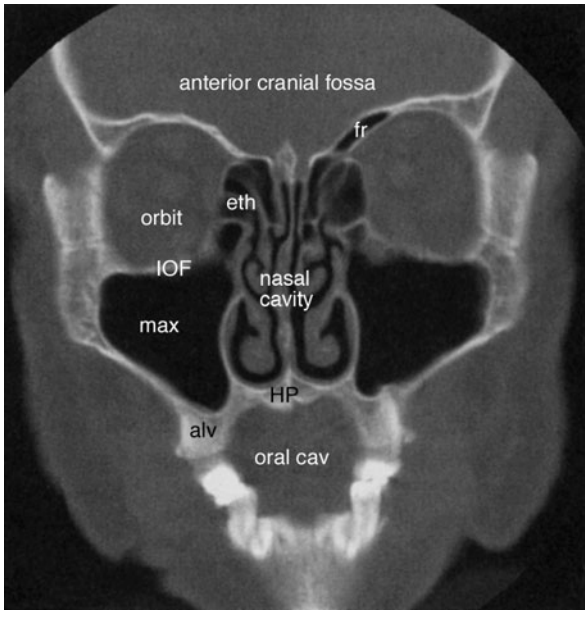
The concha bullosa or pneumatized middle turbinate is seen commonly on screening CT scans of the sinus (Figure 3–100). Usually an incidental finding, a large concha bullosa may encroach on the infundibulum or become primarily diseased with mucosal inflammation, polyps, or mucocele formation (Figure 3–101). The middle turbinate may be paradoxically curved and the uncinate process may deviate medially or laterally or may be pneumatized. Variations in ethmoid air cells are also common, notably the presence of infraorbital ethmoid air cells (so-called Haller cells, Figure 3–102) and agger nasi cells, which are extensions of anterior ethmoid air cells into the lacrimal bone.



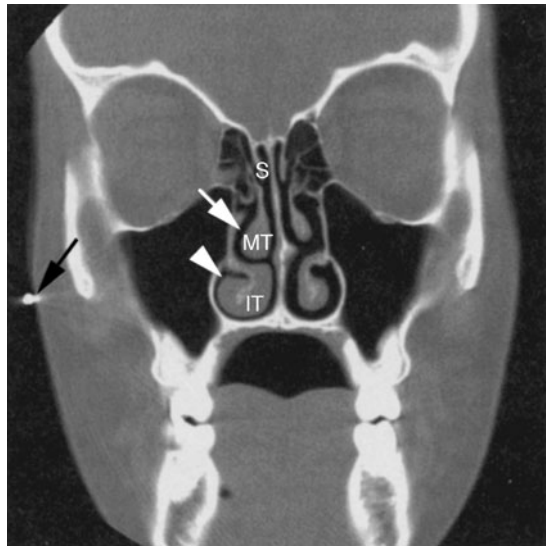




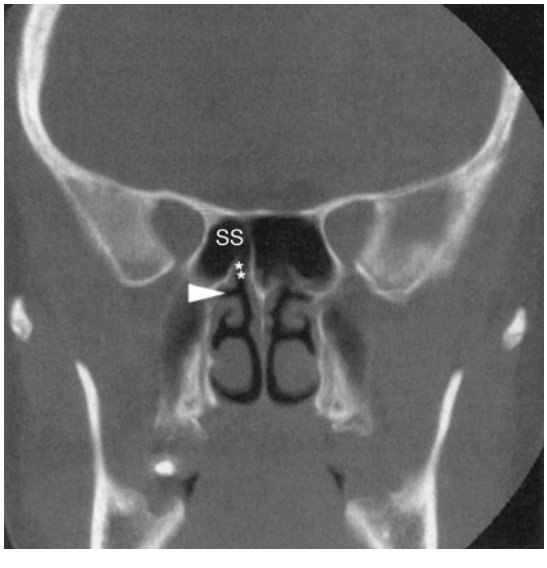
▲ **Figure 3–95.** **(A)** Axial T1-weighted image in a 2-week-old boy with torticollis and a left neck mass (arrows) demonstrates prominent soft tissue in the expected location of the sternocleidomastoid muscle. The right sternocleidomastoid muscle (SCM) is shown for comparison. **(B)** On an axial fast spin-echo T2-weighted image with fat saturation, the normal muscle is dark, whereas the left-sided mass (arrows) has areas of mixed high and low signal. **(C)** Postgadolinium, an axial T1-weighted image with fat saturation demonstrates the diffuse enhancement of the mass, whose location and morphology paralleled that of the sternocleidomastoid muscle on every image. These imaging features are consistent with fibromatosis colli, though rhabdomyosarcoma must be considered in the differential diagnosis.



▲ **Figure 3–96.** Coronal CT scan through the paranasal sinuses viewed in bone window demonstrates the anatomic relationships of the anterior paranasal sinuses. Indicated are the maxillary (max), ethmoid (eth), and frontal (fr) sinuses, as well as the maxillary alveolus (alv), hard palate (HP), and infraorbital foramen (IOF), which transmits the infraorbital nerve, a branch of V2.



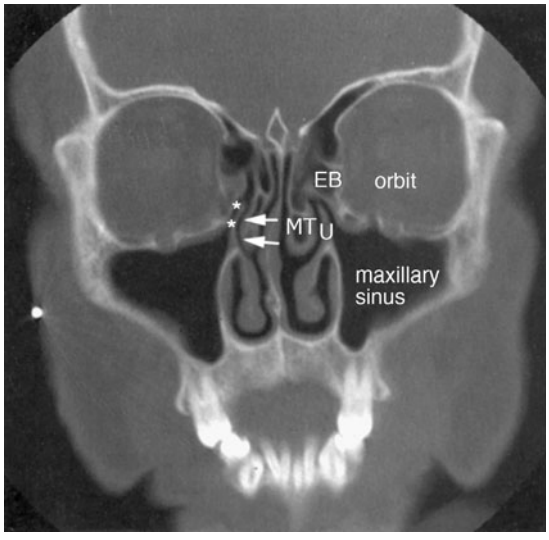
▲ **Figure 3–98.** Coronal CT scan through the paranasal sinuses viewed in bone window demonstrates the inferior (IT), middle (MT), and superior (S) turbinates projecting from the lateral nasal wall. Also indicated are the middle meatus (white arrow) and inferior meatus (white arrowhead). The black arrow points to a metallic ball bearing, which has been affixed to the skin of the patient's right cheek so that there is no confusion of right and left, a not uncommon problem with sinus CT scans.



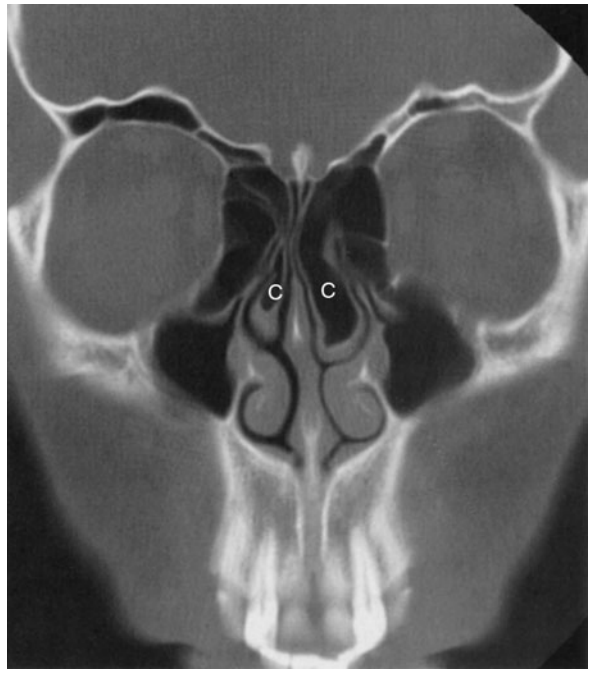
▲ **Figure 3–97.** Coronal CT scan through the sphenoid sinuses (SS) viewed in bone window demonstrates the sphenoethmoidal recess (*) and the superior meatus (arrowhead).

Anatomic Relationships

The nasal cavity is closely related to the pterygopalatine fossa, and these anatomic relationships are well delineated on cross-sectional imaging studies. Because the pterygopalatine fossa has connections to multiple deep facial and intracranial spaces (Figure 3–103), infection and neoplasm originating in the sinonasal cavity not uncommonly extend via this pathway. The nasal cavity connects with the pterygopalatine fossa via the sphenopalatine foramen, which is found on the high posterolateral nasal wall. Medially, therefore, the pterygopalatine fossa connects to the nasal cavity via the sphenopalatine foramen. The pterygopalatine fossa is bounded anteriorly by the posterior wall of the maxillary sinus; anterosuperiorly, however, the pterygopalatine fossa connects to the orbit via the inferior orbital fissure. The pterygopalatine fossa communicates laterally with the masticator space via the pterygomaxillary fissure. Posteriorly, there are two important connections to the skull base and the cranial vault: the pterygopalatine fossa connects posteroinferiorly to the region of the foramen lacerum and the carotid canal via the vidian canal, while posterosuperiorly, it connects to the cavernous sinus and the middle cranial fossa via the foramen rotundum. The pterygopalatine fossa



▲ **Figure 3–99.** Coronal CT scan through the paranasal sinuses viewed in bone window demonstrates the anatomy of the ostiomeatal unit. Indicated on the patient's left are the uncinate process (U), ethmoid bulla (EB), and middle turbinate (MT; note that it is partially pneumatized, consistent with concha bullosa). On the patient's right, the infundibulum (*) and middle meatus (arrows) are indicated.



▲ **Figure 3–100.** Coronal CT scan through the paranasal sinuses viewed in bone window demonstrates pneumatization of the middle turbinates bilaterally, consistent with bilateral concha bullosa (C).

connects inferiorly to the palate and oral cavity via the palatine foramina.

Pathology

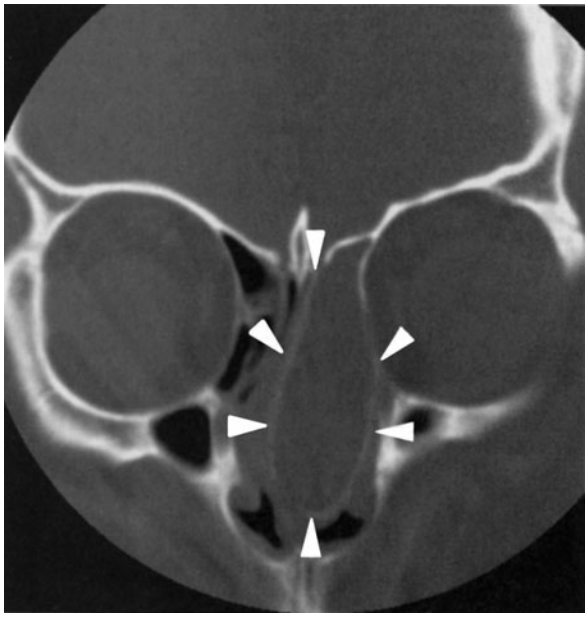
The paranasal sinuses and nasal cavity may be affected by a wide variety of pathologic processes, including congenital-developmental processes, inflammatory mucosal disease, and neoplasms.

A. Congenital and Developmental Disorders

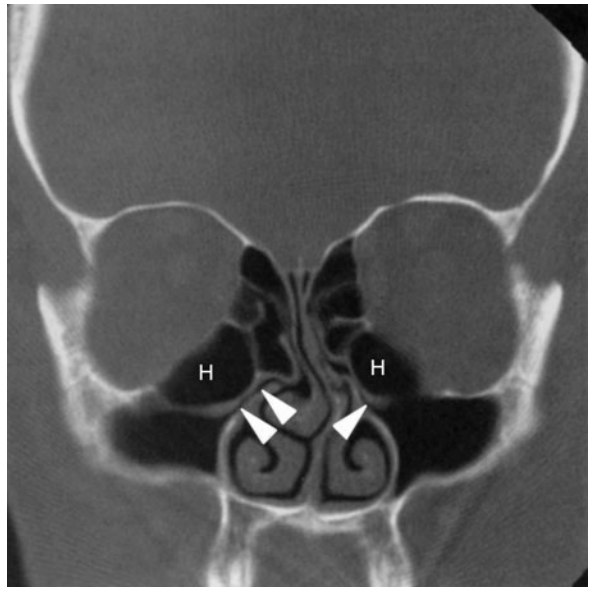
The embryology of the sinonasal region is complex, and maldevelopment may lead to nasal gliomas, dermoids, sinus tracts, and cephaloceles. It is critical that a cephalocele be recognized before a surgical procedure is undertaken in order to avoid unexpected penetration of the central nervous system. In this circumstance, CT scanning and MRI often play complementary roles. CT scans show the skull base defect and may suggest the possibility of cephalocele, but MRI helps to assess exactly which tissues have herniated through the skull base defect (Figure 3–104). Congenital abnormalities of the nasal cavity such as choanal atresia (Figure 3–105) and pyriform aperture stenosis (Figure 3–106) are well assessed with CT scanning, which should be performed with very thin sections (1–2 mm). In the setting of choanal atresia, the temporal bones, which typically are included on the same scan, should be carefully assessed for anomalies that would help to support a diagnosis of the CHARGE syndrome (ocular **c**oloboma, **h**eart defects, **a**tretic choanae, **r**etarded growth or development, **g**enital hypoplasia, and **e**ar anomalies or hearing loss). Deformations of the ossicles or aplasia of the semicircular canals, as well as other inner ear and temporal bone anomalies, are often seen in the setting of CHARGE.

B. Inflammatory Disease

Smooth or lobulated thickening of sinus mucosa is commonly seen on imaging studies of the brain, head, and neck. Air-fluid levels may be due to an acute bacterial sinusitis, but they are also seen commonly in the setting of sinus obstruction, such as from a nasogastric or endotracheal tube, notably in the ICU setting (Figure 3–107). With chronic sinusitis, there is often thickening of the bony walls of the sinus as well as mucosal thickening (so-called "mucoperiosteal" thickening or reaction). The pattern of inflammatory sinus disease provides insight into the level of blockage of the normal routes of mucociliary drainage, and the ostiomeatal unit and sphenoethmoidal recess should be assessed on all



▲ **Figure 3–101.** Coronal CT scan through the paranasal sinuses viewed in bone window in a patient with left nasal obstruction demonstrates an ovoid, well-circumscribed mass with a thin peripheral shell of bone (arrowheads). Note the superior attachment to the cribriform plate and the superolateral attachment to the lateral orbital wall. Surgery confirmed a mucocele arising in a pneumatized middle turbinate.



▲ **Figure 3–102.** Coronal CT scan through the paranasal sinuses viewed in bone window in a patient with large bilateral Haller cells (H). The infundibula (arrowheads) are indicated.

coronal sinus CT scans. If the ostiomeatal unit is obstructed, then inflammatory changes in the ipsilateral maxillary sinus, the anterior and middle ethmoid air cells, and the frontal sinus, as well as opacification of the middle meatus, are expected (Figure 3–108). When obstruction is at the level of the sphenoethmoidal recess, then inflammatory changes in the ipsilateral sphenoid sinus and, to a lesser degree, the posterior ethmoid air cells are expected.

C. Mucous Retention Cysts and Polyps

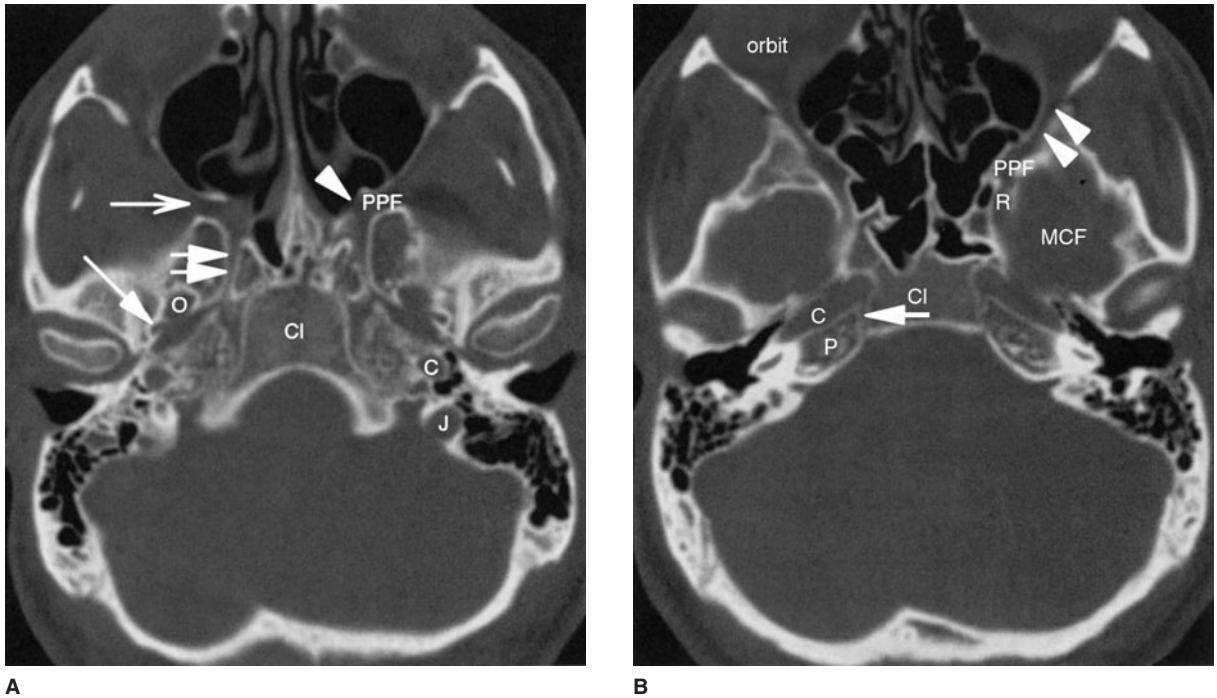
Mucous retention cysts and polyps are very common and often indistinguishable on imaging studies, appearing as lobulated masses of low-to-intermediate density on CT scans. On MRI, they are intermediate in signal on T1-weighted images and bright on T2-weighted images, and show a variable enhancement that is typically peripheral (Figure 3–109) if present at all.

D. Mucoceles

A mucocele results from the obstruction of a sinus ostium, leading to the accumulation of proteinaceous secretions and the gradual, smooth expansion of the sinus (Figure 3–110). The mucocele contents often become increasingly desiccated and have an increasing protein content over time; therefore, they may show an increased density on CT scanning and variable degrees of hyperintensity on T1-weighted MRI sequences and hypointensity on T2-weighted MRI (Figure 3–111). If sinus contents show marked hypointensity on T2-weighted images, then fungal infection should be considered in the appropriate clinical setting. Thin, linear enhancement may be seen around the margin of the expanded sinus under normal circumstances, but if there is marked enhancement, then a mucopyocele should be considered.

E. Sinonasal Polyposis

Sinonasal polyposis refers to the presence of multiple polyps in the sinuses and nasal cavities, often with accompanying mucosal thickening and mucocele formation. On imaging studies, the extensive soft tissue abnormalities and bone erosion and remodeling that often accompany sinonasal polyposis may mimic an aggressive neoplastic process (Figure 3–112). These patients are also often colonized by fungal forms and may have allergic fungal sinusitis (see below). The diffuse nature of the process and the lack of any focal or dominant destructive mass suggest polyposis and not a malignant tumor. Other non-neoplastic lesions that may lead to significant sinonasal bone destruction and



A B

▲ **Figure 3–103.** Axial thin-section CT scans through the skull base viewed in bone window illustrate the skull base anatomy and the interconnections of the pterygopalatine fossa. **(A)** Indicated are the pterygopalatine fossa (PPF), sphenopalatine foramen (white arrowhead), pterygomaxillary fissure (concave white arrow), vidian canal (double short white arrows), foramen ovale (O), foramen spinosum (long single white arrow), clivus (Cl), carotid canal (C), and jugular foramen (J). **(B)** At a slightly more superior level, foramen rotundum (R) is seen connecting the middle cranial fossa (MCF) to the pterygopalatine fossa at the level of the inferior orbital fissure (arrowheads). Also indicated are the petrous bone (P) and the petroclival fissure (white arrow).

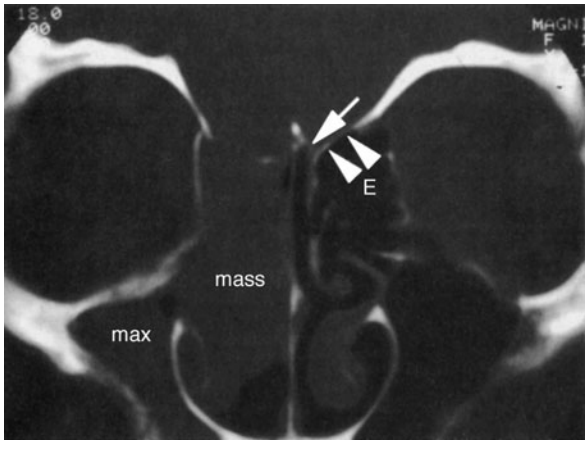
soft tissue abnormalities include Wegener granulomatosis (Figure 3–113) and invasive fungal infections such as aspergillus and mucormycosis.

F. Complications of Sinusitis

Imaging studies may be ordered to assess the complications of sinusitis. These may be local, such as orbital cellulitis, orbital abscess, or osteomyelitis of the sinus wall, or they may involve intracranial extension. Intracranial complications include epidural abscess, subdural empyema, meningitis, brain abscess (Figure 3–114), and cavernous sinus thrombosis. In most cases, intracranial complications are more completely assessed with MRI than with CT scanning.

G. Fungal Sinusitis

Fungal sinusitis can be classified into invasive and noninvasive forms, with the invasive forms usually affecting immune compromised hosts and the noninvasive forms affecting either immune-compromised or immune-competent hosts. *Aspergillus* species are most commonly isolated, but many fungal species have been implicated. Invasive forms include acute or fulminant fungal sinusitis, granulomatous invasive fungal sinusitis, and chronic invasive fungal sinusitis. Acute fungal sinusitis is characterized by extensive tissue destruction and necrosis (Figure 3–115). Tissue enhancement may be scant or absent due to the angioinvasive nature of the infection. Chronic invasive disease is also characterized by tissue destruction, but the course is far more indolent than the acute form (Figure 3–116). Orbital apex syndrome due to intraorbital extension from the ethmoid sinuses is a common association of chronic invasive disease. Noninvasive forms of fungal sinusitis include mycetoma and allergic fungal sinusitis. Mycetoma is usually seen as a mass lesion in the maxillary sinus, often in association with chronic mucosal thickening and polyps, and the mass is typically dense or even grossly calcified on a noncontrast CT scan. Mycetomas may also occur in the nasal cavity (Figure 3–117A). Allergic fungal sinusitis involves multiple sinuses, shows extensive mucosal thickening (often with complete opacification), expansion, and remodeling of



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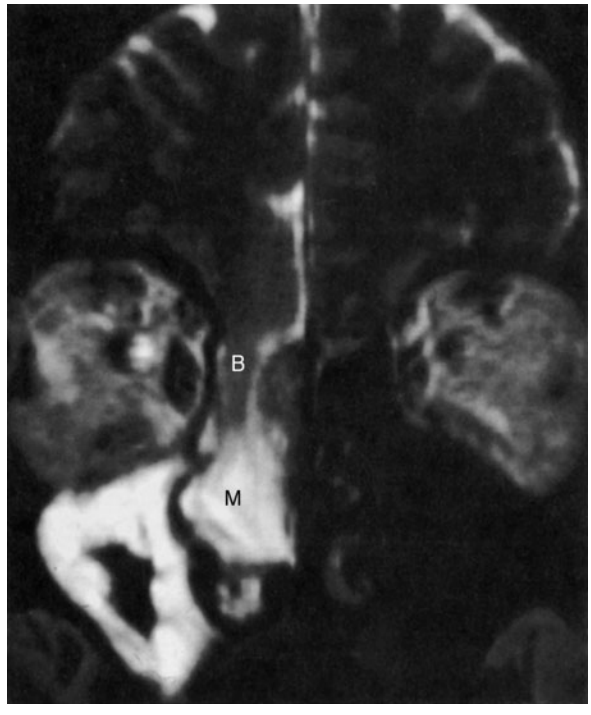


B

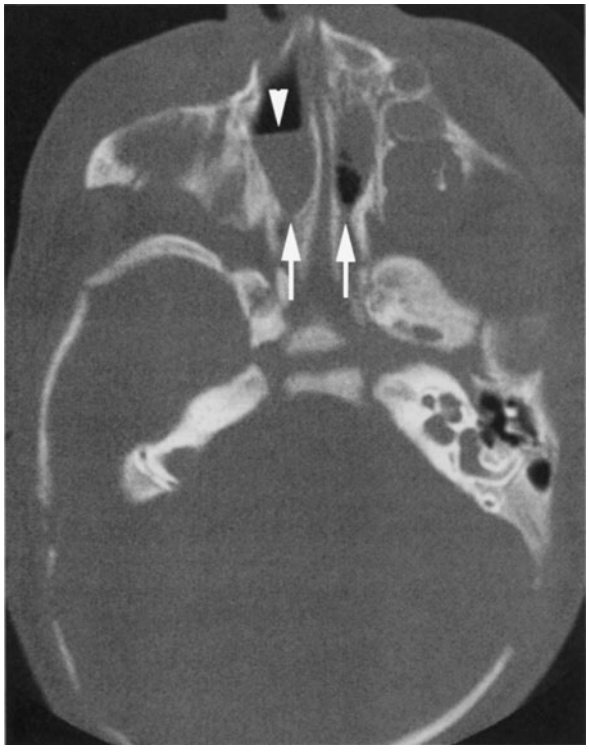
▲ **Figure 3–104. (A)** Coronal CT scan through the paranasal sinuses viewed in bone window in a 30-year-old woman with chronic right nasal obstruction demonstrates a large soft tissue mass in the right nasal cavity. Opacification of the right maxillary sinus (max) is presumably due to outlet obstruction with the accumulation of mucoid secretions. Note that the right bony ethmoid roof is largely absent. The left cribriform plate (arrow) and ethmoid roof (arrowheads) are shown for comparison. It is unclear from the CT scan whether the mass has originated in the nasal cavity and extended up or if the mass has originated intracranially and extended down. MRI is indicated for further evaluation prior to any biopsy. **(B)** Coronal fast spin-echo T2-weighted image with fat saturation demonstrates inferior herniation of brain tissue (B) and a CSF-filled meningocele sac (M) through the skull base defect. This patient's previously unrecognized meningoencephalocele was subsequently repaired.

the sinuses, and also demonstrates increased intrasinus attenuation on CT; its imaging appearance is characteristic (Figure 3–117B).

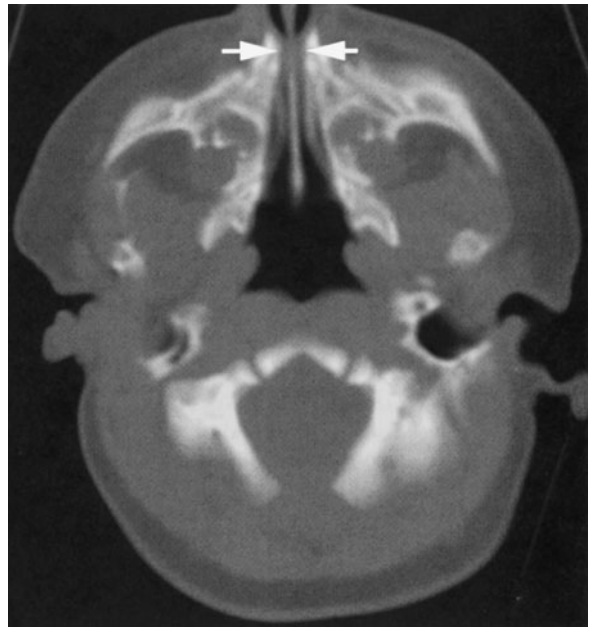
H. Neoplasms

Benign and malignant neoplasms may occur in the nasal cavity and paranasal sinuses. Benign lesions tend to slowly enlarge and therefore remodel bone rather than destroy it. Malignant processes are more likely to show frank bone erosion and destruction, as well as infiltration of adjacent tissues, evidence of perineural spread, or evidence of regional metastases. On MRI, a T2-weighted sequence is particularly helpful in separating an intermediate signal intensity tumor from the high signal of edematous mucosa or mucoid secretions; this sequence often best characterizes the full extent of disease within the nasal cavity and paranasal sinuses. MRI is also very useful for the accurate assessment of orbital or intracranial extension of aggressive sinonasal lesions, as well as perineural spread of disease.

1. Inverting papilloma—Inverting papillomas are the most common benign tumors of the nose and paranasal sinuses, and usually arise in the lateral wall of the nasal cavity and the middle meatus. CT scanning typically shows a mass extending from the middle meatus into the adjacent maxillary antrum through a widened maxillary ostium (Figure 3–118). Areas of calcification may be seen within the mass, and the surface of the lesion is typically lobulated. The appearance is nonspecific on MRI, but an inverting papilloma is typically intermediate in signal intensity on both T1- and T2-weighted images, and homogeneously enhances postgadolinium. A convoluted "cerebriform" or "gyriform" pattern



▲ **Figure 3–105.** Axial CT scan through the nasal cavity viewed in bone window in a neonate with difficulty feeding and nasal obstruction demonstrates severe bony stenosis (arrows) and presumed membranous atresia of the posterior choana bilaterally. An air-fluid level (arrowhead) is seen in the right nasal cavity. The visualized temporal bone is normal.

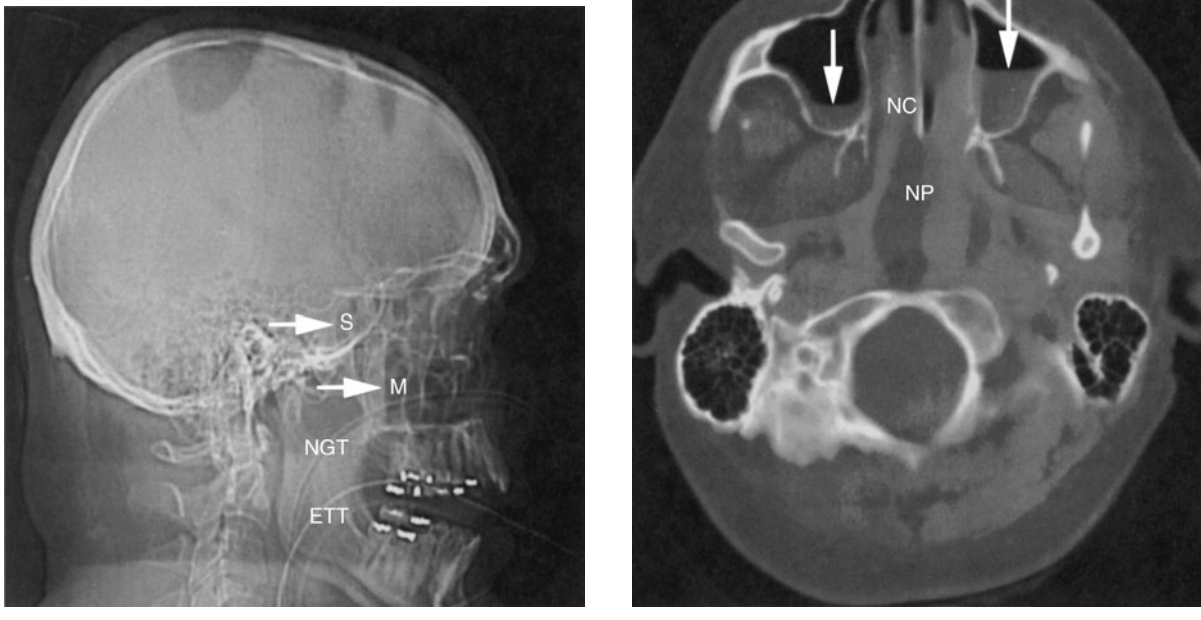


▲ **Figure 3–106.** Axial CT scan through the nasal cavity photographed in bone window in a 4-year-old boy with facial dysmorphism and respiratory difficulty demonstrates tapered narrowing of the anterior nasal cavities bilaterally (white arrows), consistent with pyriform aperture stenosis. A more inferior image (not shown) demonstrated a centrally located mega-incisor, as is often seen in conjunction with pyriform aperture stenosis. This constellation of findings has been associated with holoprosencephaly, which was not present in this case.

on T2-weighted or gadolinium-enhanced T1-weighted images may suggest an inverting papilloma. MRI is also helpful in showing the full extent of disease, especially at the skull base, as the tumor can be more clearly delineated from adjacent mucosal thickening and inflammatory secretions on MRI than on CT scanning.

2. Juvenile angiofibroma—These benign tumors generally arise on the posterolateral wall of the nasal cavity, at the level of the sphenopalatine foramen, and tend to extend early into the pterygopalatine fossa. Juvenile angiofibromas (previously known as juvenile nasal angiofibromas) are often large at the time of presentation and may extend into the nasopharynx, the sphenoid and ethmoid sinuses, and the middle cranial fossa. On CT scans, this tumor is multilobulated and enhances intensely following contrast injection. It tends to show bone remodeling rather than aggressive destruction, but the tumor may directly invade bone. On MRI, prominent flow voids are characteristic of these lesions, which may also be somewhat heterogeneous due to cyst formation and areas of hemorrhage (Figure 3–119). At catheter angiography these lesions are highly vascular, and preoperative embolization is an important intervention to minimize operative blood loss, increase the likelihood of total resection, and reduce surgical complications.

3. Squamous cell carcinoma—SCC of the sinonasal cavity most commonly arises in the maxillary sinus and tends to present when far advanced as early symptoms are often attributed to inflammatory sinus disease. Both CT scanning and MRI show a unilateral mass with aggressive bone destruction and irregular margins with adjacent soft tissue (Figure 3–120). If the disease has broken through the back wall of the maxillary sinus into the pterygopalatine fossa, then orbital and intracranial extension should be carefully sought. As with all neoplasms of the sinonasal cavity, T2-weighted images are particularly helpful for distinguishing tumor from inflamed mucosa.

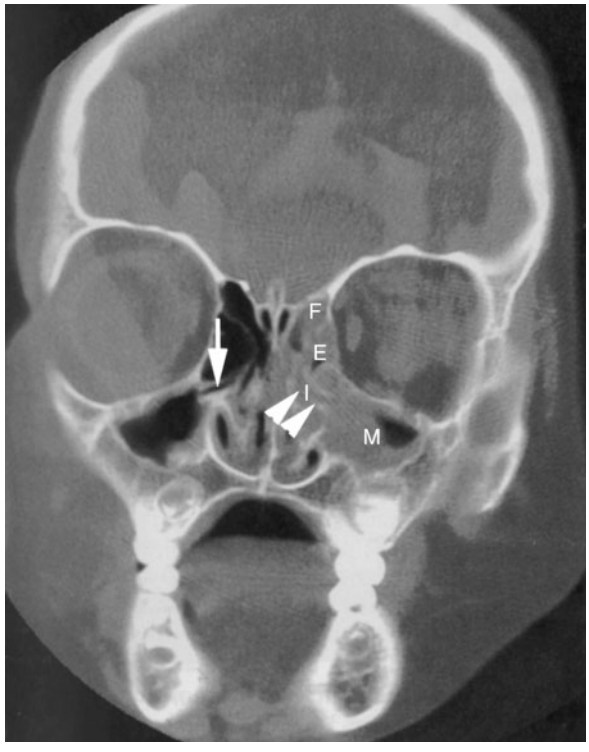


▲ **Figure 3–107. (A)** Lateral scout digital radiograph of an ICU patient with an endotracheal tube (ETT) and nasogastric tube (NGT) suggests air-fluid levels (arrows) in the sphenoid (S) and maxillary (M) sinuses. **(B)** Axial CT scan through the paranasal sinuses photographed in bone window demonstrates bilateral maxillary sinus air-fluid levels (arrows) as well as soft tissue, fluid, or both opacifying the nasal cavity (NC) and nasopharyngeal airway (NP).

4. Esthesioneuroblastoma—Esthesioneuroblastomas arise from the olfactory epithelium, which is located in the high nasal vault (olfactory recess) and upper nasal septum. This site of origin is intimately associated with the cribriform plate, and esthesioneuroblastomas have a high incidence of intracranial extension (Figure 3–121). Although this site of origin is highly suggestive of esthesioneuroblastoma, the imaging appearance is nonspecific and the diagnosis must be confirmed histologically. Peripheral cysts along the intracranial margin of a sinonasal mass have been noted, however, to be highly suggestive of esthesioneuroblastoma. Because there is a significant incidence of neck metastases even at the time of presentation, the neck should be scanned in these patients to assess for metastatic cervical lymphadenopathy.

5. Mucosal melanoma—Malignant melanoma arising from the mucosa of the nasal cavity and paranasal sinuses is rare, but should be considered in an older patient presenting with unilateral nasal obstruction, particularly with a history of epistaxis. The imaging findings may be nonspecific, but if the lesion contains melanin or there has been prior hemorrhage within the lesion, then it may appear focally or diffusely bright on a T1-weighted image (Figure 3–122). Mucosal melanomas are variable in signal intensity on T2-weighted images and show enhancement postgadolinium; both of these features are nonspecific. The metastatic workup of these patients is particularly important, as lymph node and distant metastases are common even at initial presentation. Perineural spread of disease is also common.

6. Non-Hodgkin lymphoma—Primary non-Hodgkin lymphoma of the sinonasal cavity has a variable and nonspecific appearance, but should be considered high among differential possibilities when the abnormal soft tissue involving the nasal cavity, the paranasal sinuses, or both is diffuse and infiltrative, often involving multiple locations rather than presenting as a dominant mass lesion (Figure 3–123). The infiltration of adjacent fat (ie, premalar, retroantral, or within the pterygopalatine fossa) is common, as is a permeative rather than grossly destructive pattern of bony involvement. Lymphomas are typically of low-to-intermediate signal intensity on T2-weighted images owing to a high nuclear-to-cytoplasmic ratio. This is, however, a nonspecific finding because many paranasal sinus tumors are intermediate in signal intensity on T2-weighted images. When a lymphoma simply presents as a mass lesion, it cannot be confidently



▲ **Figure 3–108.** Coronal CT scan through the nasal cavity and paranasal sinuses photographed in bone window in a young boy with chronic sinusitis demonstrates thickened mucosa in the infundibulum (I, arrowheads) and middle meatus, with mucosal thickening in the maxillary (M), ethmoid (E), and frontal (F) sinuses. This is consistent with an ostiomeatal unit pattern of disease. The contralateral normal infundibulum (arrow) is indicated just below the ethmoid bulla.

distinguished from many other sinonasal pathologies without tissue sampling. Lymphomas of T-cell origin predominate in the nasal cavity, whereas those of B-cell origin predominate in the paranasal sinuses. Nasal natural killer (NK)/T-cell lymphoma should be specifically considered when there is diffuse involvement of the nasal cavity, often accompanied by necrosis and midline destruction. Recall that the differential diagnosis of midfacial destruction includes Wegener granulomatosis, sarcoidosis, cocaine abuse, and infection (eg, syphilis, tuberculosis, leprosy, and fungus), as well as NK/T-cell lymphoma.

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Fatterpekar G, Mukherji S, Arbealez A, Maheshwari S, Castillo M. Fungal diseases of the paranasal sinuses. *Semin Ultrasound CT MR* 1999;20:391 [PMID: 10634589]. (Reviews the various types of fungal sinusitis with emphasis on the CT and MR imaging features.)

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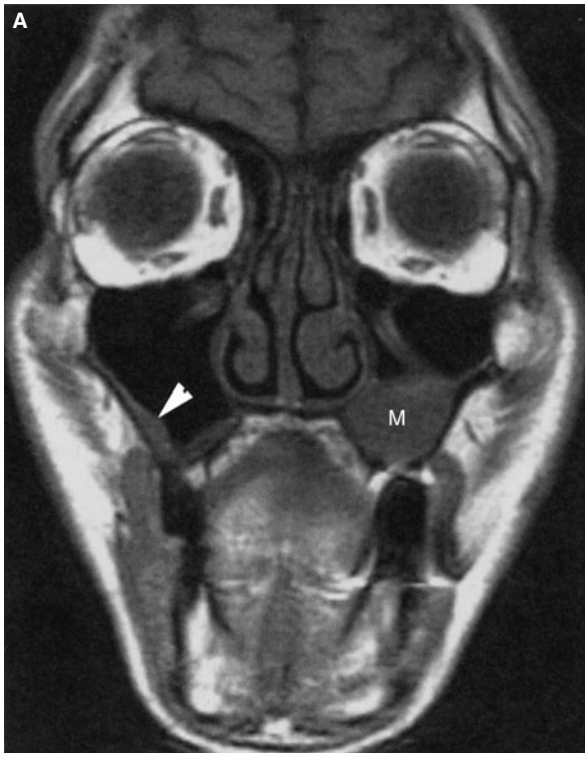
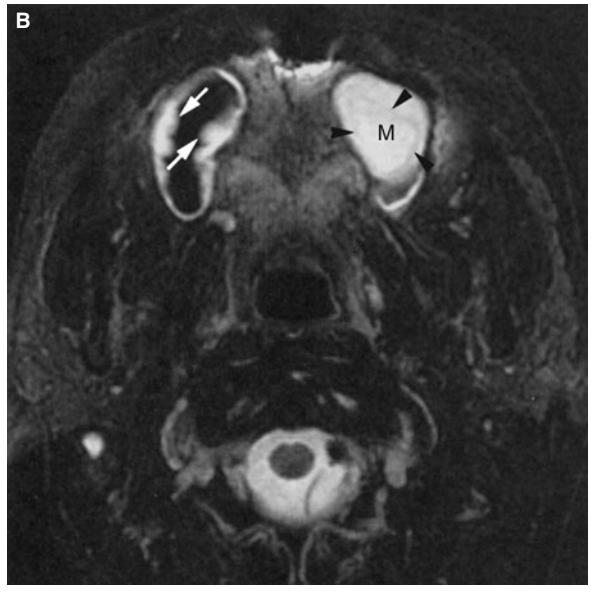
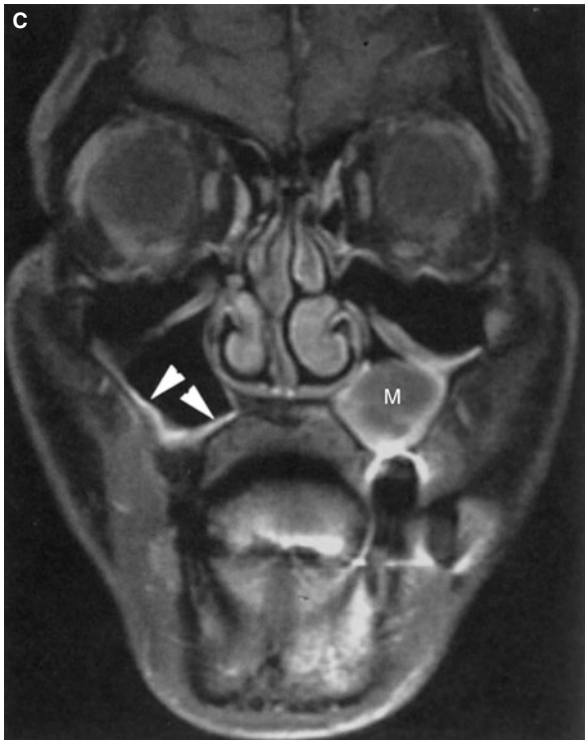
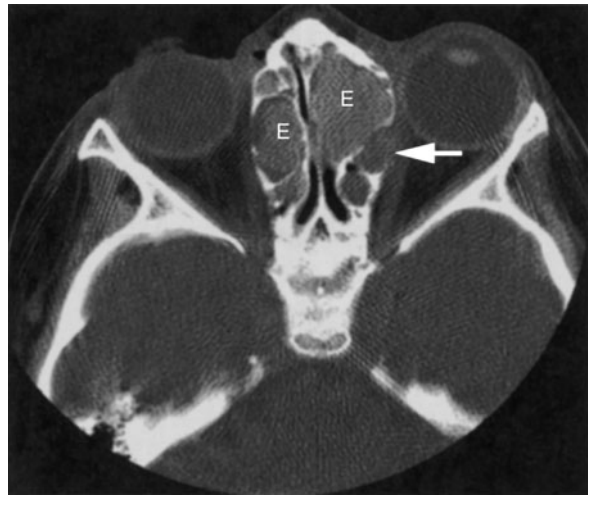
Yousem DM, Li C, Montone KT et al. Primary malignant melanoma of the sinonasal cavity: MR imaging evaluation. *Radiographics* 1996;16:1101 [PMID: 8888393]. (The signal intensity of sinonasal melanoma varies according to the histopathologic components of the tumor, with a high signal intensity within the lesion on T1-weighted images suggesting the presence of melanin.)



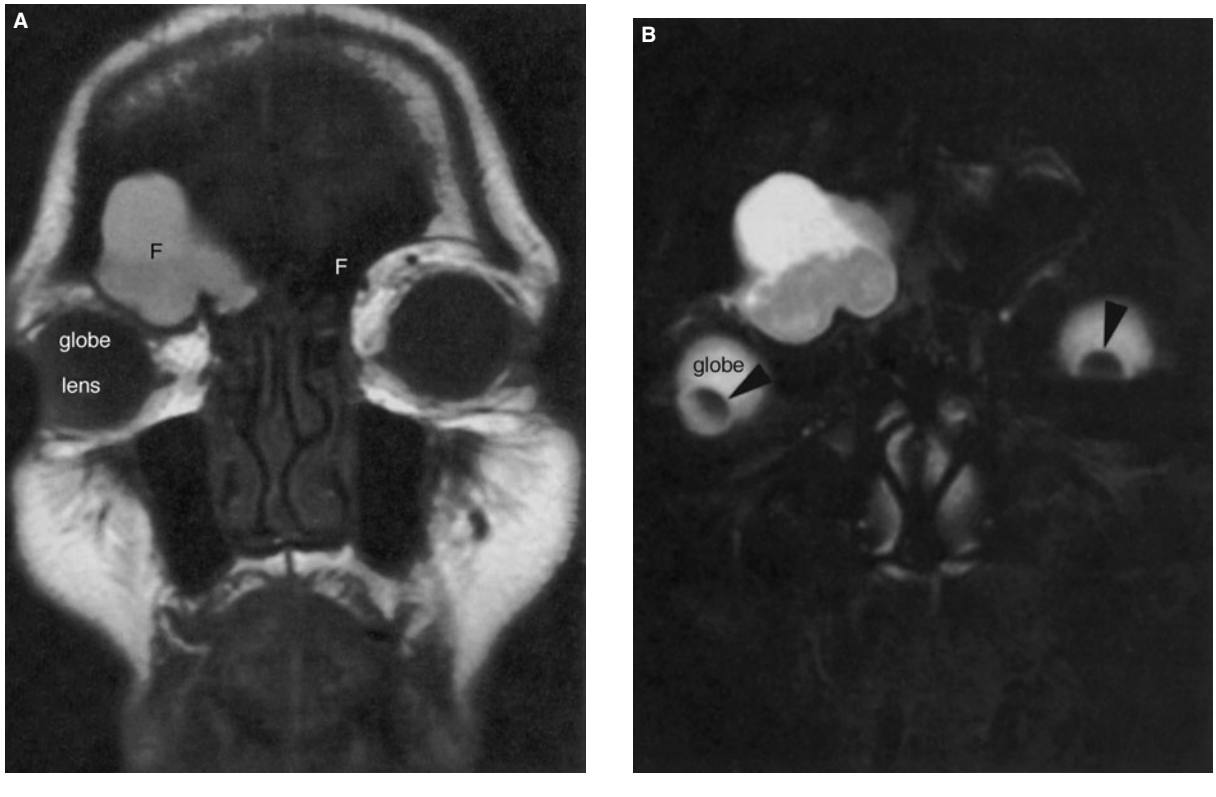




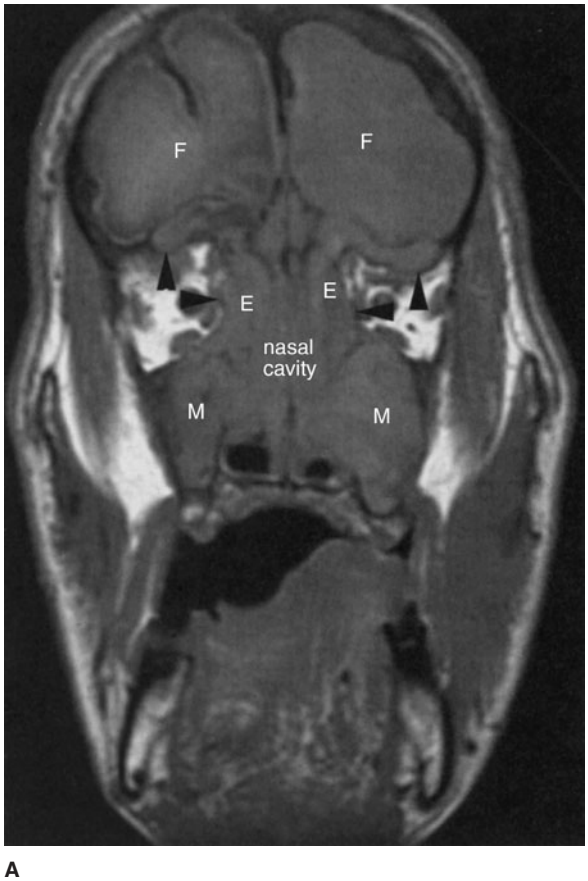
▲ **Figure 3–109. (A)** Coronal Tl-weighted image of the paranasal sinuses demonstrates a lobulated soft tissue mass (M) in the inferior aspect of the left maxillary sinus, as well as mild mucosal thickening in the right maxillary sinus (arrowhead). **(B)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates a very bright mass (M) with a slightly darker rim (black arrowheads) and surrounding hyperintense material representing thickened mucosa, mucoid secretions, or both. Contra-lateral mild lobulated mucosal thickening is also seen (white arrows). **(C)** Postgadolinium, a coronal Tl-weighted image with fat saturation shows that the mass (M) does not enhance, though there is enhancement of the adjacent mucosa, as is also seen contralaterally (white arrowheads). This mass is typical of a polyp or mucous retention cyst.



▲ **Figure 3–110.** Axial noncontrast CT scan (intermediate window) of the paranasal sinuses in a 2-year-old girl with cystic fibrosis demonstrates the expansion of multiple ethmoid air cells (E) and the absence of the bony margin of one of the air cells (arrow). The material within the air cells is mildly hyperdense, consistent with inspissation and increased protein content. Findings are consistent with multiple ethmoid mucoceles.



▲ **Figure 3–111.** **(A)** Coronal T1-weighted image in an older woman with gradually progressive proptosis and double vision demonstrates smooth expansion of the right frontal sinus (black F), which encroaches on the orbit and displaces the right globe inferolaterally. The right frontal sinus is filled with hyperintense material consistent with desiccated, proteinaceous secretions. The normal aerated left frontal sinus (white F) is shown for comparison. **(B)** On a coronal fast spin-echo T2-weighted image with fat saturation, the sinus contents have variable signal intensity owing to differences in actual protein content. Findings are typical of a frontal sinus mucocele. The globes and lenses are seen to be asymmetrically positioned due to the mass effect of the expanded sinus (arrowheads).



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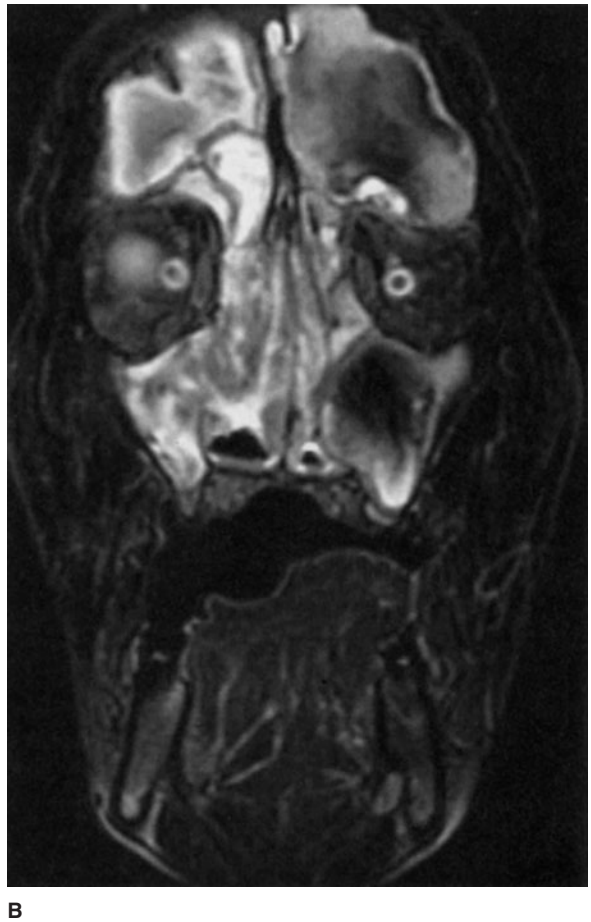

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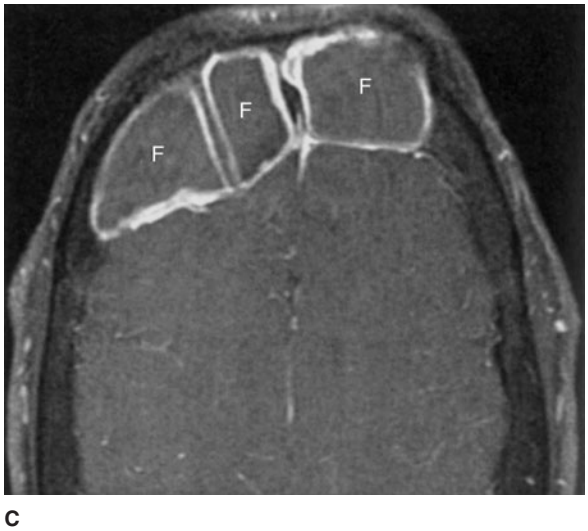
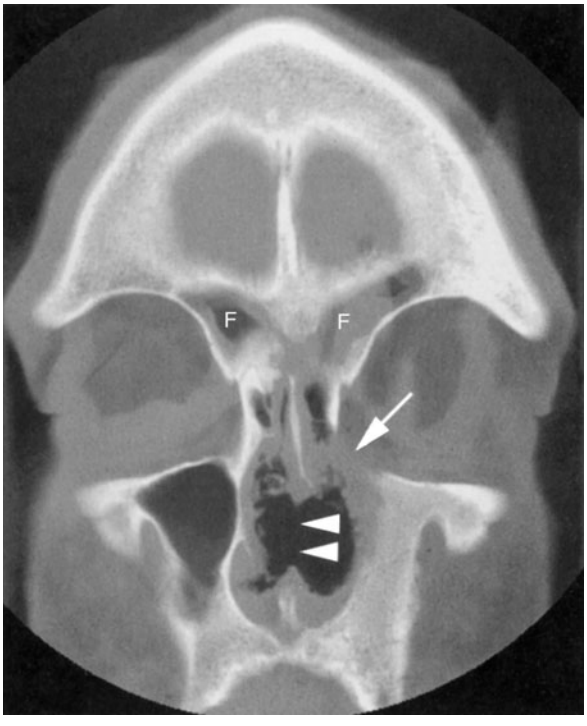
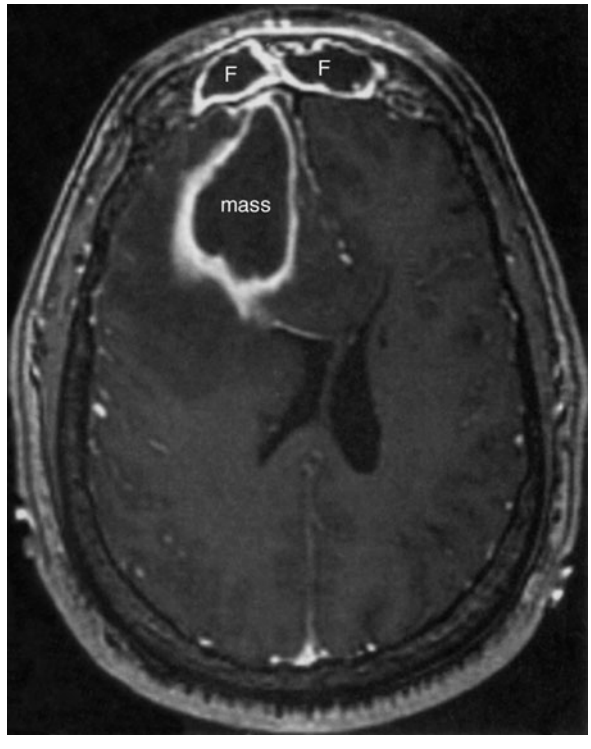


C

▲ **Figure 3–112.** A 55-year-old mentally challenged man with chronic sinus congestion. **(A)** Coronal T1-weighted image demonstrates diffuse abnormal soft tissue filling the nasal cavity and paranasal sinuses (F, frontal; E, ethmoid; M, maxillary). The material within the paranasal sinuses is of a mixed signal intensity due to variable protein content. Note the remodeling of the orbital roofs and medial orbital walls (black arrowheads) due to mucocele formation and sinus expansion. **(B)** On a coronal fast spin-echo T2-weighted image with fat saturation, the heterogeneous signal intensity of the thickened mucosa and proteinaceous secretions can be well appreciated. **(C)** Postgadolinium, an axial T1-weighted image with fat saturation demonstrates enhancement around the periphery of the markedly expanded frontal sinuses (F), but no enhancement of the centrally located mucoid material. These findings are typical of severe sinonasal polyposis and mucocele formation.



▲ **Figure 3–113.** Coronal CT scan of the sinuses viewed in bone window in a patient with known Wegener granulomatosis demonstrates the loss of the membranous septum (arrowheads) as well as focal destruction of a portion of the medial orbital wall (arrow). Mucosal thickening and reactive bony thickening is seen in the frontal sinuses (F).



▲ **Figure 3–114.** Axial postgadolinium T1-weighted image of the brain in a patient with headache and lethargy who was suspected to have a brain tumor. The imaging characteristics of the frontal lobe mass were felt to be more consistent with a brain abscess, and severe bilateral frontal sinus disease (F) was noted. In the operating room, pus was found in both the brain mass and the frontal sinuses. The patient did well after drainage and antibiotic treatment.

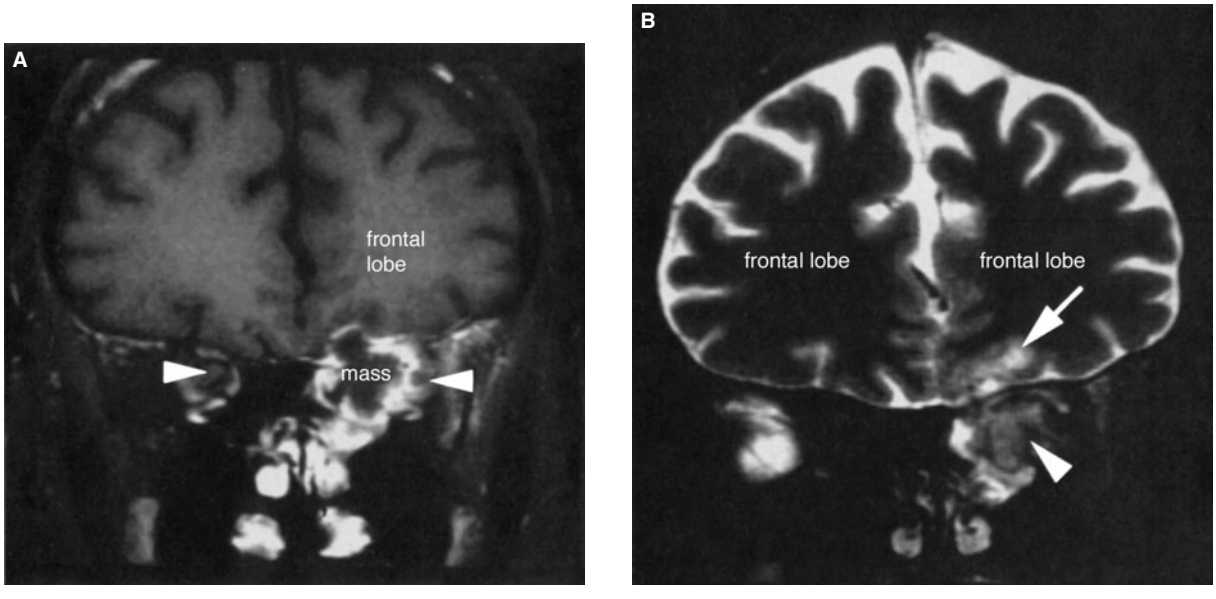
SKULL BASE

The skull base separates the extracranial head and neck from the intracranial contents. Multiple important neurovascular structures traverse the skull base, and knowledge of the complex anatomy of the skull base is essential to accurately evaluate and characterize this region. When CT scanning of the skull base is performed, both axial and coronal planes should be used, with sections no thicker than 3 mm. CT scanning of the skull base is useful for planning operative approaches, assessing many infectious, inflammatory, and congenital lesions, assessing and characterizing processes intrinsic to bone, and narrowing a differential diagnosis (ie, Is a lesion calcified or not? Does the lesion remodel or destroy bone?). MRI should also be done in multiple planes, with fat saturation on fast spin-echo T2-weighted images and post-gadolinium T1-weighted images, as in the extracranial head and neck. MRI provides additional information regarding lesion extent, lesion characterization, and the involvement of brain, meningeal or neurovascular structures by disease.

The skull base can be considered in three major sections: anterior, central, and posterolateral. The major apertures of the skull base that provide communication between the intracranial compartment and the extracranial head and neck are reviewed in Table 3–11, which lists each foramen or canal and its relevant contents. These apertures and foramina can be demonstrated on CT scanning and MRI (see Figures 3–103 and 3–124).

Anterior Skull Base

The anterior skull base makes up the floor of the anterior cranial fossa and includes the orbital plate of the frontal bone, the roof of the ethmoid bone, and the cribriform plate. From the otolaryngology perspective, the anterior skull base is most commonly involved by superior extension of neoplasms of the nasal cavity and ethmoid sinuses (see



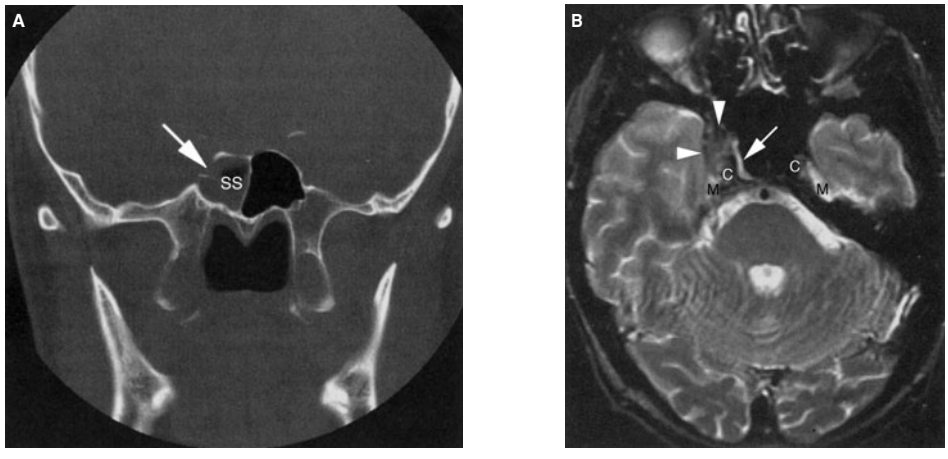
▲ **Figure 3–115. (A)** Coronal postgadolinium T1-weighted image with fat saturation in a patient with AIDS, declining vision in the left eye, and a painful supraorbital mass. An ill-marginated, peripherally enhancing lesion with central necrosis is seen involving the left orbit and extending superiorly into the anterior cranial fossa. The optic nerves are indicated (arrowheads), with the left nerve significantly displaced laterally by the mass. **(B)** A coronal fast spin-echo T2-weighted image with fat saturation demonstrates a relatively low signal intensity in the necrotic center of the mass lesion (arrowhead). Although this may represent proteinaceous or hemorrhagic material, a low signal intensity is also suggestive of a fungal process, since many fungi concentrate paramagnetic ions that shorten T2 relaxation times. Focal edema (arrow) is present in the left frontal lobe. Invasive aspergillosis was confirmed at the time of surgery and the patient died 2 days later.

Figure 3–121), intrinsic bony processes (such as fibrous dysplasia, Figure 3–125), and trauma. Because of the fragility of the cribriform plate, it is at high risk for traumatic disruption from accidental trauma or functional endoscopic sinus surgery, and this area should be carefully assessed in patients suspected of having CSF rhinorrhea (Figure 3–126).

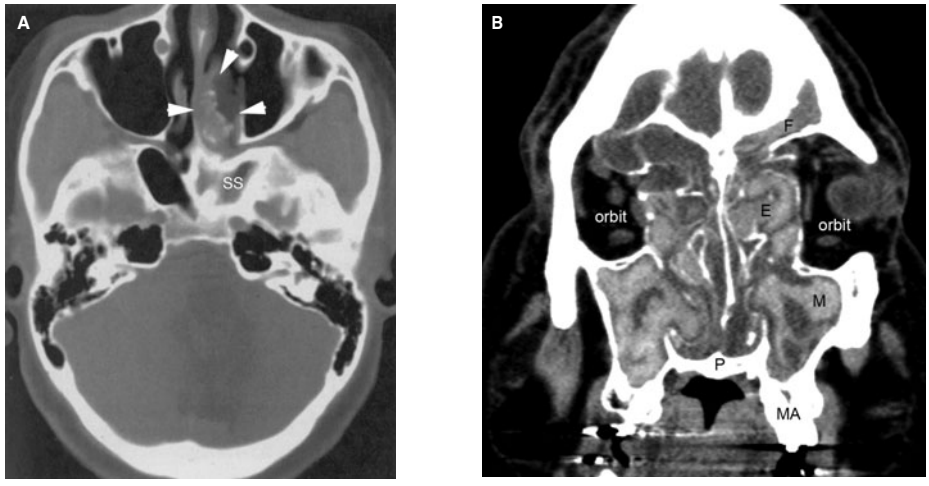
Central Skull Base

The central skull base is formed by the sphenoid and occipital bones. The sphenoid bone is anatomically complex and has five distinct parts. The basisphenoid includes the sphenoid sinus, the sella turcica, the dorsum and tuberculum sella, and the posterior clinoid processes; in combination with the basilar part of the occipital bone, the basisphenoid also forms the clivus. The paired greater wings of the sphenoid form much of the floor and anterior wall of the middle cranial fossa, whereas the paired lesser wings give rise to the anterior clinoid processes and contribute to the formation of the orbital fissure. The pterygoid process of the sphenoid bone gives rise to the pterygoid plates. The planum sphenoidale is a flat plane that extends from the tuberculum sella posteriorly to the posterior edge of the cribriform plate anteriorly. The occipital bone has three major segments. The basilar part of the occipital bone is centrally located and fuses with the basisphenoid to form the clivus; the synchondrosis between these two structures is easily visible in early childhood (Figure 3–127), but is usually completely fused by age 25. The occipital condyles are laterally located, and the squamous portion is posteriorly located and forms the majority of the floor of the posterior fossa.

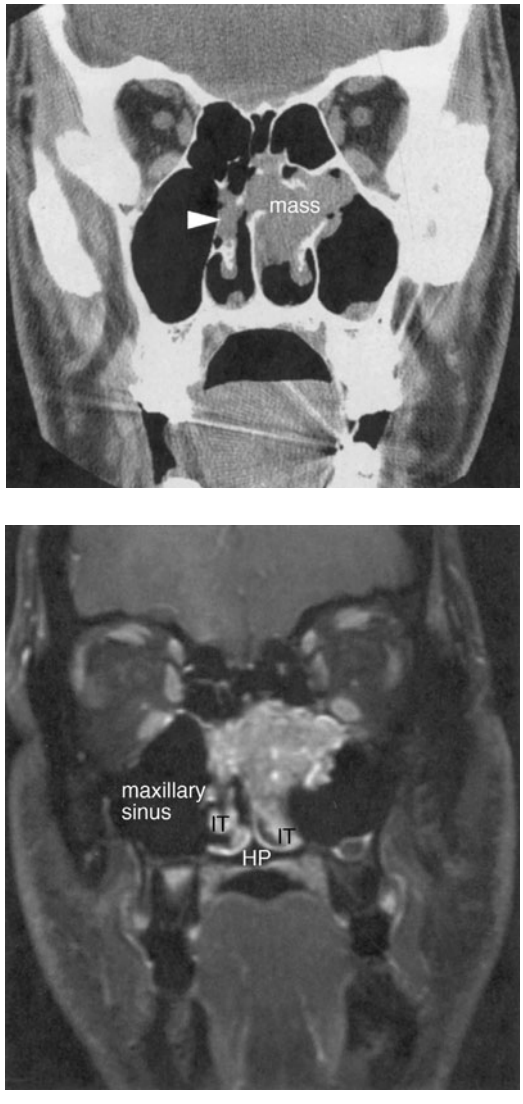
The central skull base may be involved by several categories of disease processes: (1) those that extend upward and centrally from the deep spaces of the extracranial head and neck, (2) those that extend inferiorly from the intracranial compartment, and (3) those that are intrinsic to the tissues of the central skull base. The deep facial spaces that abut the central skull base include the parapharyngeal, masticator, and prevertebral portion of the perivertebral space. Disease processes primary to these spaces, notably neoplastic and infectious disorders, may access and involve the central skull base from below. Intracranial processes that may extend inferiorly to involve the central skull base are beyond the scope of this chapter.



▲ **Figure 3–116.** **(A)** Coronal CT scan of the paranasal sinuses viewed in bone window of an HIV-positive patient with chronic sinus symptoms demonstrates mucosal thickening in the right sphenoid sinus (SS). Also present is a focal area of bone destruction (arrow) along the lateral sphenoid sinus wall, which was not noted prospectively. **(B)** Axial T2-weighted image performed 3 months later when the patient presented with new diplopia and palsy of the right cranial nerve VI on exam demonstrates a relatively low signal intensity expansile mass (white arrowheads) involving the anterior aspect of the right cavernous sinus. Sphenoid sinus mucosal disease is minimal (white arrow) and improved from the prior examination. Indicated are the cavernous internal carotid arteries (C) and Meckel cave (M). Endoscopic sphenoidotomy and biopsy confirmed a diagnosis of invasive aspergillosis, which behaved clinically in an indolent, chronic manner.



▲ **Figure 3–117.** **(A)** Axial noncontrast CT scan of the sinonasal region viewed in bone window demonstrates an expansile mass of the left nasal cavity (arrowheads) with dense, central calcification. The left sphenoid sinus (SS) is chronically obstructed and demonstrates mucoperiosteal thickening. Differential considerations included mycetoma and fibro-osseous lesions of the nasal cavity. A mycetoma was confirmed at the time of surgery. **(B)** Coronal noncontrast CT scan of the sinonasal region viewed in soft tissue in a different patient who presented with chronic nasal obstruction, facial pain and pressure, and subsequent vision loss on the left side. The maxillary (M), ethmoid (E), and frontal (F) sinuses are filled with dense as well as more flud-like material, and the ethmoid and right frontal sinuses in particular are markedly expanded. There is remodeling of the lamina papyracea bilaterally, and encroachment of the expanded ethmoid air cells into the orbits bilaterally. No aggressive bone erosion is seen, and the hard palate (P) and maxially alveolus (MA) are intact. At surgery, there was extensive fungal debris in all sinus cavities, consistent with severe allergic fungal sinusitis.



A

B

▲ **Figure 3–118.** **(A)** Coronal noncontrast CT scan of the paranasal sinuses viewed in intermediate window of a 50-year-old man with left nasal obstruction. A mass visible on clinical examination appears as a lobulated, benign-appearing lesion centered on the lateral nasal wall but extending through the left maxillary ostium and also through the nasal septum into the right nasal cavity (arrowhead). **(B)** On an MRI, a postgadolinium coronal T1-weighted image with fat saturation demonstrates a moderately intense but somewhat heterogeneous enhancement of this multilobulated transseptal lesion. The mass is separate from the right inferior turbinate (IT) but does involve the left inferior turbinate. The mass has a somewhat "cerebriform" and convoluted surface appearance. An inverting papilloma was confirmed at surgery.

A. Lesions Involving the Central Skull Base from Below

1. Direct extension—Deep face infection or neoplasm may involve the central skull base by direct extension, in which case a process or mass centered in a space of the suprahyoid head and neck extends to involve the central skull base by contiguous growth. This typically leads to remodeling or frank destruction of bone, marrow infiltration, and, possibly, gross intracranial extension if the skull base is breached (Figure 3–128).

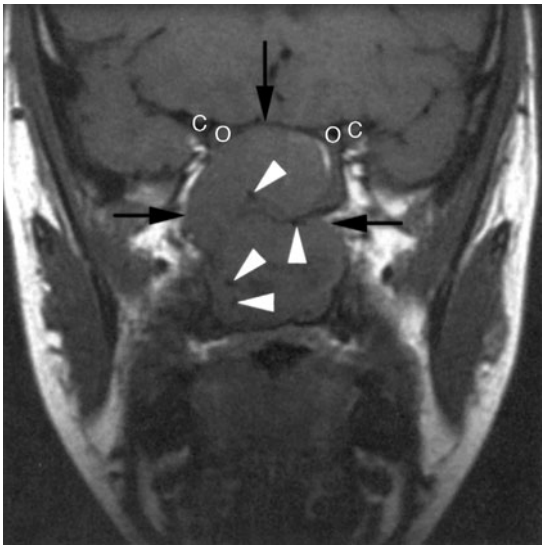
2. Perineural spread of disease—Perineural spread implies tumor extension to noncontiguous areas along nerves. In the head and neck, this most commonly involves branches of CN V and VII (the trigeminal and facial nerves, respectively). Although many malignant tumors may spread in a perineural fashion, the common head and neck lesions implicated in the perineural spread of disease include SCC of both cutaneous and mucosal origin, adenoid cystic carcinoma, lymphoma, melanoma, basal cell carcinoma, and mucoepidermoid carcinoma.

The perineural spread of tumor may result in clinical symptoms (eg, pain, dysesthesia, and hypesthesia), but may be asymptomatic even when demonstrable on imaging studies. Radiologic findings in perineural tumor spread include nerve and foraminal enlargement (Figure 3–129), foraminal destruction, obliteration of fat planes adjacent to the nerve, abnormal nerve enhancement (Figure 3–130), convexity of the lateral wall of the cavernous sinus, replacement of CSF in Meckel cave by soft tissue (Figure 3–131), and denervation changes in muscles innervated by the affected nerve (Figure 3–132). Perineural spread may occur in both antegrade and retrograde directions—for example, tumor that has spread back along V3 may reach the Gasserian ganglion and then spread in an antegrade manner along V1, V2, or both, as well as continuing to spread in a retrograde manner back along the cisternal segment of the trigeminal nerve to the pons.

B. Lesions Intrinsic to the Central Skull Base

The central skull base is composed primarily of cartilage and bone and is therefore subject to disease processes involving these tissues, especially neoplasm and infection. Certain congenital-developmental abnormalities of the central skull base may also be clinically relevant, primarily from the point of recognizing "don't touch" lesions such as fibrous dysplasia. In addition, adjacent vascular and soft tissue structures may give rise to lesions (eg, aneurysms, meningiomas, and nerve sheath tumors) that are intimately associated with the central skull base and need to be considered in the differential diagnosis of masses in this area.

1. Neoplasms—The central skull base may be involved with primary or metastatic lesions. Among the more common primary lesions are chordomas, chondrosarcomas,



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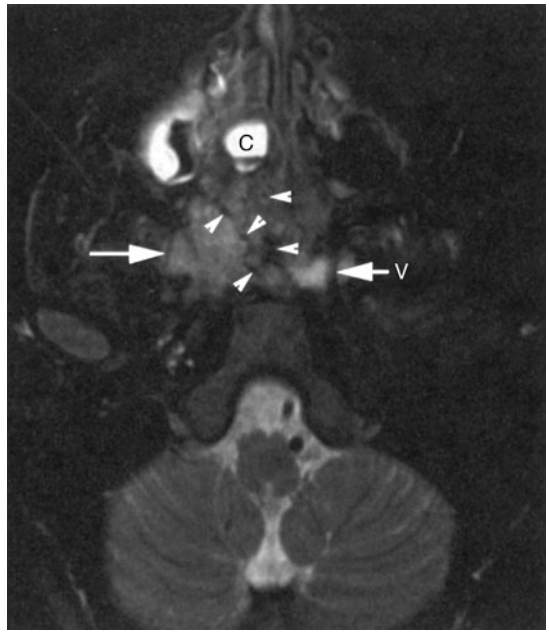


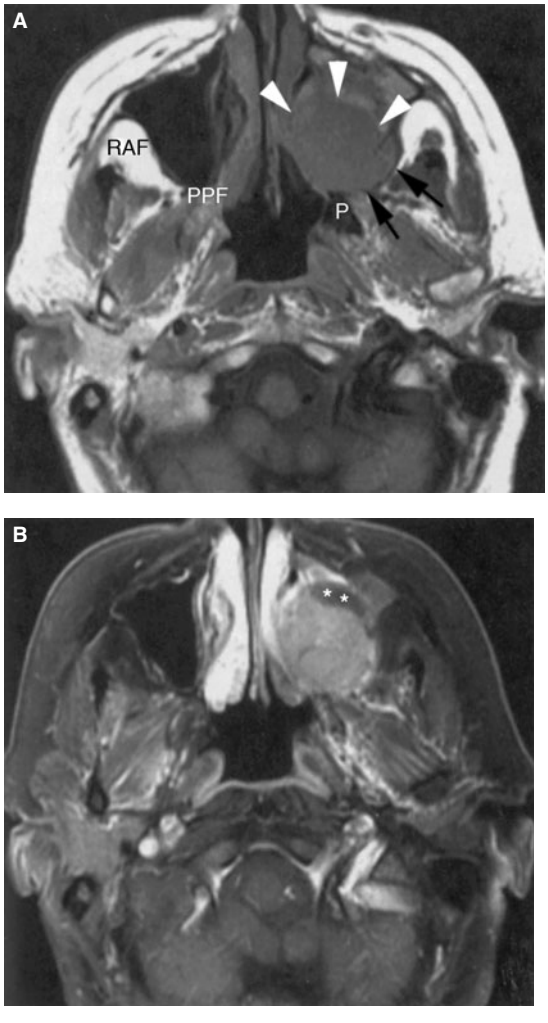
B

▲ **Figure 3–119. (A)** Coronal Tl-weighted image in a teenage male with epistaxis and nasal obstruction demonstrates a large soft tissue mass (black arrows) filling the posterior nasal cavity and nasopharynx and extending up into the sphenoid sinuses in close proximity to the optic nerves (O) in the optic canals, just medial to the anterior clinoid processes (C). Macroscopic flow voids (arrowheads) are seen within the mass. **(B)** Axial fast spin-echo T2-weighted image with fat saturation shows that the tumor is mostly intermediate in signal intensity but has a focal area of cystic degeneration (C). The tumor has invaded the right skull base (white arrow), with the contralateral skull base and vidian canal (V) shown for comparison. Flow voids are again seen within the lesion (small white arrowheads). Angiography and embolization were performed, followed by resection; pathology confirmed juvenile angiofibroma.

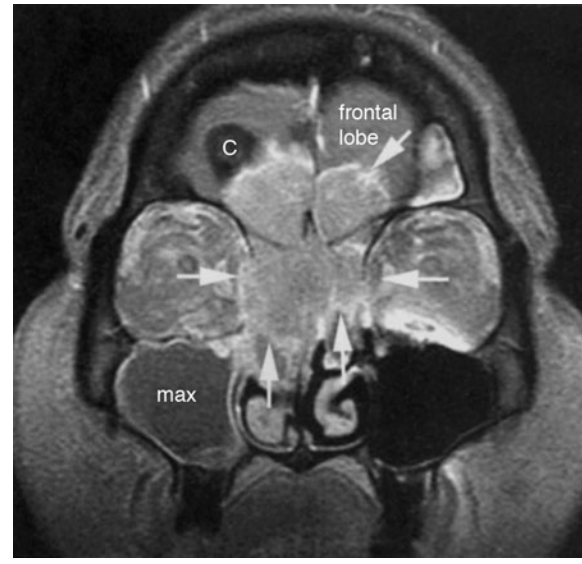
plasmacytomas, and lymphomas, as well as diffuse marrow infiltrative processes such as leukemia. MRI is generally far more sensitive than CT scanning in the detection of these lesions because T1-weighted images are very sensitive to marrow-replacing processes and become abnormal far earlier than CT scanning, which requires gross bone destruction before a lesion can be appreciated. Although the clival marrow is relatively hypointense in very young children (less than 3 years old), the marrow becomes progressively more fatty in children between 3 and 10 years and is homogeneously fatty by the teenage years. Therefore, lesions of the clivus are often best appreciated on a sagittal T1-weighted image. The normal adult clivus and, in contrast, clival marrow infiltration are demonstrated in Figure 3–133.

A. Chordomas—Chordomas arise from notochordal remnants within the clivus and are typically centered on the midline. Chordomas of the central skull base account for 35% of these lesions, which are locally aggressive and often abut or engulf vital structures by the time they are diagnosed, making surgical resection difficult or impossible. They also metastasize in approximately 40% of cases, most commonly to bone, liver, and lymph nodes. On CT scanning, a destructive mass is seen that may contain fragments of destroyed bone. On MRI, the lesions are typically intermediate in signal on T1-weighted images and markedly hyperintense on T2-weighted images (Figure 3–134), although the presence of bone fragments or hemorrhage may alter the signal characteristics. Postgadolinium, enhancement varies from mild and heterogeneous to intense and homogeneous.

B. Chondrosarcomas—Because the skull base is derived from cartilage, chondrosarcomas not uncommonly take origin here; in fact, 75% of all cranial chondrosarcomas are located in the skull base. These slow-growing malignant cartilaginous tumors typically spread by local invasion and may cause extensive destruction of the skull base. Skull base chondrosarcomas are most commonly centered on the petrooccipital fissure and their off-midline location is a helpful feature in distinguishing them from chordomas. CT scanning shows a destructive mass that may have matrix calcification. MRI shows a mass that is intermediate on T1-weighted images



▲ **Figure 3–120. (A)** Axial T1-weighted image in a 55-year-old woman with left facial pain and pressure demonstrates a soft tissue mass (white arrowheads) centered in the left maxillary sinus and extending posteriorly through the back wall of the sinus into the retroantral fat (black arrows) and pterygopalatine fossa. The normal retroantral fat (RAF) and pterygopalatine fossa (PPF) are indicated on the patient's right side. In addition, there is sclerosis of the pterygoid body and plates (P) related to tumor infiltration. Anteriorly, within the left maxillary sinus, mixed signal intensity material is consistent with inspissated proteinaceous material due to sinus obstruction. **(B)** Postgadolinium, an axial Tl-weighted image with fat saturation demonstrates enhancement of the lesion and its posterior extension into the adjacent fat and bone. More anteriorly in the maxillary sinus, inspissated proteinaceous material (**) does not enhance. Invasive squamous cell carcinoma was confirmed surgically.

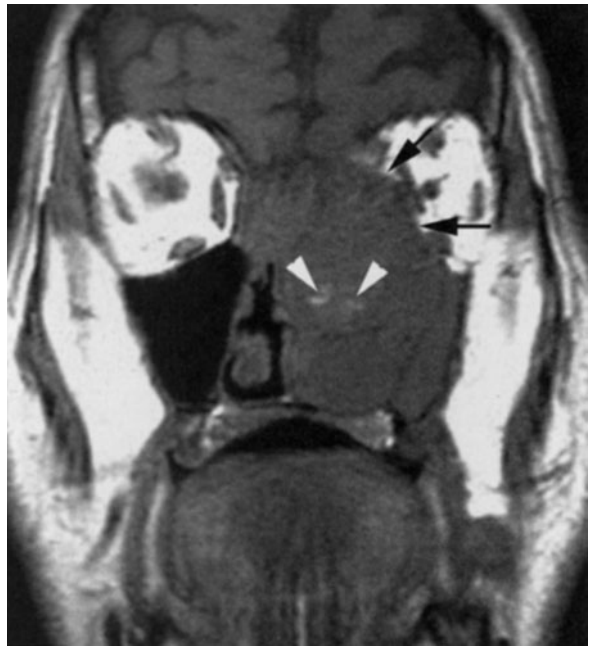


▲ **Figure 3–121.** Coronal T1-weighted image postgadolinium with fat saturation in a 45-year-old woman with anosmia and nasal obstruction demonstrates an intensely enhancing soft tissue mass (white arrows) that is centered on the upper nasal vault, involves the nasal cavity bilaterally and extends into both orbits, and extends intracranially to invade brain. A peripheral intracranial cyst (C) is noted, as are obstructed secretions in the right maxillary (max) sinus. An esthesioneuroblastoma with extensive intracranial and bilateral orbital involvement was confirmed at surgery.

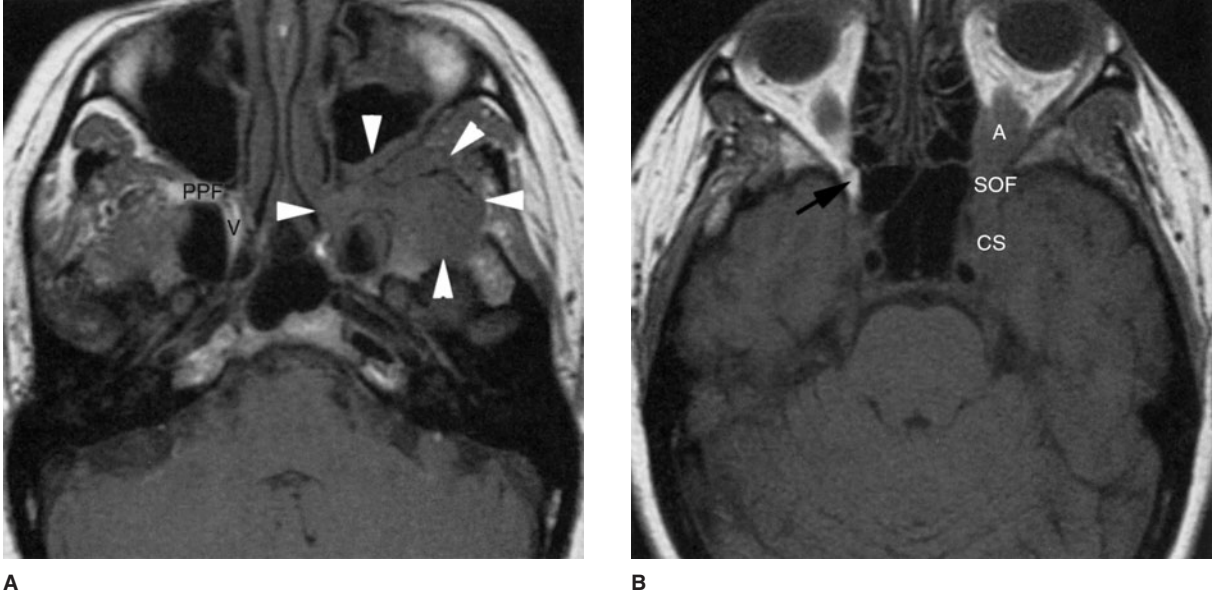
and hyperintense on T2-weighted images, with intense enhancement postgadolinium (Figure 3–135). If there is significant matrix calcification, then there may be areas of heterogeneously low signal on T2-weighted images and enhancement will be heterogeneous as well.

C. Metastatic disease—Hematogenous metastases to the skull base are more common than primary neoplasms, and most frequently originate from lung, breast, prostate, and kidney. CT scanning shows lytic bone destruction if the process is advanced enough, but may appear normal early on. MRI is far more sensitive to the replacement of normal fatty marrow by tumor. Most metastases are intermediate in signal on T1- and T2-weighted images and show enhancement postcontrast.

2. Infection—Osteomyelitis of the skull base most commonly involves the temporal bone, but may also involve the central skull base. It may result from the direct extension of sphenoid or ethmoid sinus inflammatory disease, iatrogenic or accidental trauma, or hematogenous dissemination. Infection may also spread centrally from a more lateral temporal bone focus. Diabetic and otherwise immunocompromised patients



▲ **Figure 3–122.** Coronal Tl-weighted image in an elderly man presenting with epistaxis and left nasal obstruction demonstrates a large soft tissue mass filling the left nasal cavity, invading the left orbit (black arrows), and extending through the skull base into the anterior cranial fossa. Focal areas of high signal intensity (arrowheads) are seen, consistent with hemorrhage or melanin. Mucosal melanoma was confirmed by biopsy.



A B

▲ **Figure 3–123.** **(A)** Axial T1-weighted image in a 50-year-old woman with numbness in the left V2 distribution demonstrates abnormal soft tissue (arrowheads) infiltrating the posterior mucosa of the maxillary sinus, the fat of the pterygopalatine fossa, and the muscle and fat of the nasopharyngeal masticator space just below the skull base. The normal right pterygopalatine fossa (PPF) and vidian canal (V) are shown for comparison. **(B)** A more cephalad axial Tl-weighted image shows abnormal soft tissue infiltrating the orbital apex (A), superior orbital fissure (SOF), and cavernous sinus (CS). The normal right superior orbital fissure is shown for comparison (black arrow). Biopsy of the posterior wall of the maxillary sinus via a Caldwell-Luc approach confirmed the diagnosis of B-cell lymphoma.

Table 3–11. Major Openings of the Skull Base.

Aperture	Contents
Cribriform plate	Olfactory nerves
Optic canal	Optic nerve sheath complex
	Ophthalmic artery
Superior orbital fissure	CN III, IV, VI, and V1 (ophthalmic nerve)
	Superior ophthalmic vein
Foramen ovale	V3 (mandibular nerve)
Foramen rotundum	V2 (maxillary nerve)
Foramen spinosum	Middle meningeal artery
Vidian canal	Vidian artery
	Vidian nerve
Carotid canal	Internal carotid artery
	Sympathetic plexus
Jugular foramen, pars nervosa	CN IX and inferior petrosal sinus
Jugular foramen, pars vascularis	Internal jugular vein
	CN X and XI
Stylomastoid foramen	CN VII
Hypoglossal canal	CN XII

are at higher risk for skull base osteomyelitis, which may be a difficult and subtle diagnosis to render on imaging studies. The careful assessment of pregadolinium T1-weighted images for the loss of a normal, bright, fatty marrow signal and the subtle infiltration of fat planes adjacent to the skull base is particularly useful (Figure 3–136). MRI is the study of choice if this diagnosis is being considered.

3. Vascular lesions—A large or giant aneurysm, usually of the cavernous segment of the internal carotid artery, may present with headache, cranial neuropathy, or both, and may cause considerable remodeling of the sphenoid bone, thereby mimicking a neoplastic process. It is important that such a lesion be properly diagnosed rather than embarking on a biopsy, which could be fatal. On CT scanning, the lesion appears to smoothly remodel bone and may have a peripherally calcified rim. On MRI, layers of lamellated thrombus are seen if the aneurysm is partly thrombosed, and phase artifact related to pulsatile flow may be noted (Figure 3–137). In addition, MRA may directly demonstrate flow within the aneurysm.

4. Congenital and developmental disorders—A cephalocele refers to a protrusion of intracranial contents through a congenital defect in the skull; it may contain meninges and CSF only (meningocele) or may contain brain tissue as well (encephalocele). Basal cephaloceles account for approximately 10% of all cephaloceles and may present as a mass visible on examination (see Figure 3–104) or may be detected incidentally on a CT scan or MRI. Patients may also present with meningitis or other complaints. It is important to avoid unintentional violation of these lesions since this may lead to meningitis, CSF leak, and other complications (Figure 3–138).

5. Other disorders—A number of conditions that affect the skull base may present a potentially confusing picture on imaging studies.

A. Fibrous dysplasia—Fibrous dysplasia commonly involves the skull base and may be focal, multifocal, or diffuse. Fibrous dysplasia causes bone expansion and, on CT scans, a classic "ground glass" appearance of hazy sclerosis; focal lytic or cystic areas may also occur. On MRI, the hallmark is also bone expansion. The signal is typically intermediate on T1-weighted images and intermediate to dark on T2-weighted images, with prominent enhancement postgadolinium. Signal characteristics vary with the extent of the fibrous component and the presence of cystic areas. This diagnosis is often much more difficult to make on MRI than on a CT scan and is a potential pitfall of skull base imaging because this benign "don't touch" condition may be misdiagnosed as a skull base neoplasm. If MRI presents a confusing picture, then CT scanning may be very helpful for confirming the diagnosis of fibrous dysplasia (Figure 3–139).

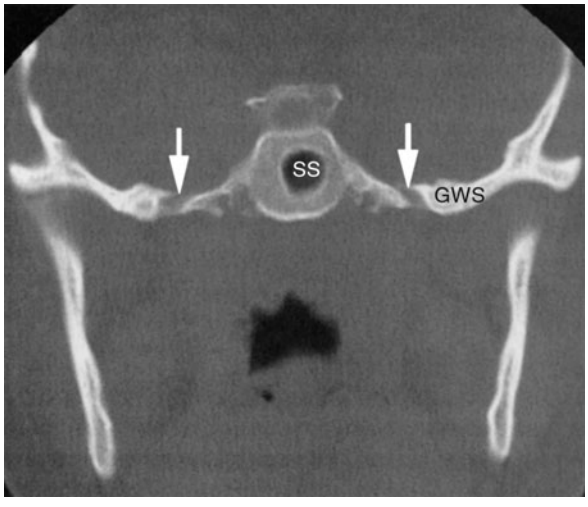
B. Paget disease—Paget disease is typically seen in older patients and appears as bone thickening and sclerosis on CT scans; on MRI, bone is expanded and often quite heterogeneous in signal intensity. Although this potentially mimics fibrous dysplasia, it is typically diffuse rather than focal.

C. Osteoradionecrosis—Osteoradionecrosis of the skull base may be seen in patients who have received prior high-dose radiation therapy for head and neck cancer (notably of the nasopharynx) or for sellar or parasellar pathology. This typically appears as a mixed lytic and sclerotic process on CT scans and as heterogeneous marrow signal intensity on MRI. The differentiation from chronic osteomyelitis can be difficult, and in fact, infection may complicate osteoradionecrosis.

Borges A. Imaging of the central skull base. *Neuroimaging Clin N Am* 2009;19:441–468 [PMID: 19733317]. (This first part of a two-part review focuses on a systematic approach to imaging the central skull base that takes into account the major tissue constituents of the central skull base.)

Borges A. Imaging of the central skull base. *Neuroimaging Clin N Am* 2009;19:669–696 [PMID: 19959012]. (This second part of a two-part review continues a review of the anatomy and pathology of the central skull base.)

Borges A. Skull base tumors part I: imaging technique, anatomy and anterior skull base tumors. *Eur J Radiol* 2008;66:338–347 [PMID: 18462901]. (This review focuses on advances in imaging techniques for the skull base as well as the imaging appearance of tumors of the anterior skull base.)



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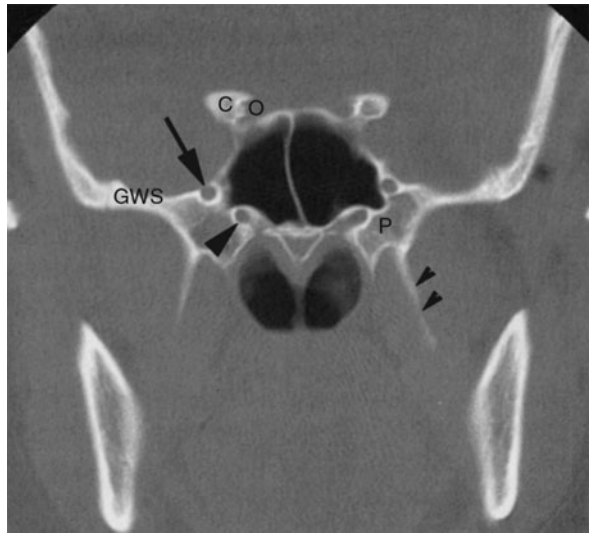

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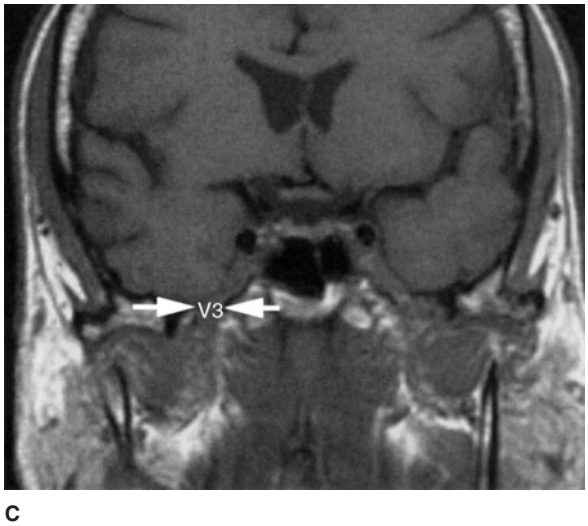

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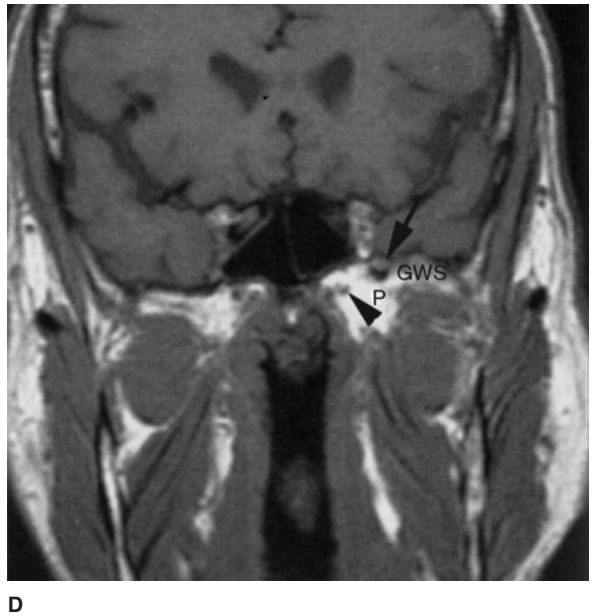
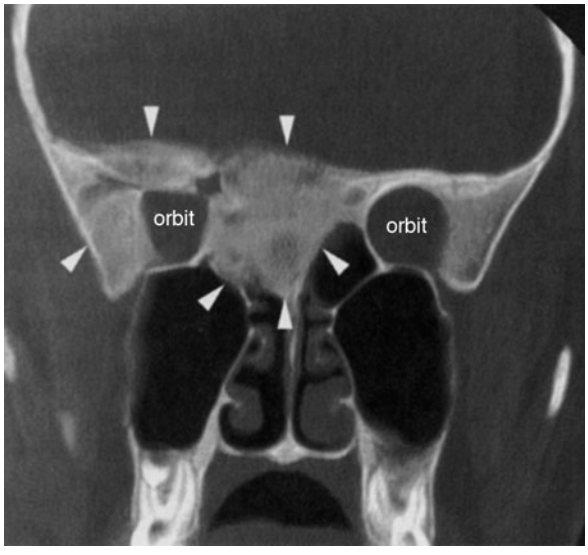


D

▲ **Figure 3–124.** **(A)** Coronal CT scan of the skull base viewed in bone window demonstrates the foramen ovale bilaterally (white arrows) and the sphenoid sinus (SS) and greater wing of the sphenoid bone (GWS). **(B)** A more anterior image demonstrates foramen rotundum (black arrow) and the vidian canal (black arrowhead), as well as the anterior clinoid process (C) and the optic canal (O). Also seen are the greater wing of the sphenoid (GWS), the pterygoid process (P), and the lateral pterygoid plate (small double arrowheads). **(C)** A coronal T1-weighted image demonstrates the corresponding soft tissue anatomy, with V3 seen passing through the foramen ovale (arrows). **(D)** A more anterior image demonstrates foramen rotundum (black arrow) and the vidian canal (black arrowhead). Fatty marrow in the left pterygoid process of the sphenoid bone (P) and the greater wing of the sphenoid is indicated.



▲ **Figure 3–125.** Coronal CT scan of the skull base viewed in bone window demonstrates a benign-appearing expansion of the central and right anterior skull base and right lateral orbital wall (arrowheads), which also has a somewhat "ground glass" texture. This appearance is diagnostic of fibrous dysplasia. Note that the right orbit is smaller than the left because of encroachment on the orbit by the expanded bone.

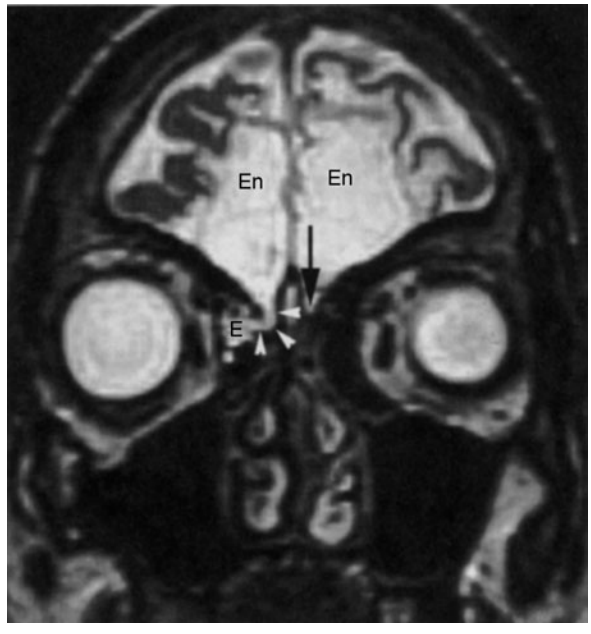
Borges A. Skull base tumors part II: central skull base tumors and intrinsic tumors of the bony skull base. *Eur J Radiol* 2008;66:348–362 [PMID: 18472241]. (This review covers the imaging appearance of the gamut of pathologies seen in the central skull base.)

Caldemeyer KS, Mathews VP, Righi PD, Smith RR. Imaging features and clinical significance of perineural spread or extension of head and neck tumors. *Radiographics* 1998;18:97 [PMID: 9460111]. (Reviews the normal cranial nerve anatomy and the radiologic appearance and assessment of perineural tumor extension.)

Ginsberg LE. Neoplastic diseases affecting the central skull base: CT and MR imaging. *AJR Am J Roentgenol* 1992;159:581 [PMID: 1503031]. (Reviews some of the more commonly encountered tumors that can affect the skull base and describes their CT and MR imaging appearance.)

Posterolateral Skull Base

The posterolateral skull base can be equated with the temporal bone. Imaging techniques must be specially tailored to best assess the small structures of the temporal bone. In addition, a number of disease processes are unique to the temporal bone or most commonly found in the temporal bone, and these will be reviewed.



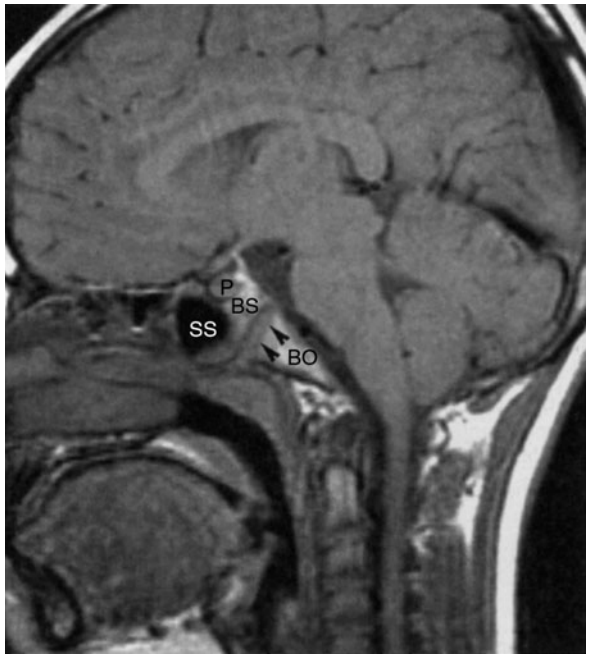
▲ **Figure 3–126.** Coronal thin-section (1.5 mm) fast spin-echo T2-weighted image in a young male with post-traumatic cognitive dysfunction, anosmia, and a right-sided CSF leak. Bifrontal encephalomalacia (En) is seen. The normal left cribriform plate is demonstrated (black arrow). On the right, the cribriform plate is disrupted, and high signal intensity material consistent with CSF is seen to track from the anterior cranial fossa to the ethmoid sinus (arrowheads leading to E). At surgery, a focal defect in the right cribriform plate was confirmed and repaired.

A. CT Scanning

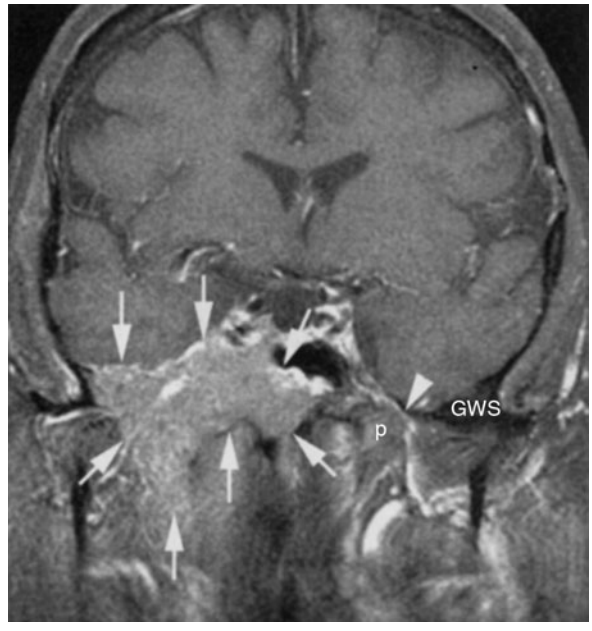
Computed tomography is the dominant imaging modality for depicting the bony anatomy of the temporal bone. CT imaging of the temporal bone is usually performed in the axial and coronal planes with a slice thickness of ≤1 mm. Ideally, the source images are retargeted to a small display field of view of 10 cm for both the right and left sides individually. For the depiction of bony anatomy, intravenous contrast is not needed. The normal anatomy of the temporal bone depicted on CT scans is demonstrated in Figure 3–140.

B. MRI

Magnetic resonance imaging is useful for imaging the soft tissues and fluid compartments of the temporal bone. For suspected neoplastic and inflammatory pathologies, the intravenous administration of gadolinium is important to identify areas of abnormal enhancement.



▲ **Figure 3–127.** Sagittal Tl-weighted image in a normal 8-year-old girl demonstrates the sphenooccipital synchondrosis (small black arrowheads) between the basisphenoid (BS) and the basilar part of the occipital bone (BO). Also shown are the sphenoid sinus (SS) and the pituitary gland (P) in the sella turcica.



▲ **Figure 3–128.** Coronal postgadolinium Tl-weighted image with fat saturation in a patient with deep-seated skull base pain and right V3 dysfunction demonstrates a large soft tissue mass (arrows) destroying the right greater wing of the sphenoid. This was eventually proved to be a nasopharyngeal carcinoma that had grown primarily superolaterally to destroy the skull base and invade the middle cranial fossa (note the elevation of the right temporal lobe). Shown for comparison on the left are the greater wing of the sphenoid (GWS), the pterygoid process (P), and V3 (arrowhead).

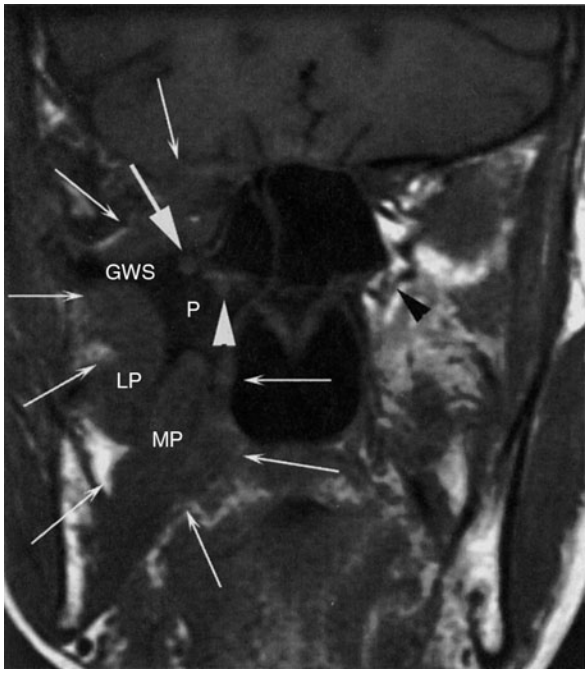
The following sequences are routinely used in examining the temporal bone:

- Axial T1-weighted imaging
- Axial FIESTA (fast imaging employing steady-state acquisition) or CISS (constructive interference in the steady-state) imaging
- Diffusion-weighted imaging
- Pregadolinium axial T1-weighted imaging
- Postgadolinium axial T1-weighted imaging with fat saturation
- Postgadolinium coronal T1-weighted imaging with fat saturation

To best depict the detailed anatomy of the temporal bone, a field of view of 17 cm by 17 cm with a slice thickness of 2 mm with a 0-mm skip and a matrix size of 256 by 192 for T1-weighted images, both pre- and postgadolinium, are used. For T2-weighted imaging, submillimeter slices are acquired with either a FIESTA or a CISS sequence. A pregadolinium T1-weighted imaging sequence is useful in order to identify areas of fat (such as a lipoma), hemorrhage, or elevated protein content within the inner ear, as might be seen with a process such as labyrinthitis. Fat saturation is extremely important for postgadolinium sequences in order to identify enhancement that might otherwise be obscured by fatty marrow in the petrous bone. In many centers, diffusion-weighted imaging is now added to the temporal bone MR imaging protocol to evaluate temporal bone cholesteatomas and cerebellopontine angle epidermoid cysts. These lesions typically demonstrate reduced diffusion of water molecules, which is seen as localized high signal intensity on a diffusion-weighted image.

Fitzek C, Mewes T, Fitzek S et al. Diffusion-weighted MRI of cholesteatomas of the petrous bone. *J Magn Reson Imaging* 2002;15:636 [PMID: 12112513]. (Discusses the utility of DWI for evaluating cholesteatomas of the temporal bone.)

Gunlock MG, Gentry LR. Anatomy of the temporal bone. *Neuroimaging Clin N Am* 1998;8(1):195 [PMID: 9449760]. (Description of normal temporal bone anatomy.)



▲ **Figure 3–129.** Slightly oblique coronal Tl-weighted image in a patient with adenocarcinoma of the palate and extensive perineural spread of disease. Normal fat planes of the skull base and infratemporal fossa have been obliterated on the right by infiltrative tumor. The extent of tumor infiltration on the right is indicated by the thin concave white arrows. The right pterygoid process (P) and greater sphenoid wing (GWS) are low in signal intensity due to tumor infiltration instead of showing the expected high signal of fatty marrow; the medial and lateral pterygoid muscles (MP, LP) are also infiltrated. Foramen rotundum (white arrow) and the vidian canal (white arrowhead) are enlarged on the right due to the perineural spread of disease. The normal left vidian canal is indicated (black arrowhead).

Nayak S. Segmental anatomy of the temporal bone. *Semin Ultrasound CT MR* 2001;22(3):184 [PMID: 11451096]. (Description of normal temporal bone anatomy.)

Stone JA, Chakeres DW, Schmalbrock P. High-resolution MR imaging of the auditory pathway. *Magn Reson Imaging Clin N Am* 1998;6(1):195 [PMID: 9449749]. (The current techniques in high-resolution MRI of the temporal bone are presented, followed by a review of normal anatomy.)

DISEASES OF THE TEMPORAL BONE

The temporal bone has five anatomic components: squamous, mastoid, petrous, tympanic, and styloid portions. It can be subdivided into three major clinically relevant compartments: the external auditory canal, the middle ear cavity, and the inner ear.

1. External Auditory Canal

Anatomy

The external auditory canal extends from the level of the pinna to the tympanic membrane. It has both cartilaginous and bony segments.

Pathology

Abnormalities that may be encountered on imaging studies of the external auditory canal are listed in Table 3–12.

A. Atresia and Stenosis

Both atresia (Figure 3–141) and stenosis of the external auditory canal are secondary to failure of canalization of epithelial cells during the formation of the canal. Atresias of the external auditory canal can be bony, membranous, or mixed. When external auditory canal stenosis or atresia is encountered, associated deformities of the pinna and ossicles are often present. In addition, the facial nerve often has an abnormal course, being more anteriorly located than usual and exiting into the glenoid fossa rather than more medially into the stylomastoid foramen.

B. Exostoses

Exostoses (Figure 3–142) can form within the external auditory canal. This is commonly known as "surfer's ear" because this condition appears to be induced by chronic exposure to cold water. This condition is usually bilateral, and the exostosis has a broad base against the adjacent bone. Osteoma of the external auditory canal has a similar appearance to an exostosis, but it is typically unilateral and pedunculated.

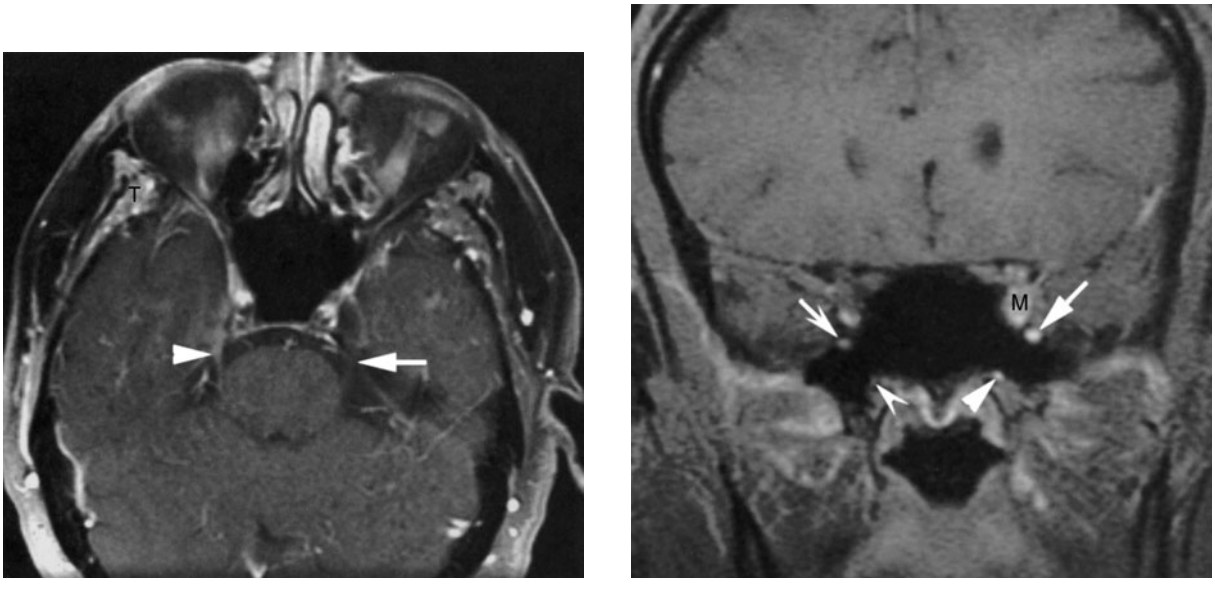
Davis TC, Thedinger BA, Greene GM. Osteomas of the internal auditory canal: a report of two cases. *Am J Otol* 2000;21(6):852 [PMID: 11078075]. (Surgical intervention may be warranted to remove an osteoma of the internal auditory canal if symptoms are present.)

Swartz JD, Faerber EN. Congenital malformations of the external and middle ear: high-resolution CT findings of surgical import. *AJR Am J Roentgenol* 1985;144(3):501 [PMID: 3871559]. (Description of surgically important findings in congenital malformations of the external and middle ear.)

2. Middle Ear

Anatomy

The middle ear is separated from the external auditory canal by the tympanic membrane (see Figure 3–140). In the coronal plane, the tympanic membrane extends from the scutum to the tympanic annulus. The middle ear cavity contains three ossicles: the malleus, the incus, and the stapes. Sound



A B

▲ **Figure 3–130.** **(A)** Axial postgadolinium Tl-weighted image with fat saturation demonstrates asymmetric enhancement of the cisternal segment of the right trigeminal nerve (arrowhead) compared with the normal left trigeminal nerve (arrow) in a patient with known perineural spread of carcinoma. The asymmetric enhancement of the right temporalis muscle (T) is a consequence of acute denervation change. **(B)** Coronal postgadolinium T1-weighted image with fat saturation in a different patient with the perineural spread of tumor demonstrates asymmetric enhancement and enlargement of left V2 (straight white arrow) compared with the right (concave white arrow) and asymmetric enhancement and enlargement of the left vidian nerve (straight white arrowhead) compared with the right (concave white arrowhead). Also shown is a soft tissue mass (M) in the left orbital fissure.

is mechanically transmitted from the tympanic membrane to the malleus to the incus to the stapes and finally to the cochlea via the oval window. The oval window and the round window provide access from the middle ear cavity to the inner ear structures.

The middle ear can be further divided into three compartments: the epitympanum, the mesotympanum, and the hypotympanum. In the coronal plane, these compartments are defined by drawing imaginary extensions of the superior and inferior borders of the bony external canal across the middle ear cavity. These two lines effectively divide the middle ear cavity into three compartments. The most cephalad compartment is the epitympanum, the middle compartment is the mesotympanum, and the most caudad compartment is the hypotympanum.

A. Epitympanum

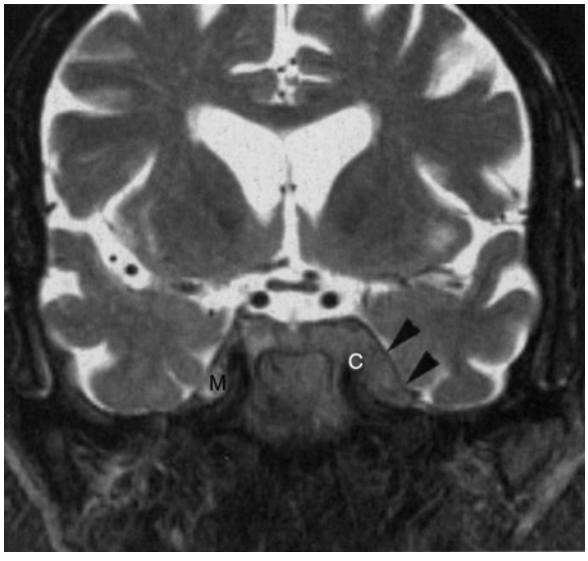
The epitympanum is bounded superiorly by the tegmen tympani. The relatively thin tegmen tympani separates the middle ear cavity from the middle cranial fossa. Within the epitympanum is the head of the malleus and the body and short process of the incus. Prussak space is the space between the lateral wall of the epitympanum and the neck of the malleus. Prussak space is the most common site of acquired pars flaccida cholesteatomas.

B. Mesotympanum

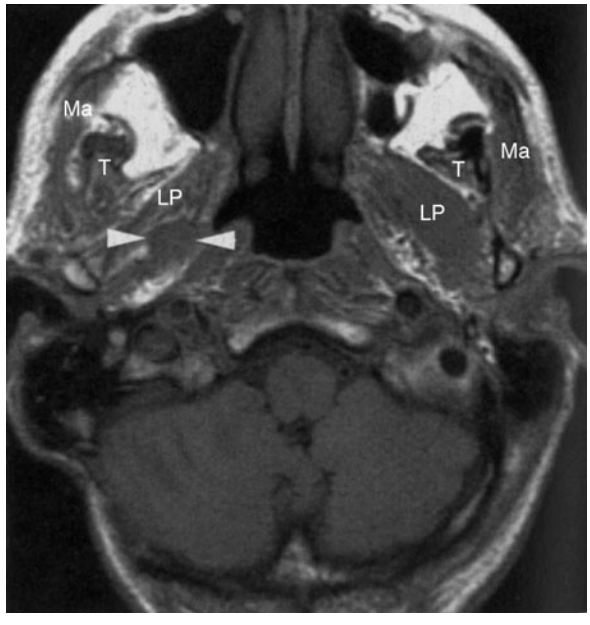
The mesotympanum contains the manubrium of the malleus, the long process of the incus, and the stapes. Two muscles are located in the mesotympanum. The stapedius and tensor tympani muscles serve to dampen sound transmission. The tensor tympani tendon inserts on the manubrium of the malleus. The stapedius muscle is located in the pyramidal eminence, and the stapedius tendon inserts on the head of the stapes. An important anatomic site is the sinus tympani, a clinical blind spot where cholesteatomas may hide.

C. Hypotympanum

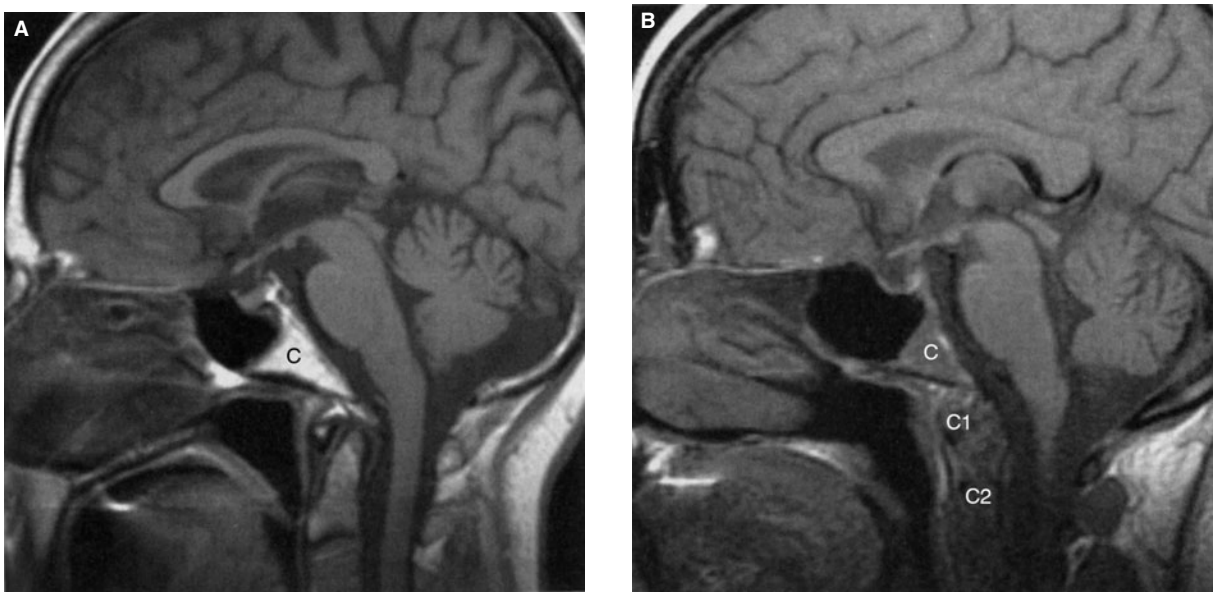
The hypotympanum is the smallest compartment of the middle ear and contains no portions of the ossicles.



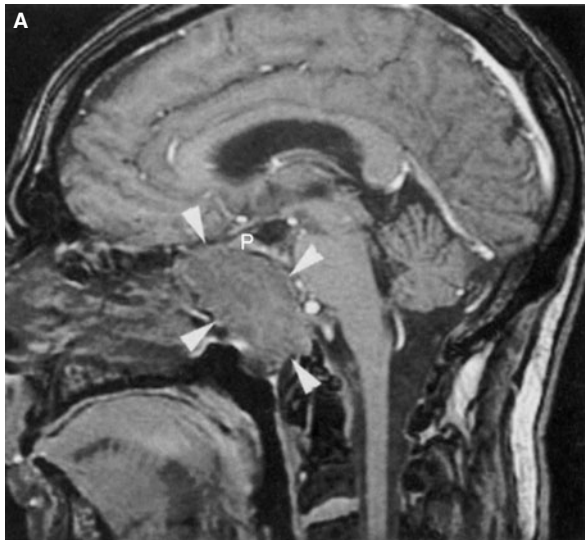
▲ **Figure 3–131.** Coronal fast spin-echo T2-weighted image with fat saturation in a patient with perineural spread of squamous cell carcinoma demonstrates normal fluid intensity in the right Meckel cave (M), but the replacement of normal fluid by abnormal soft tissue (black arrowheads) on the left. The abnormal soft tissue also invaded the left cavernous sinus and surrounded the cavernous segment of the internal carotid artery (C).

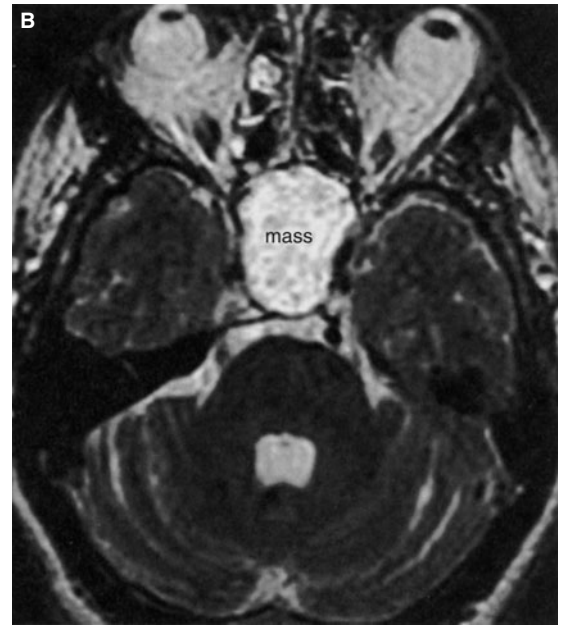


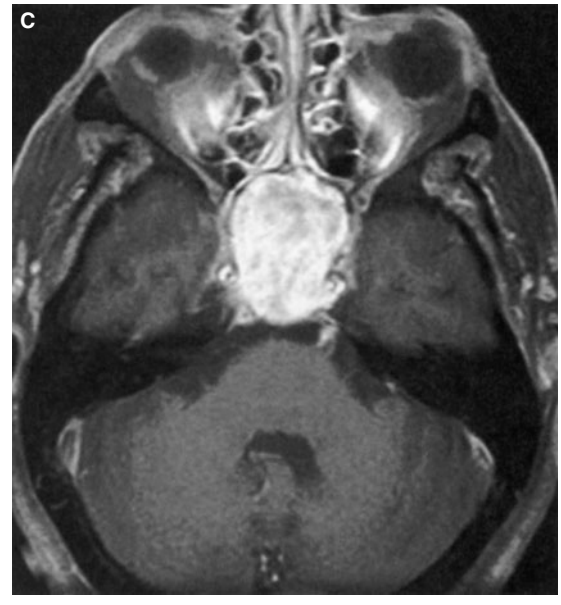
▲ **Figure 3–132.** Axial T1-weighted image in a patient with perineural spread of squamous cell carcinoma along the right V3, which is massively enlarged (arrowheads). Denervation atrophy (decreased bulk, fatty infiltration) is seen in the right muscles of mastication compared with the left. Indicated are the lateral pterygoid (LP), masseter (Ma) and temporalis (T) muscles.



▲ **Figure 3–133.** **(A)** Sagittal T1-weighted image demonstrates the normal, homogeneously fatty adult clivus (C). **(B)** Sagittal T1-weighted image in a different patient demonstrates abnormal hypointensity of the marrow spaces of the clivus (C) and C1 and C2 vertebral bodies in this patient with chronic myelogenous leukemia.







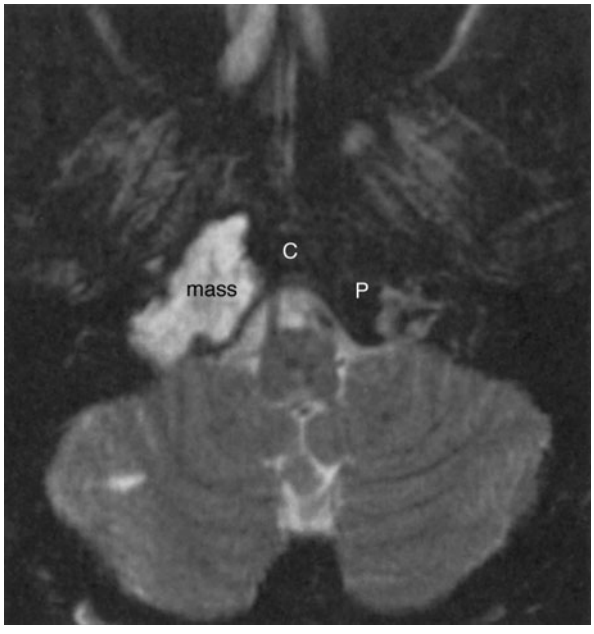
▲ **Figure 3–134. (A)** A sagittal T1-weighted gradient echo image acquired as part of a surgical navigation study demonstrates an intermediate signal intensity soft tissue mass (arrowheads) obliterating the sphenoid sinus and clivus, and elevating the pituitary gland (P). **(B)** On an axial fast spin-echo T2-weighted image, the mass is high in signal intensity. **(C)** Postgadolinium, a T1-weighted image with fat saturation demonstrates intense and homogeneous enhancement. The pathology confirmed the diagnosis of chordoma.

Pathology

Abnormalities that may be encountered on imaging studies of the middle ear are listed in Table 3–13.

A. Congenital Vascular Abnormalities

Congenital vascular abnormalities of the middle ear are important lesions to exclude before considering either a biopsy or surgery for a retrotympanic mass. An aberrant internal carotid artery (Figure 3–143) and a persistent stapedial artery are rare; they can be seen together or separately. The theories of development of an aberrant internal carotid artery include the presence of a persistent stapedial artery that "fixes" or "pulls" the internal carotid artery laterally into the middle ear. A second theory is that agenesis of a segment of the internal carotid artery results in the redirection of blood flow into the inferior tympanic and hyoid arteries in the middle ear. These arteries would



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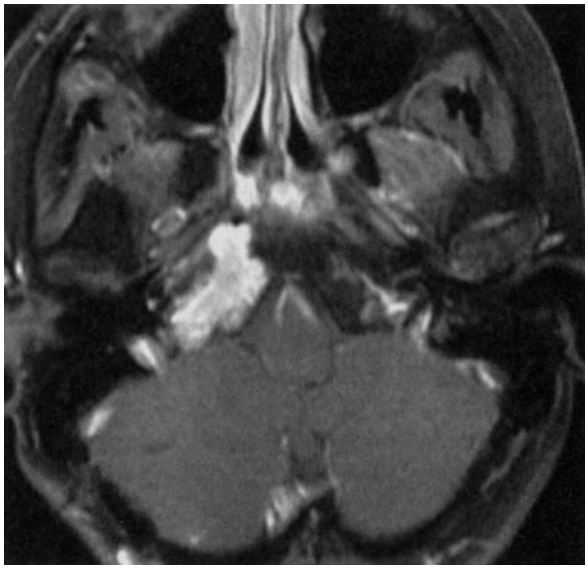
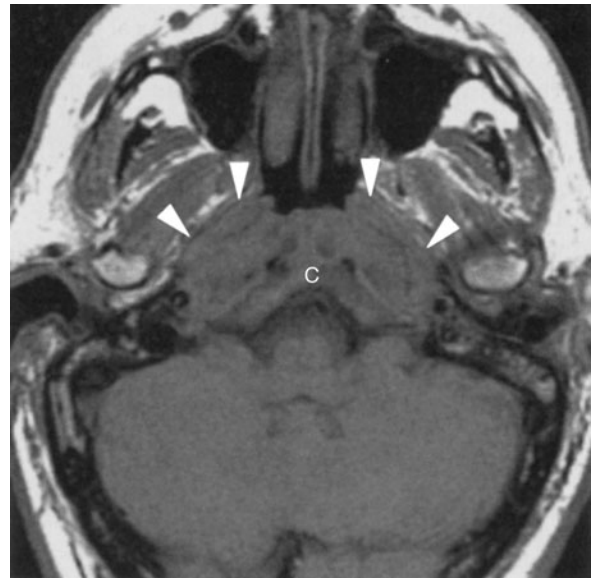


B

▲ **Figure 3–135. (A)** Axial fast spin-echo T2-weighted image with fat saturation in a young woman with a sixth nerve palsy demonstrates a multilobulated, high signal intensity lesion involving the right lateral clivus (C) and petrous bone. The left petrous bone is identified (P). **(B)** Postgadolinium, a T1-weighted image with fat saturation demonstrates intense and homogeneous enhancement of the lesion. Imaging and pathology were consistent with chondrosarcoma.

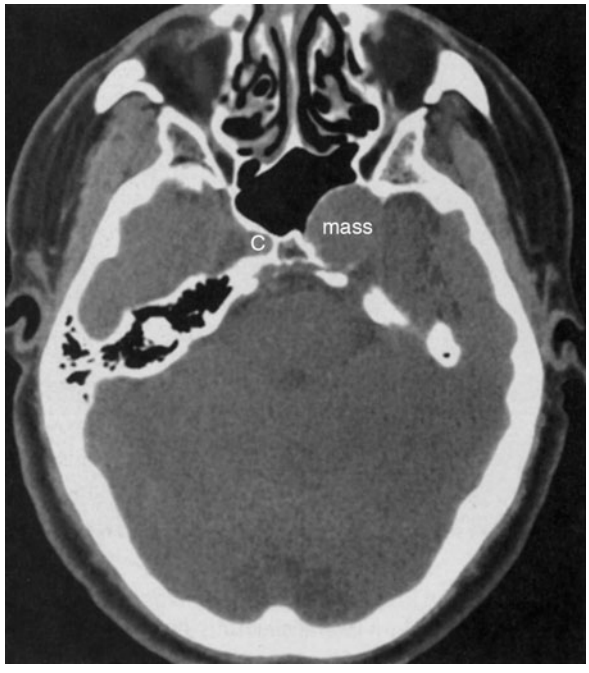


▲ **Figure 3–136.** Axial T1-weighted image in a 56-year-old diabetic man with headache, low-grade fever, and lower cranial neuropathy demonstrates abnormal hypointensity of clival marrow (C). In addition, the soft tissues anterior to the central skull base (arrowheads) are abnormally full and normal fat planes are obliterated, further supporting an infiltrative neoplastic or inflammatory process. Skull base osteomyelitis was eventually confirmed by tissue sampling.

typically have minor blood flow, but, in this situation, these arteries dilate and provide an alternate pathway through the middle ear cavity to bypass the absent segment of the internal carotid artery.

B. Cholesteatomas

Cholesteatomas arise from ectopic rests of epithelial tissue. The presence of bony erosion on imaging is strong supportive evidence for the diagnosis of cholesteatoma. A cholesteatoma can be present, however, without any evidence of bony erosion on imaging. In those cases, it is very difficult on CT to distinguish cholesteatoma from the soft tissue changes that are seen with chronic otitis media. Cholesteatomas can be divided into congenital and acquired varieties (Figure 3–144). A congenital cholesteatoma is considered on imaging when there is a globular lesion within the middle ear with adjacent bone erosion, but without evidence or history of an inflammatory or infectious process or trauma. Acquired cholesteatomas occur when epithelial tissue gains entry to the middle ear cavity via infection or trauma that violates the tympanic



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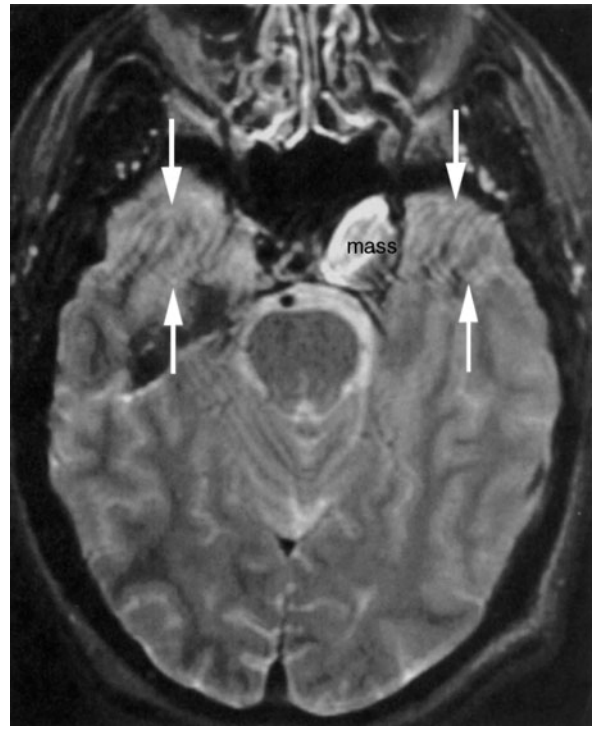


B

▲ **Figure 3–137.** **(A)** Axial noncontrast CT scan of the skull base viewed in bone window in a young man with headache demonstrates a rounded mass with faint peripheral calcification that has remodeled the bone of the skull base. The mass is centered on the left carotid canal. The contralateral carotid canal (C) is demonstrated. **(B)** Axial T2-weighted image in the same patient demonstrates heterogeneous signal intensity within the left mass, consistent with lamellated thrombus. Phase artifact (white arrows) confirms the vascular nature of the lesion, and a large aneurysm of the cavernous carotid artery was confirmed with angiography.

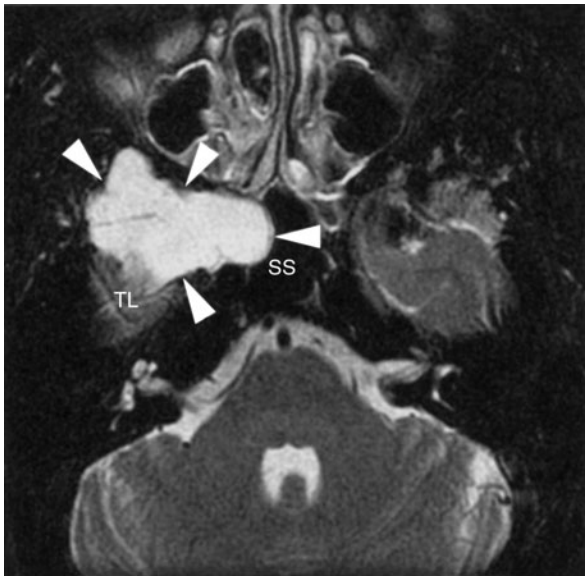
membrane. The presence of a globular mass with adjacent erosions is typical. There are two types of acquired cholesteatomas. The more common type is the pars flaccida cholesteatoma, whereby the cholesteatoma arises from the pars flaccida of the tympanic membrane and extends into the Prussak space. The erosion of the scutum is one of the signs of this entity. A pars tensa cholesteatoma arises in a posterosuperior retraction pocket of the tympanic membrane and often involves the sinus tympani. On MRI, a cholesteatoma has intermediate signal intensity on T1-weighted images, high signal intensity on T2-weighted images, and, on postgadolinium images, either no enhancement or a thin rim of enhancement representing adjacent granulation tissue. Diffusion-weighted images can be very helpful as they show reduced diffusion (high signal intensity) in cholesteatoma. In contrast, a cholesterol granuloma of the middle ear has high signal on T1-weighted sequences that does not diminish with fat saturation, and there is no reduced diffusion.

C. Langerhans Cell Histiocytosis

Langerhans cell histiocytosis is a disease of children and young adults. It most commonly presents as solitary or multiple lytic lesions of bone. The temporal bone is a common location for these lesions, which appear as nonspecific unilateral or bilateral enhancing soft tissue masses on MRI and erosive lesions on CT.

D. Infection

Infection of the middle ear cavity frequently occurs in conjunction with infection of the mastoid air cells since these two compartments are connected via various channels, the largest being the aditus ad antrum. These spaces are vulnerable to infection with bacteria from the upper respiratory tract via the eustachian tubes. Coalescent mastoiditis (Figure 3–145) is diagnosed when there is erosion of the bony septa of the mastoid air cells and an abscess develops in the mastoid bone. Complications that need to



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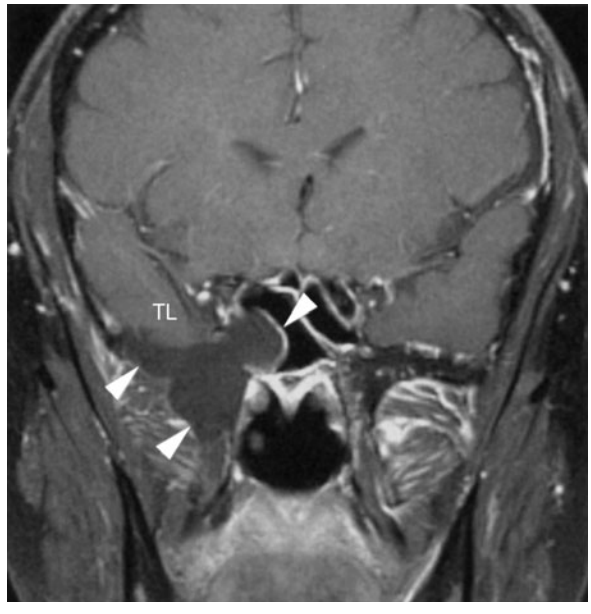

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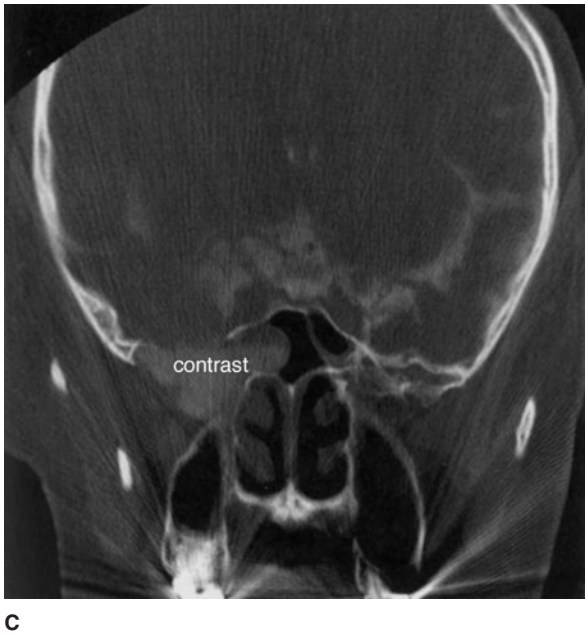


C

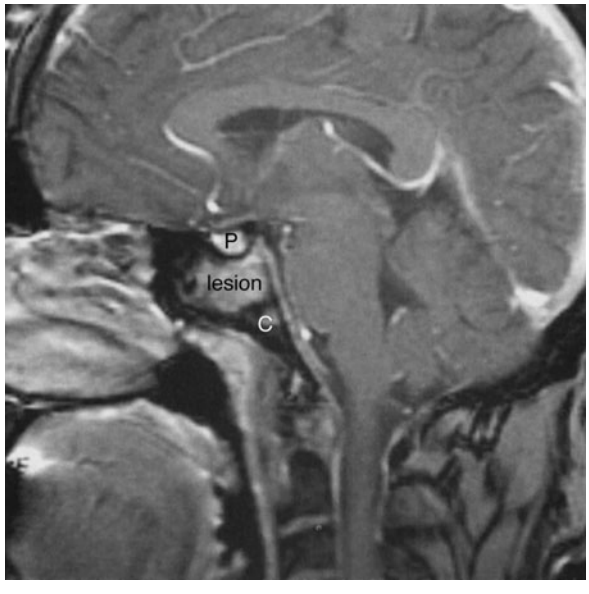
▲ **Figure 3–138.** A 22-year-old man underwent MRI for evaluation of headache and was referred for treatment of a skull base "mass" that was discovered. **(A)** Axial fast spin-echo T2-weighted image with fat saturation demonstrates a well-circumscribed, strikingly hyperintense mass (arrowheads) involving the right skull base and encroaching on the sphenoid sinus (SS). It is located immediately adjacent to the temporal lobe (TL). **(B)** On a coronal postgadolinium T1-weighted image with fat saturation, the lesion is centered just below the temporal lobe at the level of the greater wing of the sphenoid and is isointense to cerebrospinal fluid. The diagnosis of lateral sphenoid meningocele was questioned and the planned biopsy was cancelled. **(C)** The patient underwent CT cisternography. Complete filling of the skull base "lesion" with contrast confirmed the diagnosis of lateral sphenoid meningocele. Note the absence of much of the greater wing of the sphenoid on the right, presumably secondary to congenital deficiency and thinning and remodeling over time due to CSF pulsations.

be recognized include subperiosteal abscess, thrombosis of adjacent dural venous sinuses (Figure 3–146), and intracranial extension.

E. Neoplasms

The most common benign tumor of the middle ear is a paraganglioma. If a paraganglioma is located in the middle ear overlying the cochlear promontory, it is called a glomus tympanicum. Often, there is a component of the lesion near the jugular bulb. The combined lesion is known as a glomus jugulotympanicum (Figure 3–147). A facial nerve schwannoma may also present as a middle ear mass.

Malignant tumors of the middle ear cavity are not common. Metastases to bone or dura may erode into the middle ear and present as a middle ear mass.



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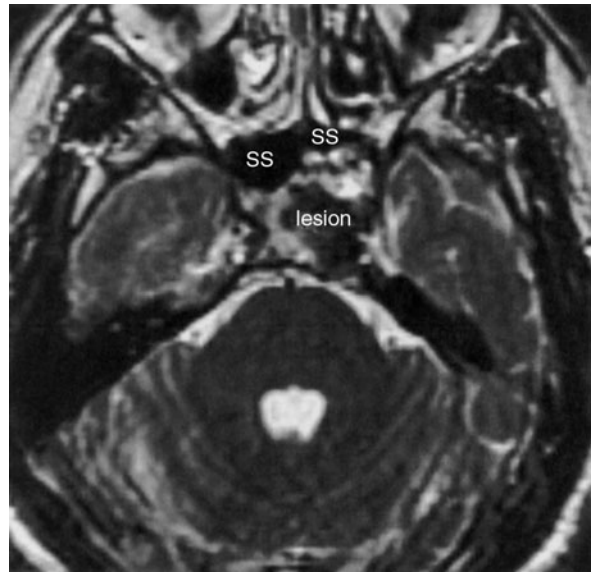

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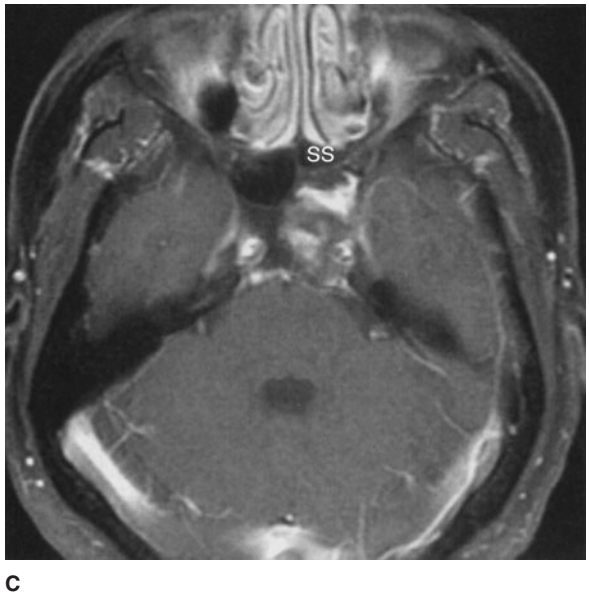

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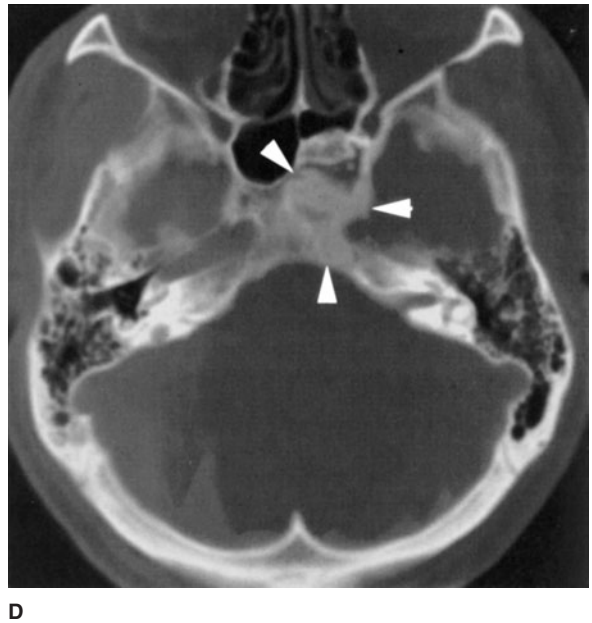
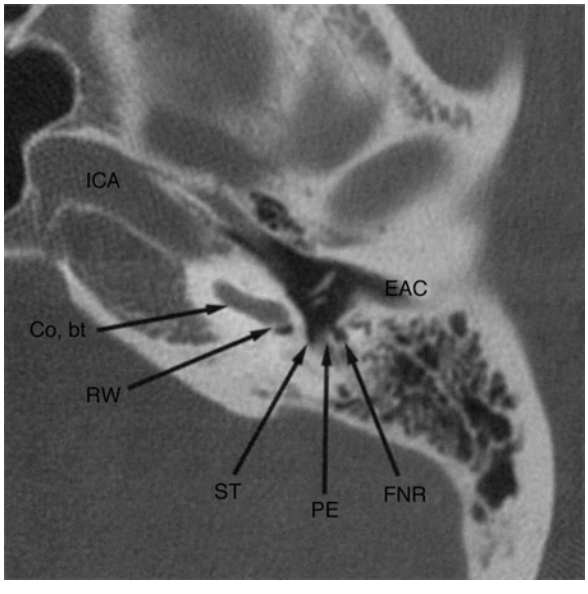


D

▲ **Figure 3–139.** **(A)** Sagittal postgadolinium Tl-weighted gradient echo image of the skull base acquired as part of a preoperative surgical navigation protocol on a patient referred for a biopsy of a skull base mass. Indicated are the normal clivus (C, which appears dark on a gradient echo image), the pituitary gland (P), and the enhancing lesion. **(B)** Axial fast spin-echo T2-weighted image shows that the lesion is quite low in signal intensity and the left sphenoid sinus (SS) appears small compared to the right. A more anterior component of the left-sided lesion is heterogeneously hyperintense. **(C)** On an axial postgadolinium T1-weighted image with fat saturation, it is clear that the left clivus is expanded, the left sphenoid sinus (SS) is small, and the bony lesion demonstrates heterogeneous but fairly intense enhancement. No destructive or aggressive features are noted. The diagnosis of fibrous dysplasia was questioned and a CT scan was recommended. **(D)** Axial CT scan of the skull base viewed in bone window demonstrates expansion of the left sphenoid bone and areas of ground glass opacity, consistent with a diagnosis of fibrous dysplasia. The unnecessary biopsy was cancelled.



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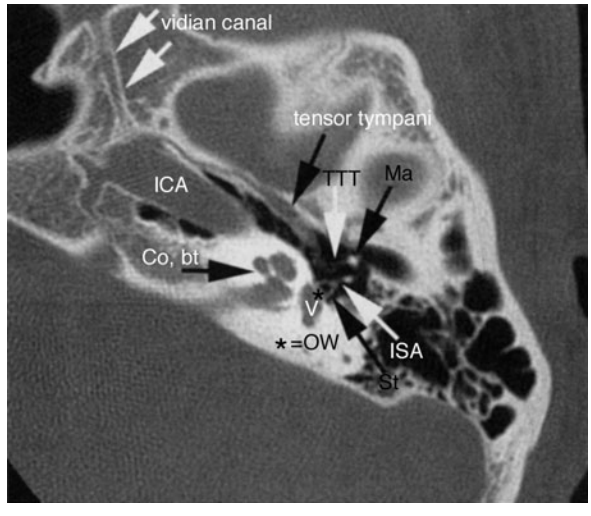

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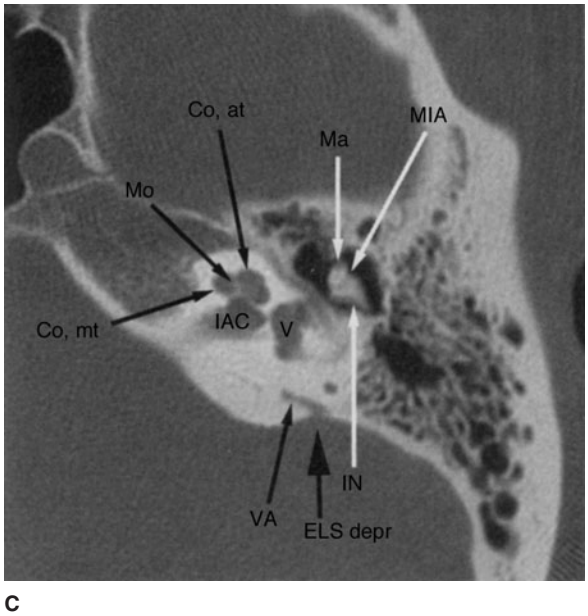

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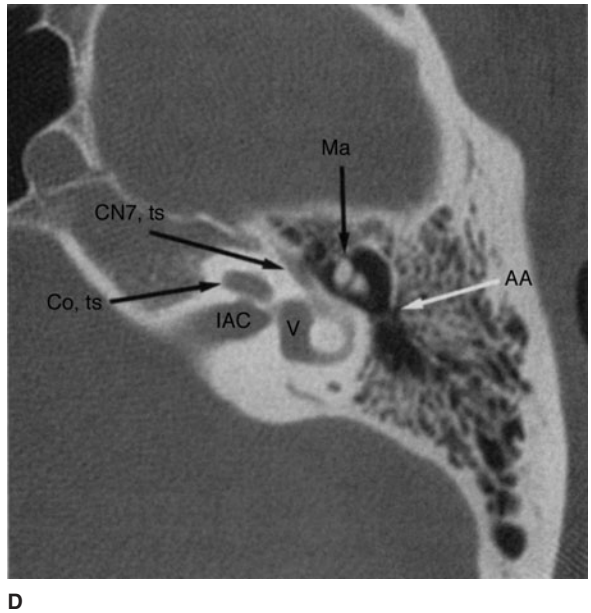
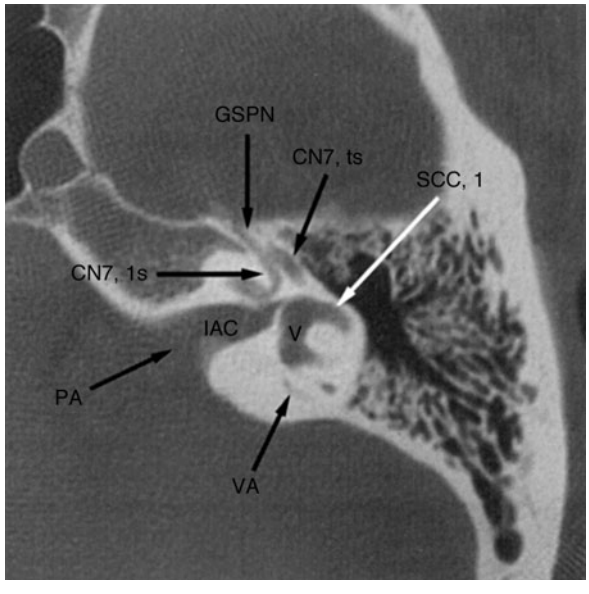


D

▲ **Figure 3–140.** CT scan of normal temporal bone, photographed in bone window. Axial images **(A)** to **(G)** are inferior to superior. Legend for parts **(H)** to **(K)** appears on page 151. *(continued)*



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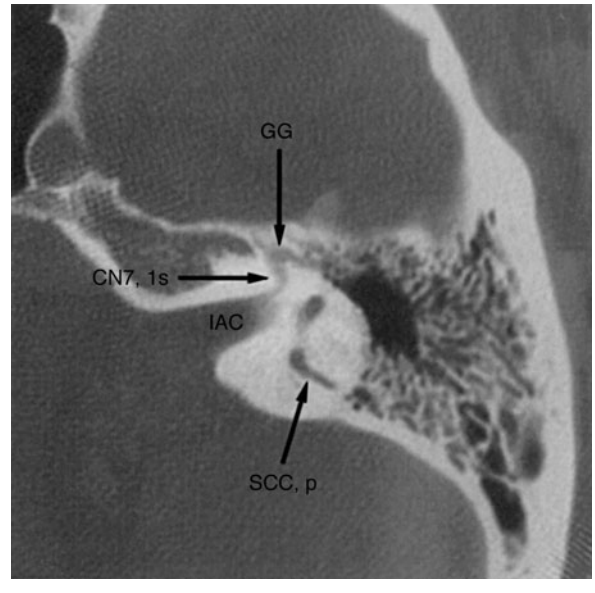

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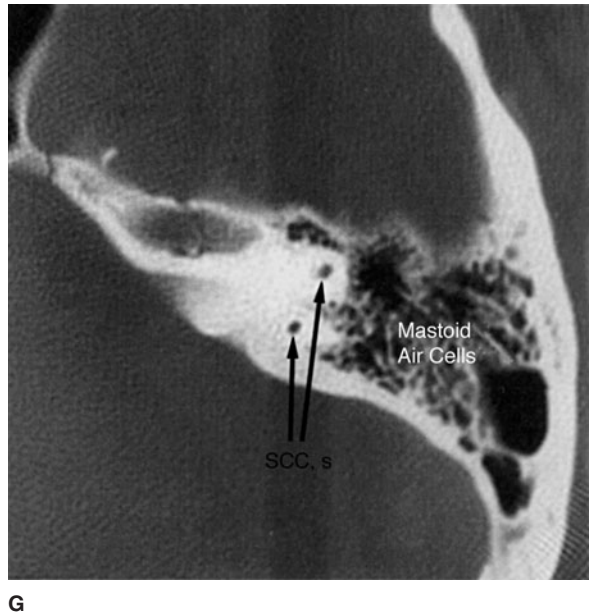
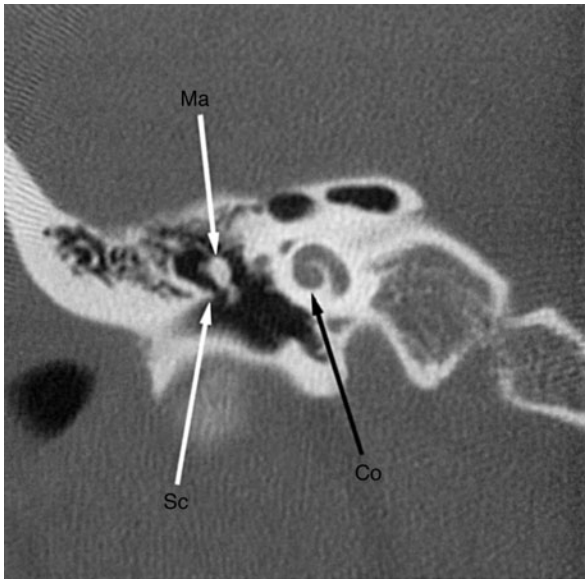


G

▲ **Figure 3–140.** *(continued)* CT scan of normal temporal bone, photographed in bone window. Axial images **(A)** to **(G)** are inferior to superior. *(continued)*



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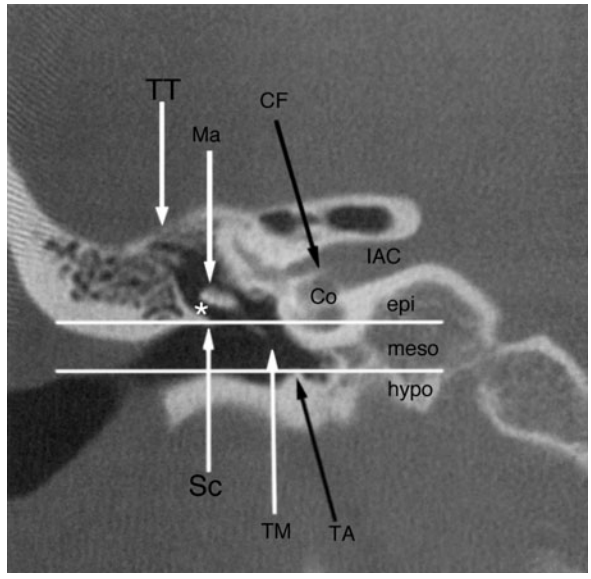

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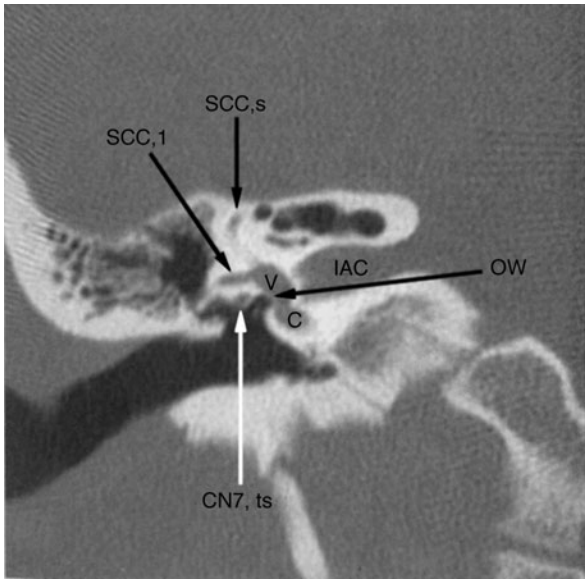

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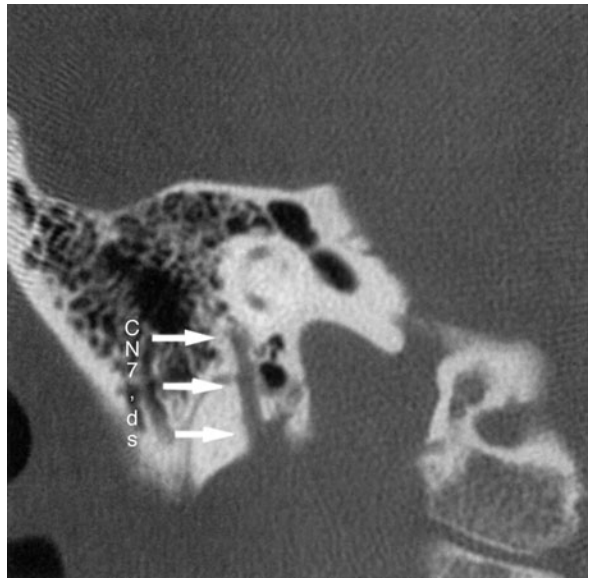


K

▲ **Figure 3–140.** *(continued)* CT scan of normal temporal bone, photographed in bone window. Coronal images **(H)** to **(K)** are anterior to posterior. Abbreviations: AA, aditus ad antrum; CF, crista falciformis; CN7,ds, CN VII, descending mastoid segment; CN7,ls, CN VII, labyrinthine segment; CN7,ts, CN VII, tympanic segment; Co, cochlea; Co,at, cochlea, apical turn; Co,bt, cochlea, base turn; Co,mt, cochlea, middle turn; EAC, external auditory canal; ELS dep, endolymphatic sac depression; epi, epitympanum; FNR, facial nerve recess; GG, geniculate ganglion; GSPN, greater superficial petrosal nerve; hypo, hypotympanum; IAC, internal auditory canal; ICA, internal carotid artery; In, incus; ISA, incudostapedial articulation; Ma, malleus; meso, mesotympanum; Mo, modiolus; MIA, malleoincudal articulation; OW, oval window; PE, pyramidal eminence; PA, porus acusticus; *, Prussak space; RW, round window; Sc, scutum; SCC,l, semicircular canal, lateral; SCC,p, semicircular canal, posterior; SCC,s, semicircular canal, superior; St, stapes; ST, sinus tympani; TA, tympanic annulus; TM, tympanic membrane; TT, tegmen tympani; TTT, tensor tympani tendon; V, vestibule; VA, vestibular aqueduct.

Table 3–12. Abnormalities of the External Auditory Canal.

Congenital Aural Dysplasia	Inflammatory/Reactive	Neoplastic	
		Benign	*Malignant*
Atresia	Chronic external otitis (swimmer's ear)	Osteoma	Basal cell carcinoma
Stenosis	Exostoses (surfer's ear)	Ceruminous gland origin tumor	Squamous cell carcinoma
	Malignant otitis externa (necrotizing external otitis)		Melanoma
	Keratosis obturans		Metastasis
	Cholesteatoma		Ceruminous gland origin tumor

F. Ossicular Chain Abnormalities

The ossicular chain consists of the malleus, the incus, and the stapes. Abnormalities of this chain lead to a conductive hearing loss. Acquired abnormalities are typically due to inflammation or trauma. These processes can lead to ossicular fusion, fracture, dislocation (Figure 3–148), and erosion. Ossicular prostheses can be used to reconstruct some or all of the ossicular chain (Figure 3–149).

G. Abnormal Communications

Abnormal communication between the middle ear cavity and the middle cranial fossa can occur from inflammation, infection, trauma, neoplasm, or postoperative complications. Developmental or acquired thinning of the tegmen tympani (as in the setting of benign intracranial hypertension, or pseudotumor cerebri) may also result in abnormal communication of the compartments of the ear with the middle cranial fosssa. Brain, meninges, or both may herniate through the defect into the middle ear/mastoid cavity, external auditory canal, or both (Figure 3–150).

Jackson CG, Pappas DG Jr, Manolidis S et al. Brain herniation into the middle ear and mastoid: concepts in diagnosis and surgical management. *Am J Otol* 1997;18(2):198 [PMID: 9093677]. (Prompt and effective surgical repair is successful and integral to preventing complications in cases of temporal bone encephaloceles.)

Lo WW, Solti-Bohman LG, McElveen JT Jr. Aberrant carotid artery: radiologic diagnosis with emphasis on high-resolution computed tomography. *Radiographics* 1985;5(6):985 [PMID: 3880011]. (Classic text describing the imaging of aberrant internal carotid arteries.)

Maroldi R, Farina D, Palvarini L et al. Computed tomography and magnetic resonance imaging of pathologic conditions of the middle ear. *Eur J Radiol* 2001;40(2):78 [PMID: 11704355]. (Description of middle ear pathologies as seen on CT scanning and MRI.)

Soderberg KC, Dornhoffer JL. Congenital cholesteatoma of the middle ear: occurrence of an "open" lesion. *Am J Otol* 1998;19(1):37 [PMID: 9455945]. (Investigation of the occurrence of an "open" form of congenital cholesteatoma.)

Swartz JD. Imaging diagnosis of middle ear lesions. *Curr Probl Diagn Radiol* 2002;31(1):4 [PMID: 11859313]. (A review and description of middle ear lesions.)

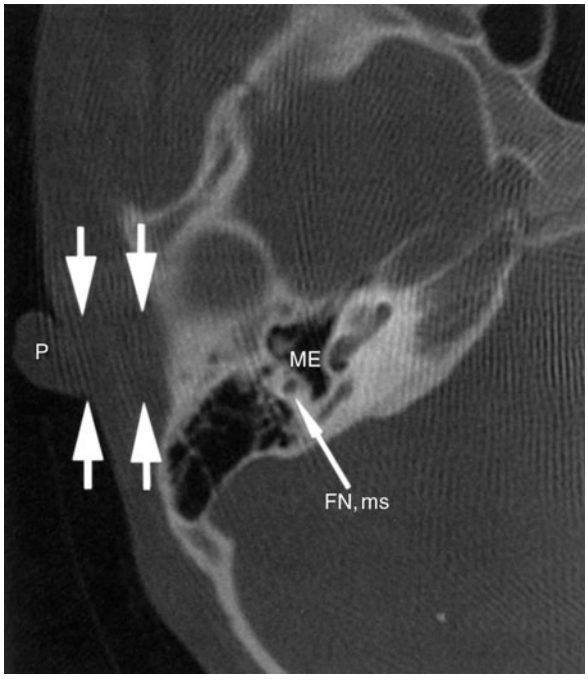
Veillon F, Riehm S, Emaschescu B et al. Imaging of the windows of the temporal bone. *Semin Ultrasound CT MR* 2001;22(3):271 [PMID: 11451100]. (Detailed description of anatomy and pathology involving the round window.)

3. Inner Ear

Anatomy

The inner ear contains structures for hearing and balance (see Figure 3–140). The cisternal portions of CN VII and VIII exit the pons near the level of the middle cerebellar peduncles. The nerves enter the internal auditory canal through the porus acusticus. The internal auditory canal, in cross section, can be divided into four quadrants, each of which contains a nerve. The crista falciformis divides the upper two quadrants from the lower two quadrants, and "Bill's bar" divides the anterosuperior quadrant from the posterosuperior quadrant. In the anterosuperior quadrant is the facial nerve, which cannot be visualized in the internal auditory canal on CT scans but can be well seen on a thin-section T2-weighted MR scan. Below it, in the anteroinferior quadrant, is the cochlear nerve. In the posterosuperior quadrant is the superior division of the vestibular nerve. In the posteroinferior quadrant is the inferior division of the vestibular nerve. The vestibular nerves are posterior to the facial and cochlear nerves. The mnemonic "seven-up, coke down" reminds us to place CN VII (the facial nerve) superior to the cochlear nerve. The nerves in the posterior quadrants are easy to arrange since one has the superior and inferior divisions of the vestibular nerve. High-resolution sagittal and axial T2-weighted images demonstrating this anatomy are shown in Figure 3–151.

In any discussion of the anatomy of the inner ear, understanding the compartmentalization of endolymph and perilymph is useful. The structures that are visualized on CT scans represent the bony shell of the inner ear structures. An inner membrane lines the bony walls and forms a "soft shell" of ducts that essentially parallels the bony structures.



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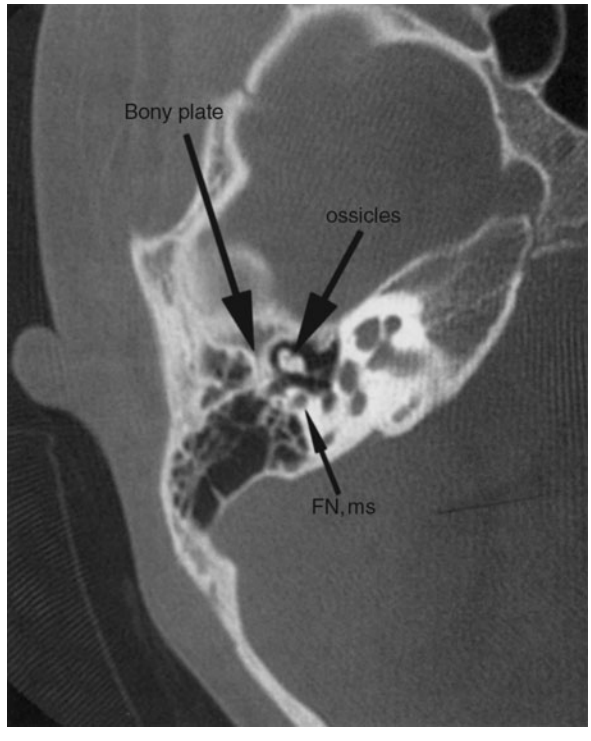

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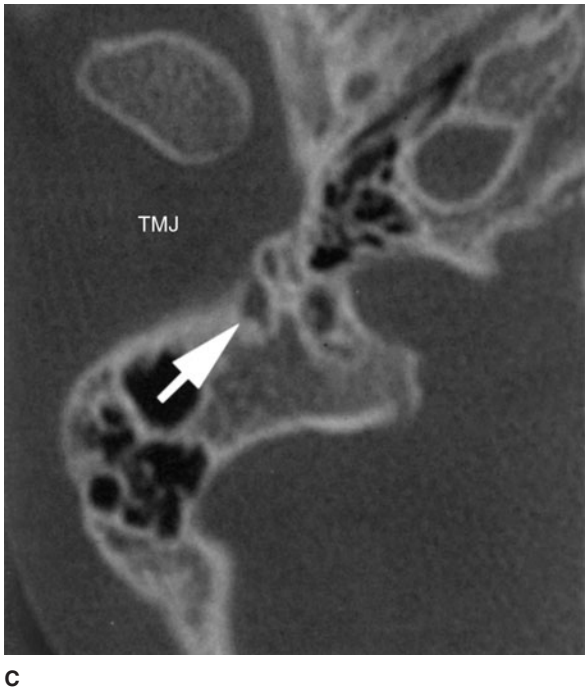
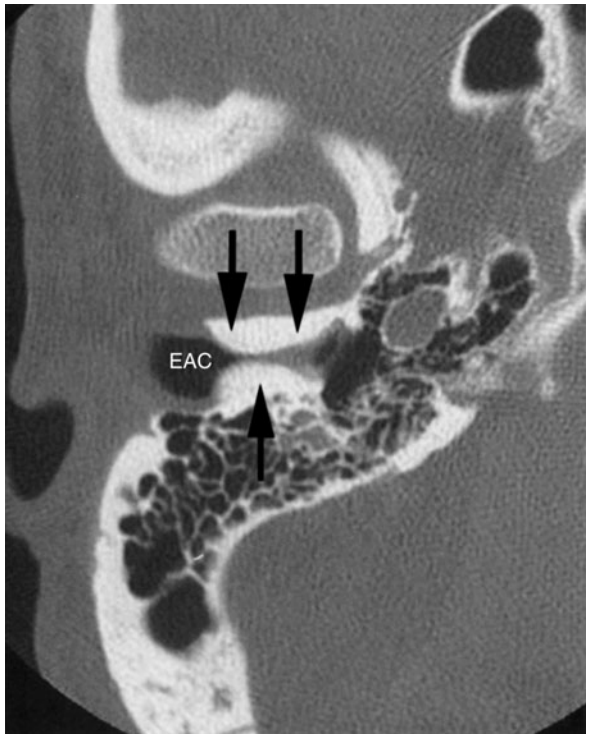


C

▲ **Figure 3–141.** External auditory canal atresia. **(A)** Axial CT scan viewed in bone window demonstrates a malformed pinna (P) and absence of the external auditory canal (white arrows indicate expected position of the EAC). The middle ear (ME) and descending mastoid segment of facial nerve (FN, ms) are indicated. **(B)** A more superior image in the same patient demonstrates a small middle ear cleft, a bony atresia plate, and dysplasticappearing ossicles. The inner ear is normal. **(C)** At a more inferior level, the facial nerve (arrow) exits into the posterior aspect of the temporomandibular joint (TMJ), more anterior and lateral than normal.



▲ **Figure 3–142.** Exostosis ("surfer's ear"). Axial CT scan viewed in bone window demonstrates a marked narrowing of the external auditory canal by bony overgrowths (black arrows) representing exostoses. Abnormal soft tissue is secondary to impacted cerumen. The opposite side (not shown) was identical.

Endolymph is the fluid that fills the membranous shell. Perilymph is the fluid that fills the space between the inner membranous soft shell and the outer bony shell. The oval window and the round window are openings onto the perilymphatic space.

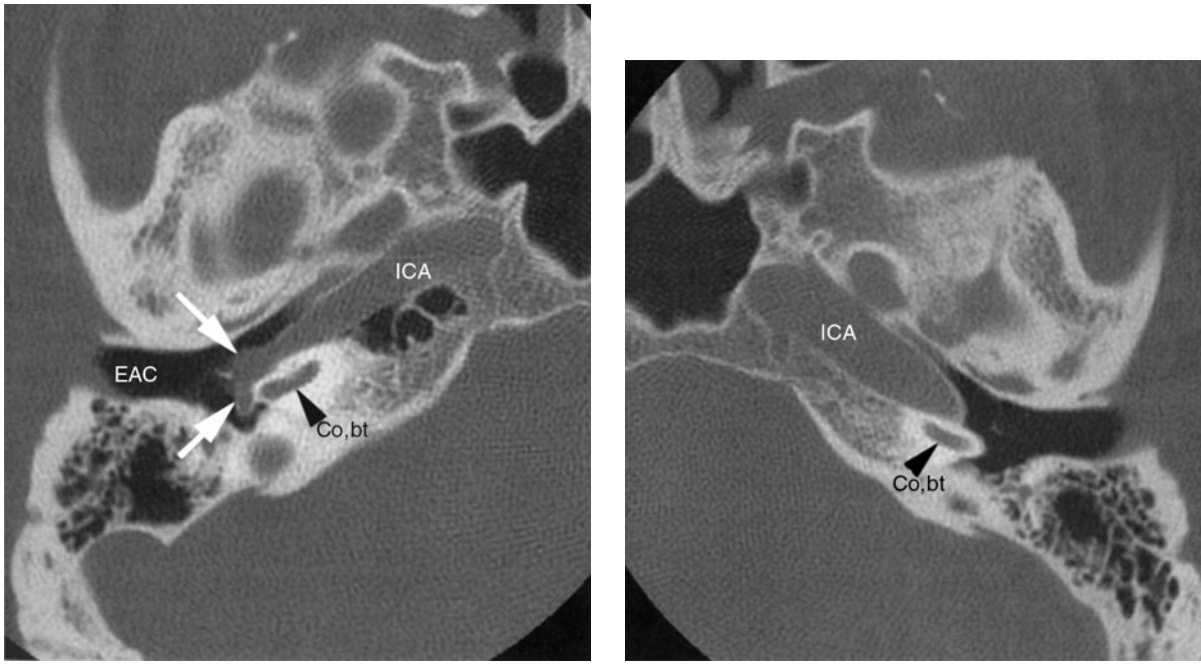
The cochlear nerve arises from the spiral ganglion, which resides in the bony modiolus of the cochlea. On imaging studies, it is important to inspect the cochlea for 2¼ to 2½ turns. On axial imaging, the base turn, middle turn, and apical turn of the cochlea can be identified. Within the cochlea, the scala vestibuli begins at the oval window, spirals to reach the helicotrema at the apex of the cochlea, and then spirals back down as the scala tympani. The scala tympani terminates at the round window. The scala vestibuli and scala tympani contain perilymph. The cochlear duct spirals between the scala vestibuli and scala tympani to the helicotrema. The cochlear duct is part of the membranous labyrinth and contains endolymph. Differentiating the scala vestibuli, cochlear duct, and scala tympani is not possible on routine CT and MRI examinations, but is possible to some extent (at least scala tympani and scala vestibuli) with high-resolution MRI.

The superior and inferior divisions of the vestibular nerve enter the bony vestibule and synapse in the vestibular ganglion. The bony vestibule contains the utricle and the saccule. The utricle and the saccule contain a motion-sensitive structure called the macula, which helps to determine head position and provides information about acceleration and deceleration. Nerve fibers from the utricle and saccule originate from the vestibular ganglion.

There are three horseshoe-shaped semicircular canals: the lateral, the superior, and the posterior semicircular canals, which are at right angles to one another. The posterior

Table 3–13. Abnormalities of the Middle Ear.

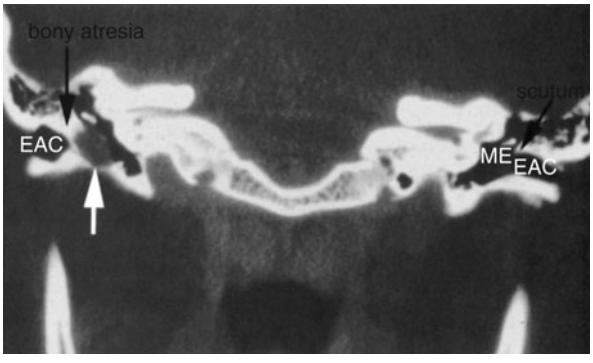
Congenital Vascular Abnormalities	Congenital Masses	Inflammatory Abnormalities	Infectious Abnormalities	Neoplastic Masses		Ossicular Abnormalities
				Benign	*Malignant*	
Aberrant internal carotid artery	Congenital cholesteatoma	Acquired cholesteatoma —Pars flaccida —Pars tensa	Otitis media	Paraganglioma	Squamous cell carcinoma	Ossicular fixation
Persistent stapedial artery		Cholesterol granuloma		Hemangioma	Adenocarcinoma	Ossicular erosion
Dehiscent jugular bulb		Langerhans cell histiocytosis (eosinophilic granuloma)		Meningioma	Adenoid cystic carcinoma	Ossicular dislocation
		Tympanosclerosis		Osseous tumors	Metastasis	Ossicular deformity
						Ossicular prosthesis



▲ **Figure 3–143.** Aberrant internal carotid artery (ICA) in a patient presenting with right pulsatile tinnitus and a vascular retrotympanic mass. **(A)** Axial CT scan viewed in bone window demonstrates the aberrant ICA coursing through the middle ear cavity (white arrows) and overlying the cochlear promontory. The base turn of the cochlea is indicated (black arrow). The course of this carotid artery is more posterolateral than normal. **(B)** Contralateral ICA in the same patient shows the normal course of the horizontal segment of the ICA and a normal bony covering over the carotid canal.

and superior semicircular canals share a common crus. Therefore, there are five (instead of six) connections to the utricle. Each canal contains a semicircular duct, which is part of the membranous labyrinth, surrounded by perilymph. Each semicircular duct has an ampulla that contains cristae that are sensitive to movements of the head. Nerve fibers run from the ampullae to the vestibular ganglion. The superior semicircular canal normally protrudes into the middle cranial fossa. This small bony protrusion is called the arcuate eminence. In some cases, a dehiscence of the bony covering of the superior semicircular canal may be present, a condition that has been associated with sound- and/or pressure-induced vertigo. There is normally only a thin bony covering over the lateral aspect of the lateral semicircular canal, and this can potentially be a site of fistulous connection between the middle ear and inner ear structures, typically in the setting of infection or cholesteatoma.

The facial nerve has a complex course through the inner ear. After it leaves the internal auditory canal, it curves anteromedially for a short distance to the geniculate ganglion. This first segment of the facial nerve is called the labyrinthine segment, and it travels in the bony Fallopian canal. From the geniculate ganglion, the greater superficial petrosal nerve continues forward in the anteromedial direction. From the geniculate ganglion, the facial nerve reverses course and takes a straight course posterolaterally, just under the lateral semicircular canal, until it reaches the posterior genu. This second segment is called the horizontal or tympanic segment. From the posterior genu, the facial nerve makes an almost 90° turn and heads directly downward, just posterolateral to the facial nerve recess. This is known as the vertical or descending mastoid segment of the facial nerve. The stapedius nerve branches from the high mastoid segment of the facial nerve to innervate the stapedius muscle. The chorda tympani branches from the inferior aspect of the vertical segment of the facial nerve and enters the middle ear cavity, where it then crosses between the manubrium of the malleus and the long process of the incus. The chorda tympani innervates the tongue (for taste) and the submandibular and sublingual glands. The vertical segment exits the stylomastoid foramen, located between the styloid process and the mastoid tip. The nerve then enters the substance of the parotid gland, where it ramified into (typically five) major branches (temporal, zygomatic, buccal, marginal mandibular, cervical).



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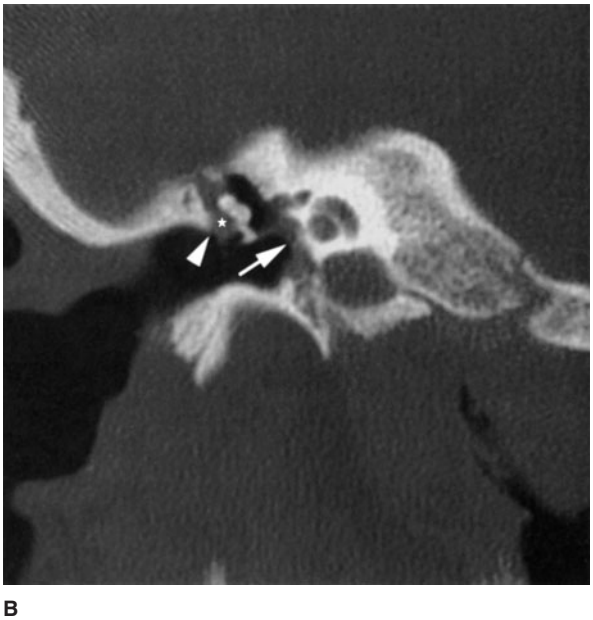

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▲ **Figure 3–144.** Cholesteatomas, congenital and acquired. **(A)** Coronal CT scan (intermediate window) demonstrates bony atresia of the right external auditory canal (EAC). Medial to the atretic plate is a rounded soft tissue mass (white arrow) that has caused some bone remodeling. At surgery, a congenital cholesteatoma was confirmed. ME, middle ear. **(B)** Coronal CT scan viewed in bone window in an adult with long-standing inflammatory disease of the right middle ear and mastoid demonstrates retraction of the right tympanic membrane (white arrow) and abnormal soft tissue in the middle ear. Soft tissue fills the right Prussak space (*), displacing the ossicles medially, and there is erosion of the scutum (arrowhead). Cholesteatoma was confirmed at surgery.

The cochlear aqueduct is a bony canal that connects the cochlea to the intracranial subarachnoid space. This aqueduct appears like a "mini" version of the internal auditory canal because it is oriented parallel to the internal auditory canal, but is located more caudally. The cochlear aqueduct, which is ultimately in communication with the scala vestibuli, the scala tympani, and the semicircular canals, contains perilymph. The function of the cochlear aqueduct is not well understood, but it is a potential route for meningitis to spread to the inner ear.

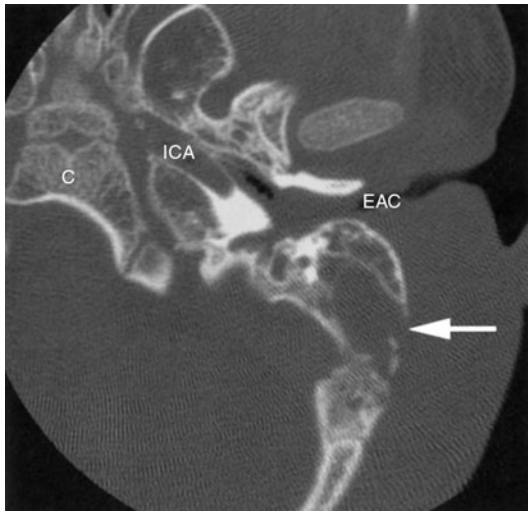
The vestibular aqueduct is another bony connection between the cerebral subarachnoid space and the inner ear. This bony canal is located at the level of the lateral semicircular canal and is oriented almost perpendicular to the internal auditory canal. It extends from the posterior petrous face at the level of the depression for the endolymphatic sac to the vestibule. The vestibular aqueduct contains the endolymphatic duct which, as the name suggests, contains endolymph. The upper limit of the normal size of the vestibular aqueduct is approximately 1.5 mm in diameter at the midpoint between the common crus and the bony aperture of the vestibular aqueduct.

Pathology

Abnormalities that may be encountered on imaging studies of the inner ear are listed in Table 3–14. Narrowing of the internal auditory canal (Figure 3–152) in the setting of congenital sensorineural hearing loss has been associated with cochlear nerve deficiency or absence. An oblique sagittal high-resolution MRI can visualize and evaluate the cochlear nerve within the internal auditory canal to assess directly for its presence and its caliber.

A. Congenital Abnormalities

Congenital abnormalities of the bony labyrinth represent a spectrum of bony abnormalities that are hypothesized to be caused by developmental arrest at specific time points. Since the development of the inner ear is separate from the development of the external and middle ears, congenital malformations of the inner ear are usually not associated with malformations of the external and middle ears. This separation is not absolute, however, and inner ear malformations can occur with external and middle ear malformations (and vice versa). Michel deformity is complete aplasia of the labyrinth. On imaging, there is total absence of the normal inner ear structures. In the Mondini malformation, or incomplete partition of the cochlea, there are only l½ turns of the cochlea owing to the confluence of the middle and apical turns. The basal turn is normal. The common cavity is seen when the cochlea, the vestibule, and the semicircular canals appear to merge into one large cavity (Figure 3–153). In semicircular canal dysplasia and aplasia, one or more of the canals may be abnormal. As the lateral semicircular canal develops after the other two



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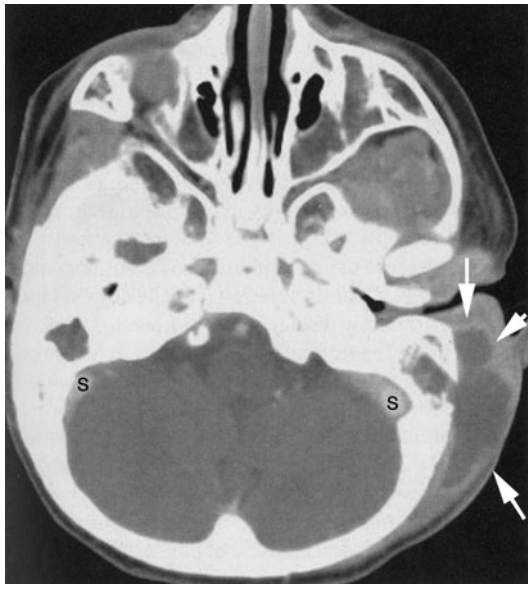

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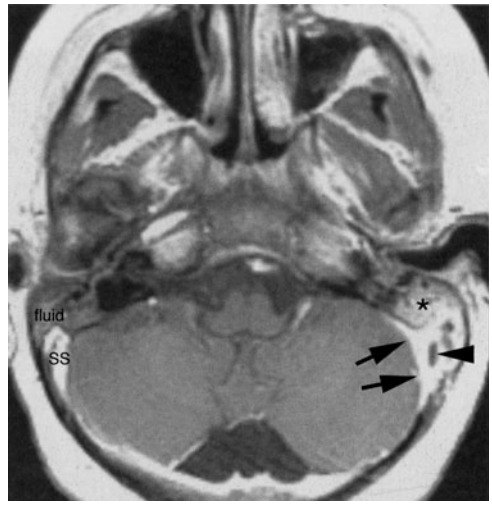
▲ **Figure 3–145.** Coalescent mastoiditis. **(A)** Axial CT scan viewed in bone window demonstrates soft tissue narrowing of the external auditory canal, abnormal soft tissue in the middle ear cavity, and opacification of mastoid air cells. Erosion of multiple mastoid septa is consistent with coalescent mastoiditis. A focal defect is present (white arrow) in the lateral mastoid cortex, and marked overlying soft tissue swelling is seen. C, clivus; ICA, internal carotid artery; EAC, external auditory canal. **(B)** Postcontrast CT scan in the same patient demonstrates a large abscess (white arrows) involving the mastoid and extending laterally into adjacent soft tissues. The sigmoid sinuses (S) are patent bilaterally.



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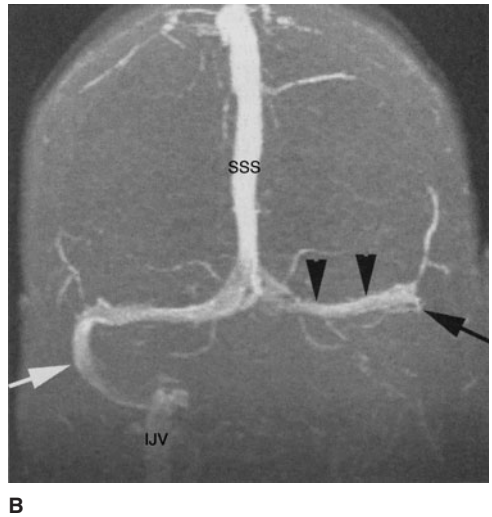
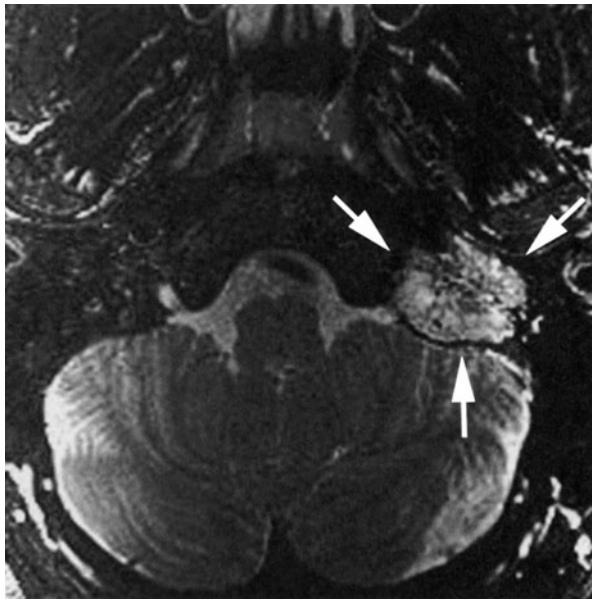


B

▲ **Figure 3–146.** Mastoiditis and sigmoid sinus thrombosis. **(A)** Postgadolinium axial T1-weighted sequence shows enhancement in the left mastoid air cells (*) with adjacent intracranial extension and intense enhancement of dura at the level of the sigmoid sinus (arrows). Nonspecific mastoid fluid and a normal sigmoid sinus (SS) are indicated on the right. A focal area of nonenhancement (arrowhead) is suggestive of a partial or complete sigmoid sinus thrombosis. **(B)** MR venogram of the same patient shows a lack of flow-related enhancement of the left sigmoid sinus and internal jugular vein, confirming sigmoid sinus thrombosis. The black arrow indicates the junction of the patent transverse sinus (black arrowheads) with the thrombosed sigmoid sinus. Note the normal and patent right sigmoid sinus (white arrow). The patent superior sagittal sinus (SSS) and right internal jugular vein (IJV) are also indicated.



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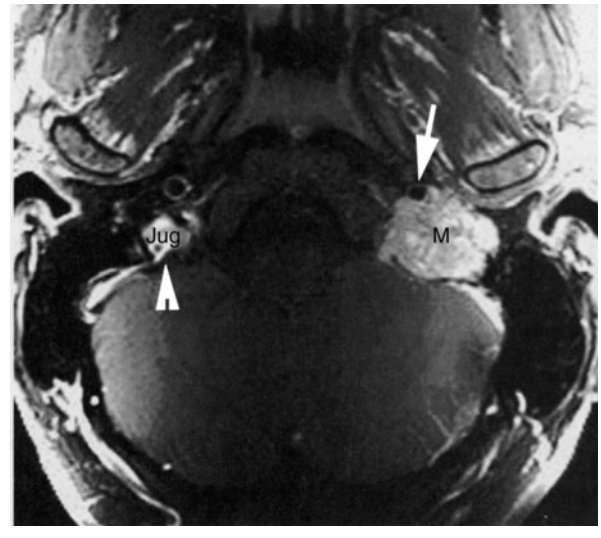

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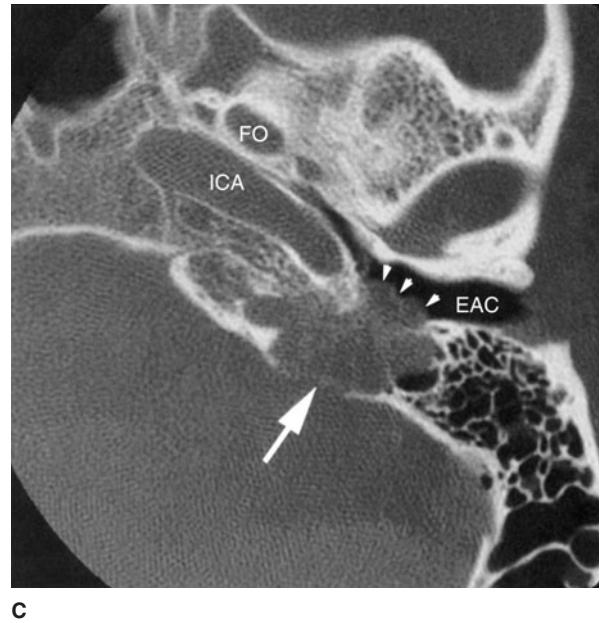

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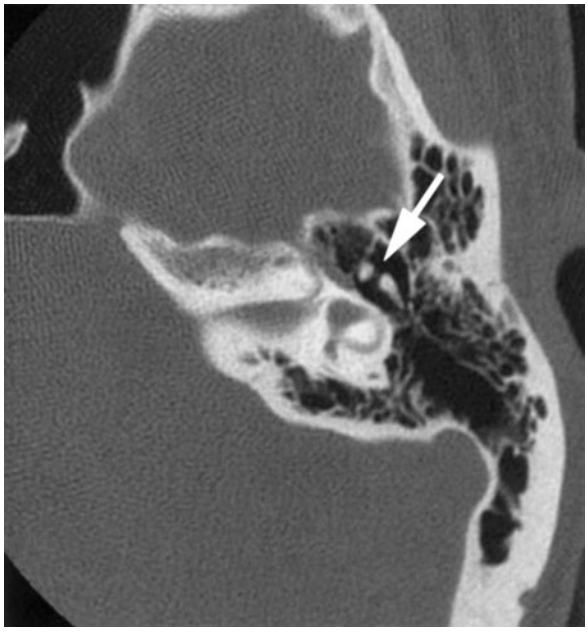
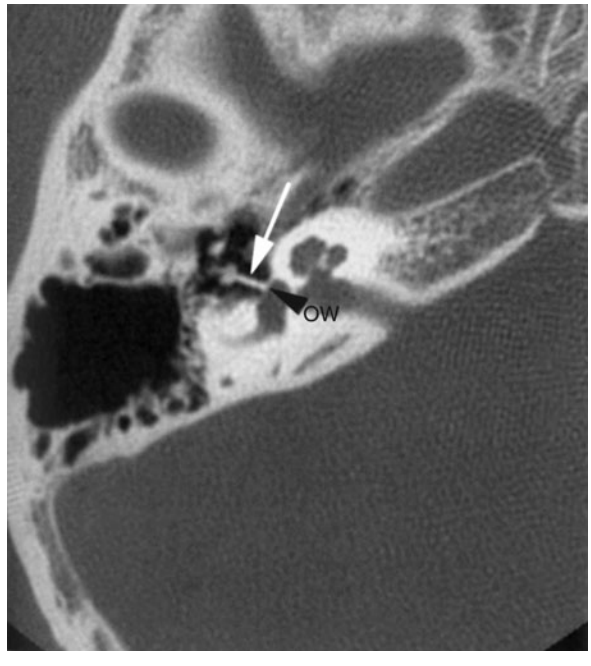
▲ **Figure 3–147.** Paraganglioma. **(A)** Axial T2-weighted image shows a soft tissue mass centered at the jugular foramen (white arrows) with a "salt-and-pepper" appearance. The "pepper" represents small flow voids in this vascular tumor. **(B)** Axial postgadolinium T1-weighted image in the same patient shows the avid enhancement of this highly vascular mass lesion (M). The close relationship to the anteriorly displaced left ICA (white arrow) is demonstrated. The normal right jugular bulb (white arrowhead) is shown for comparison. **(C)** Axial CT scan viewed in bone window in the same patient demonstrates a lobulated lesion (white arrow) that has eroded the bone of the adjacent petrous apex, mastoid, and external auditory canal, and has extended into the hypotympanum (white arrowheads). This is consistent with a glomus jugulotympanicum type of paraganglioma. FO, foramen ovale; ICA, internal carotid artery; EAC, external auditory canal.

canals have already developed, abnormal development can affect the lateral semicircular canal in isolation after the other two semicircular canals have already developed normally, whereas an abnormality earlier in development that affects the posterior or superior semicircular canals generally also affects the subsequently developing lateral semicircular canal. Enlarged vestibular aqueduct syndrome (Figure 3–154) is the most common imaging abnormality in sensorineural hearing loss presenting in infancy or childhood. At the midpoint between the opening of the aqueduct to the subarachnoid space and the common crus, the vestibular aqueduct should measure no more than 1.5 mm. Comparing the diameter with the width of the lateral semicircular canal may also be useful, because



▲ **Figure 3–148.** Ossicular dislocation. The head of the malleus is dislocated from the short process of the incus. The normal "ice cream cone" appearance is disrupted, and the "ice cream" has fallen off the "cone." The white arrow indicates the widened, disrupted malleoincudal articulation.



▲ **Figure 3–149.** Axial CT scan viewed in bone window demonstrates a partial ossicular reconstruction prosthesis (arrow) extending from the oval window (OW) (arrowhead) toward the undersurface of the incus.

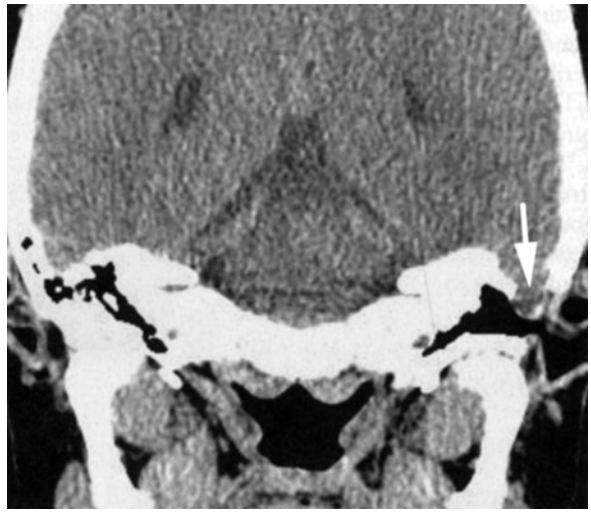
they are normally equivalent, or the vestibular aqueduct is smaller. Sometimes the bony vestibular aqueduct appears normal on a CT scan, but an MRI may show an enlarged endolymphatic sac. The large vestibular aqueduct is often associated with cochlear abnormalities, notably a deficiency of the modiolus.

B. Otosclerosis

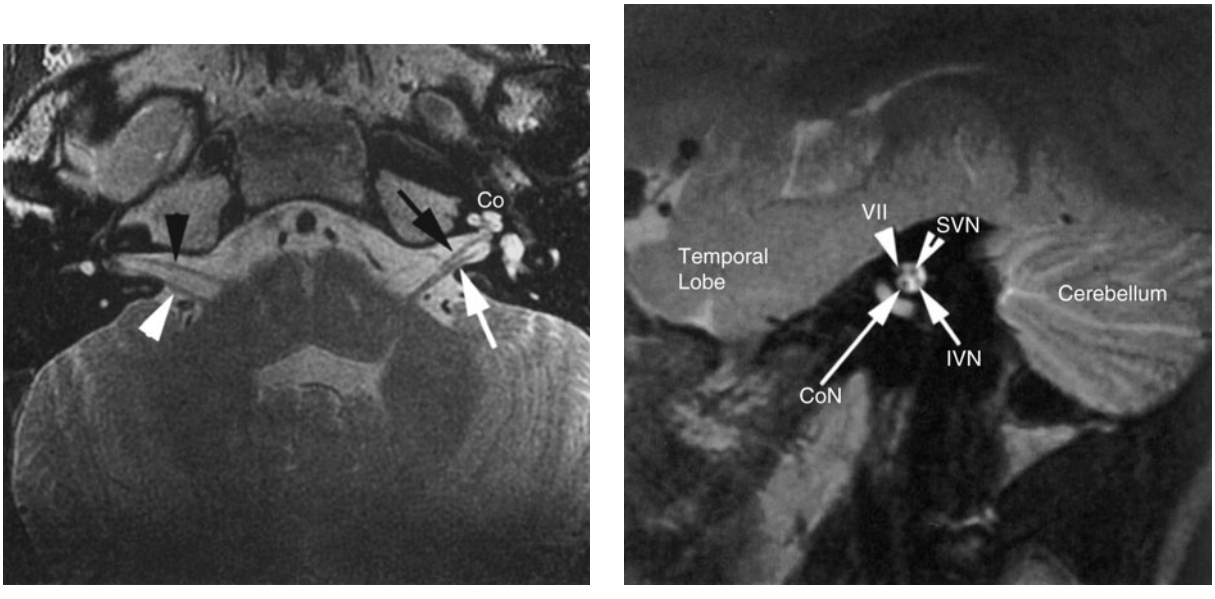
Otosclerosis is divided into two types: fenestral and retrofenestral.

1. Fenestral otosclerosis—Fenestral otosclerosis (Figure 3–155) is the most common form and involves the oval window and the footplate of the stapes. The most common imaging finding is a subtle bony rarefaction at the anterior wall of the oval window. This rarefaction is due to the replacement of normal bone with hypodense spongiotic bone. The bony abnormality extends to the stapes footplate. Eventually, sclerotic changes develop and fix the stapes to the oval window. This entity presents with a conductive hearing loss.

2. Retrofenestral otosclerosis—Retrofenestral otosclerosis (Figure 3–156) is also known as cochlear otosclerosis and



▲ **Figure 3–150.** Coronal CT scan viewed in bone window in a patient who has undergone a prior mastoidectomy demonstrates the inferior herniation of brain tissue and meninges (white arrow) through a surgical defect into the external auditory canal.



▲ **Figure 3–151. (A)** Axial T2-weighted image shows the four nerves of the internal auditory canal. On this asymmetrically positioned image, the right internal auditory canal (IAC) is at a slightly higher level than the left. Therefore, the two nerves entering the right IAC are the facial nerve (black arrowhead) and the superior division of the vestibular nerve (white arrowhead). In the left IAC, the more anterior nerve that enters the cochlea (Co) is the cochlear nerve (black arrow) and the posterior nerve is the inferior division of the vestibular nerve (white arrow). **(B)** Sagittal T2-weighted image through the IAC shows the four nerves in cross-section. The anterior and superior nerve is the facial nerve (VII, arrowhead). The anterior and inferior nerve is the cochlear nerve (CoN, long arrow). The posterior and superior nerve is the superior division of the vestibular nerve (SVN, notched arrowhead). The posterior and inferior nerve is the inferior division of the vestibular nerve (IVN, short arrow). (Image contributed by Dr. Christine Glastonbury, University of California, San Francisco.)

presents as a sensorineural or mixed hearing loss. On CT scanning, a ring of lucency around the cochlea is characteristic of this disease. On MRI, the abnormal bone shows high signal intensity on T2-weighted images and enhancement postgadolinium.

C. Schwannomas

Schwannomas can occur in the labyrinth as well as in the more common location of the internal auditory canal and cerebellopontine angle. They may arise in the vestibule or cochlea (branches of CN VIII, Figure 3–157) or along the course of the facial nerve (CN VII, Figure 3–158). Facial nerve schwannomas tend to occur at the geniculate ganglion, but may occur anywhere along the course of the facial nerve. Occasionally they can enlarge significantly and extend anteriorly and superiorly into the middle cranial fossa, presenting with seizures or other symptoms due to brain compression.

D. Temporal Bone "Hemangiomas"

Temporal bone hemangiomas are actually venous malformations of the temporal bone that tend to occur along the temporal bone course of the facial nerve and also at the level of the internal auditory canal. Some are associated with bony spicules and have been called ossifying hemangiomas. On CT scans, focal enlargement of the facial nerve canal and the presence of irregular calcification or ossification suggest this lesion. On MRI, these lesions are typically bright on T2-weighted images and enhance intensely postgadolinium (Figure 3–159).

E. Endolymphatic Sac Tumors

Endolymphatic sac tumors (Figure 3–160) are locally aggressive papillary neoplasms that arise from the endolymphatic duct, sac, or both and aggressively erode and remodel bone along the posterior petrous face and the otic capsule. They can cause signal abnormalities within the structures of the

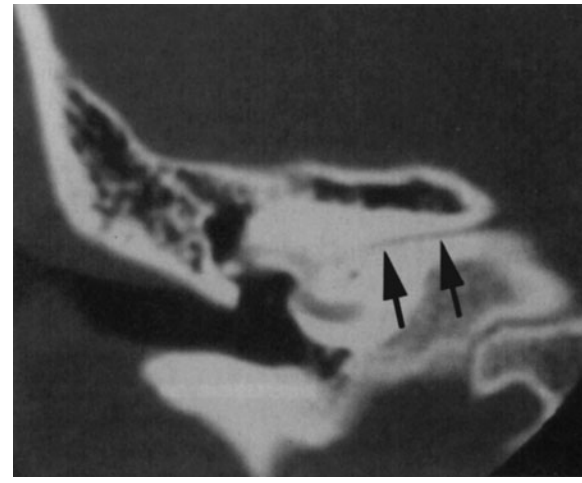
Table 3–14. Abnormalities of the Inner Ear.

Congenital	
Internal auditory canal	Narrow (Figure 3–152)
Bony labyrinth	Michel (labyrinthine aplasia)
	Mondini (incomplete partition of the cochlea)
	Common cavity (Figure 3–153)
	Cochlear aplasia/hypoplasia
	Semicircular canal dysplasia/aplasia
	Large vestibular aqueduct syndrome (Figure 3–154)
Membranous labyrinth	Scheibe
	Alexander
Otodystrophies	Otosclerosis/otospongiosis
	Fenestral (Figure 3–155)
	Retrofenestral (Figure 3–156)
	Paget's
	Fibrous dysplasia
	Osteopetrosis
	Osteogenesis imperfecta
Masses	Intralabyrinthine schwannoma (Figure 3–157)
	Facial nerve schwannoma (Figure 3–158)
	Hemangioma (Figure 3–159)
	Endolymphatic duct tumors (Figure 3–160)
	Metastases/with perineural spread of tumor (Figure 3–161)
Inflammation	Labyrinthitis and labyrinthitis ossificans (Figure 3–162)
	Postradiation labyrinthitis (Figure 3–163)
Trauma	Fracture/pneumolabyrinth (Figure 3–164)

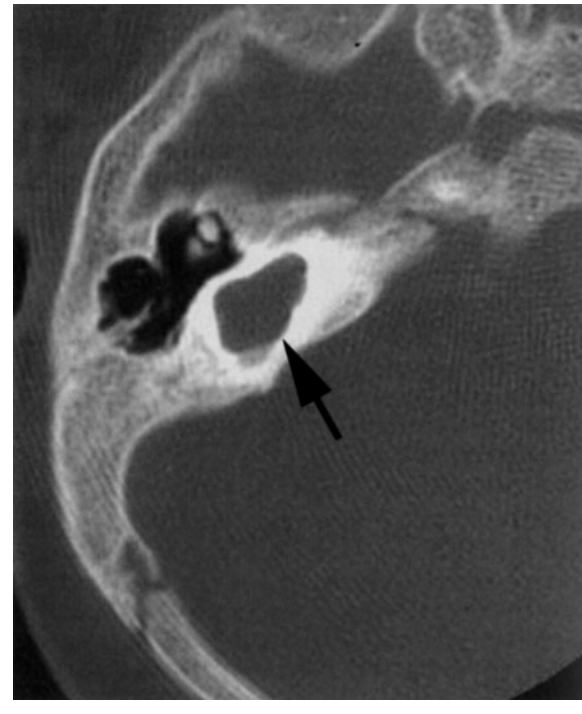
inner ear secondary to fistulization and hemorrhage. These lesions are heterogeneous on MRI and show prominent flow voids and marked enhancement. An increased incidence of these lesions is seen in von Hippel–Lindau syndrome.

F. Perineural Spread

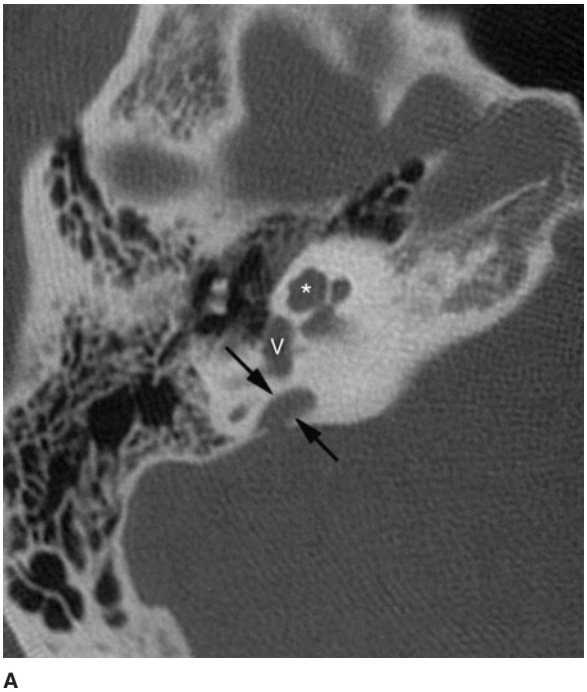
Perineural spread from a malignant parotid tumor extending back along the facial nerve (Figure 3–161) is important to identify. These patients usually present with a parotid mass, but, in some cases, only a new or progressive facial palsy or even a middle or inner ear mass may be noted initially.



▲ **Figure 3–152.** Narrowing of the internal auditory canal (IAC). Coronal CT scan viewed in bone window in a young girl with congenital sensorineural hearing loss demonstrates marked narrowing of the internal auditory canal. In these cases (if MRI is performed), very often only the facial nerve runs through the IAC and the vestibular and cochlear nerves are absent.



▲ **Figure 3–153.** Common cavity. Axial CT scan viewed in bone window demonstrates that the cochlea, vestibule, and semicircular canals appear "merged" into a common cavity rather than having developed into distinct structures.



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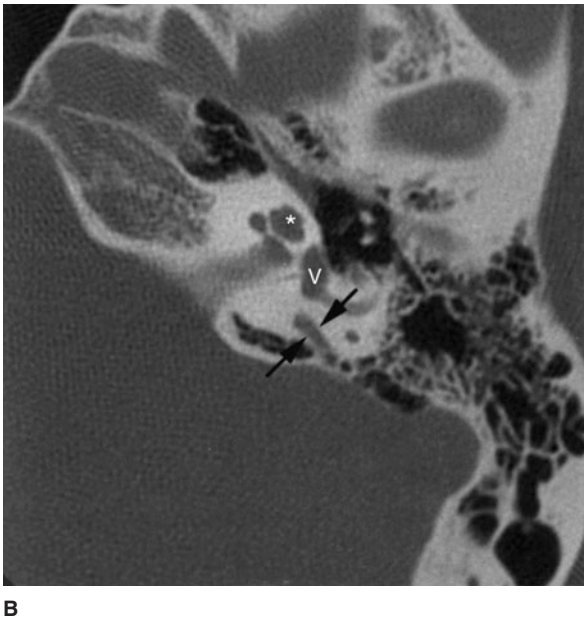

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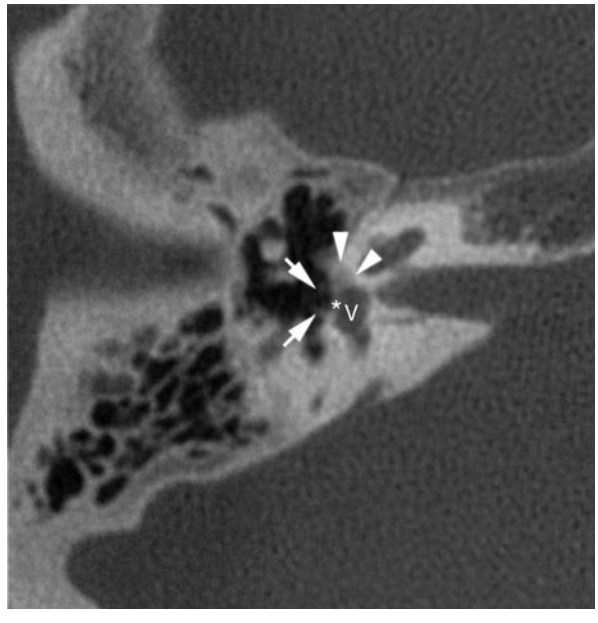
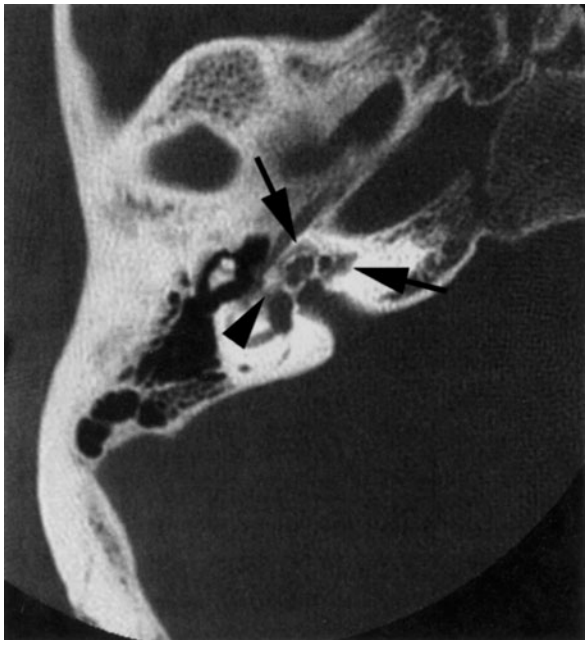
▲ **Figure 3–154.** Enlarged vestibular aqueduct syndrome in a 40-year-old man with bilateral sensorineural hearing loss. **(A)** Axial CT scan viewed in bone window of the right temporal bone demonstrates enlargement of the vestibular aqueduct (black arrows) as well as deficiency of the cochlear modiolus (*). **(B)** The left temporal bone shows similar changes, but with less severe enlargement of the vestibular aqueduct. The vestibule (V) is also indicated.



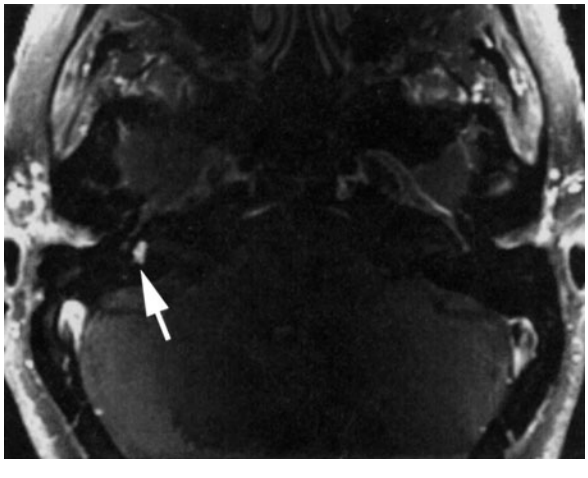
▲ **Figure 3–155.** Fenestral otosclerosis. Axial CT scan viewed in bone window demonstrates the focal rarefaction of bone (white arrowheads) lateral to the cochlea and anterior to the vestibule. The oval window is indicated (*), as are the crura of the stapes (white arrows).

G. Inflammation and Infection

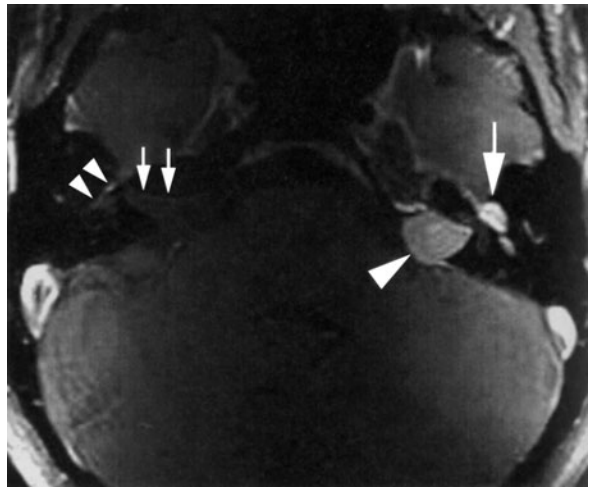
Inflammatory and infectious processes of the inner ear can be classified by origin and etiology: tympanogenic, meningogenic, hematogenic, autoimmune, or post-traumatic. In tympanogenic labyrinthitis, inflammatory processes of the middle ear can spread by direct extension into the inner ear, usually through the oval or round windows. Infection can also spread through a fistula, most commonly involving the lateral semicircular canal. Tympanogenic labyrinthitis is usually unilateral. Meningogenic labyrinthitis is usually bilateral, with organisms and inflammatory cells entering the inner ear via the internal auditory canal or the cochlear aqueduct. The classic pathogens that cause hematogenic labyrinthitis are mumps and measles, and this is typically bilateral. Acute labyrinthitis can be identified on MRI when it causes a change in the signal intensity of inner ear fluid, enhancement of inner ear structures, or both. Labyrinthitis can lead to an increased intensity on T1-weighted images within the membranous labyrinth from elevated protein content or hemorrhage secondary to inflammation. Postgadolinium, there is typically intense contrast enhancement within the labyrinth, which may persist over weeks or even months. Pregadolinium T1-weighted images are especially helpful to determine that the hyperintensity seen on postgadolinium



▲ **Figure 3–156.** Retrofenestral otosclerosis. Axial CT scan viewed in bone window demonstrates rarefied bone (black arrows) surrounding the cochlea. Note that the abnormality also involves bone adjacent to the oval window (black arrowhead).



▲ **Figure 3–157.** Schwannoma of the vestibule in a young man with an acute right-sided sensorineural hearing loss. Postgadolinium T1-weighted image with fat saturation shows a masslike enhancement in the vestibule (arrow) with extension into the semicircular canals. Initial considerations included intralabyrinthine schwannoma versus labyrinthitis. Over months of follow-up, the lesion gradually progressed and an intralabyrinthine schwannoma was eventually confirmed surgically.



▲ **Figure 3–158.** Facial nerve schwannoma. Axial postgadolinium T1-weighted image with fat saturation shows an enhancing mass in the internal auditory canal (IAC; white arrowhead) and also along the horizontal portion (tympanic segment) of CN VII (white arrow). The normal right IAC (double small arrows) and normal right tympanic segment of the facial nerve (double small arrowheads) are indicated for comparison.

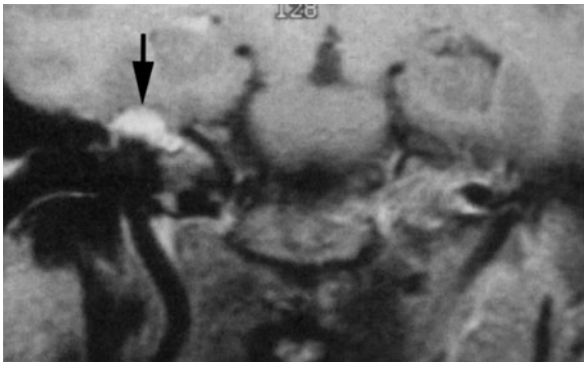
T1-weighted images in the membranous labyrinth is due to hemorrhage and not actually abnormal enhancement due to an intralabyrinthine mass. If no abnormality on a pregadolinium T1-weighted image is seen and fairly focal enhancement postgadolinium is evident, then it is wise to get a follow-up study to make sure that the patient does not have an intralabyrinthine schwannoma that is presenting acutely. Post-labyrinthitis, sclerosis of the bony labyrinth may eventually result. This latter situation is termed labyrinthitis ossificans (Figure 3–162). Labyrinthitis can also be caused by radiation therapy (Figure 3–163) and other noninfectious insults.

H. Anomalous Course of the Facial Nerve

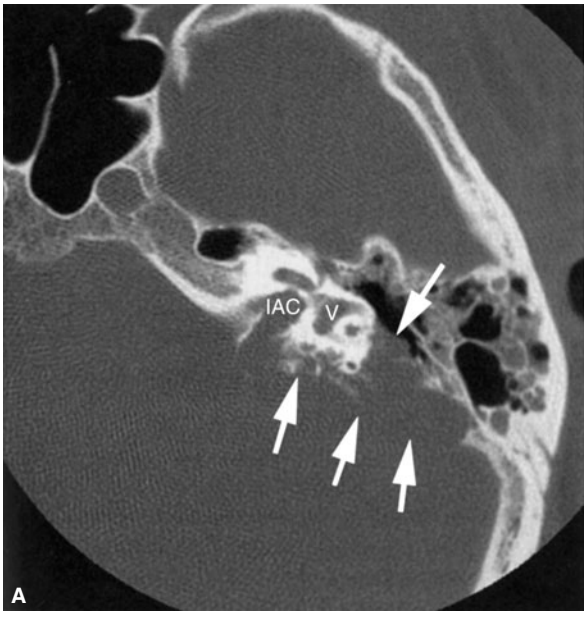
Occasionally, the facial nerve can have an anomalous course through the inner ear. This is most often seen in association with external auditory canal atresia (see Figure 3–141), but it may occur sporadically or in association with syndromic malformations. Knowledge of the course of the facial nerve is important for preoperative planning.

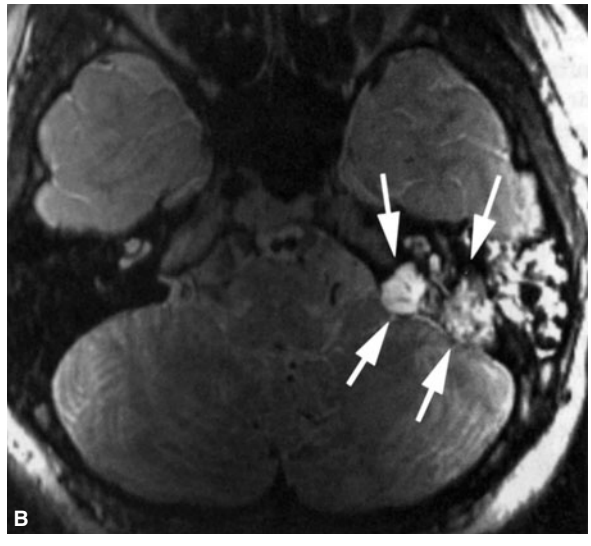
I. Fractures of the Petrous Bone

Fractures of the petrous bone can traverse and injure the structures of the inner ear, as well as disrupting the ossicular chain. In a trauma setting, the finding of fluid in the mastoid

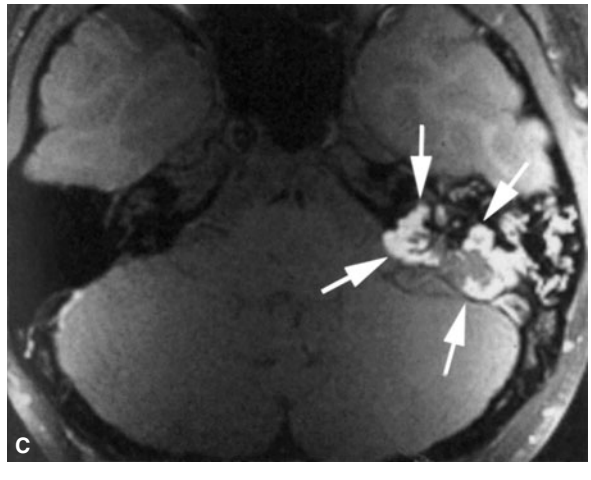


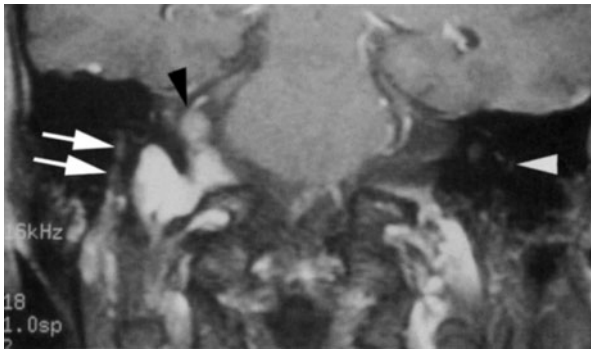
▲ **Figure 3–159.** Hemangioma in a 40-year-old woman with right-sided hemifacial spasm. Postgadolinium coronal T1-weighted image demonstrates an intensely enhancing mass (arrow) at the level of the geniculate ganglion extending up into the middle cranial fossa. The overlying dura is intact and there is no brain involvement. The diagnosis of hemangioma was confirmed at surgery.





▲ **Figure 3–160.** Endolymphatic sac tumor. **(A)** Axial CT scan viewed in bone window demonstrates a destructive lesion (arrows) centered along the posterior petrous bone, eroding the dense bone of the otic capsule and extending into the middle ear and mastoid. IAC, internal auditory canal; V, vestibule. **(B)** Axial T2-weighted image in the same patient shows a very heterogeneous but predominantly hyperintense lesion (arrows). Some of the linear and round areas of signal void represent enlarged vessels, while other areas represent bone fragments. Fluid is present more laterally in the mastoid air cells. **(C)** Axial T1-weighted fat-saturated image shows a heterogeneous, lobulated lesion in the temporal bone (arrows) with areas of intrinsic high signal due to hemorrhagic and proteinaceous material. Note that this is a pregadolinium image. The lack of signal suppression with fat saturation confirms that the high signal intensity areas do not represent fat. Postgadolinium (not shown), enhancement of the center of the lesion was seen.





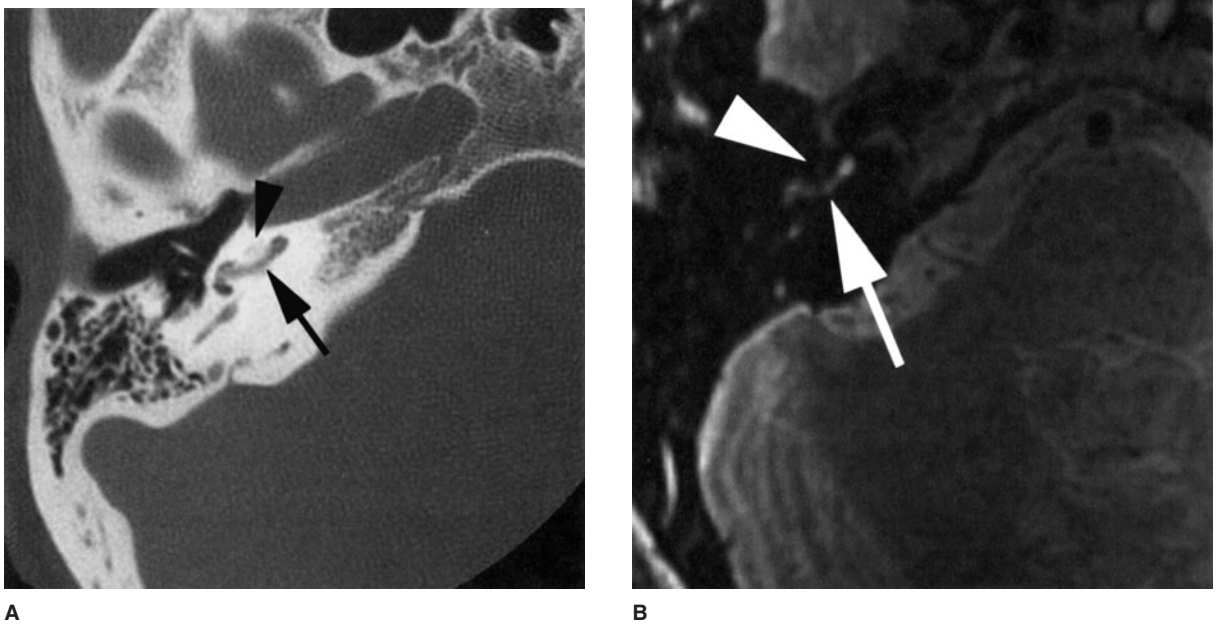
▲ **Figure 3–161.** Perineural spread of parotid adenocarcinoma. Coronal postgadolinium T1-weighted image with fat saturation demonstrates asymmetric thickening and enhancement extending centrally along the descending mastoid segment of the right facial nerve (white arrows). The normal left descending facial nerve is barely seen (white arrowhead). The tumor spread all the way back to the level of the cerebellopontine angle (black arrowhead).

air cells on a CT scan of the head suggests that a temporal bone fracture may be present, as does pneumocephalus in proximity to the mastoid air cells. A dedicated CT scan of the temporal bone should be obtained to more sensitively assess a trauma patient for temporal bone fracture. In some cases, frank pneumolabyrinth may be seen (Figure 3–164).

Casselman JW, Offeciers EF, De Foer B, Govaerts P, Kuhweide R, Somers T. CT and MR imaging of congenital abnormalities of the inner ear and internal auditory canal. *Eur J Radiol* 2001;40(2):94 [PMID: 11704356]. (A description of imaging of inner ear and internal auditory canal abnormalities.)

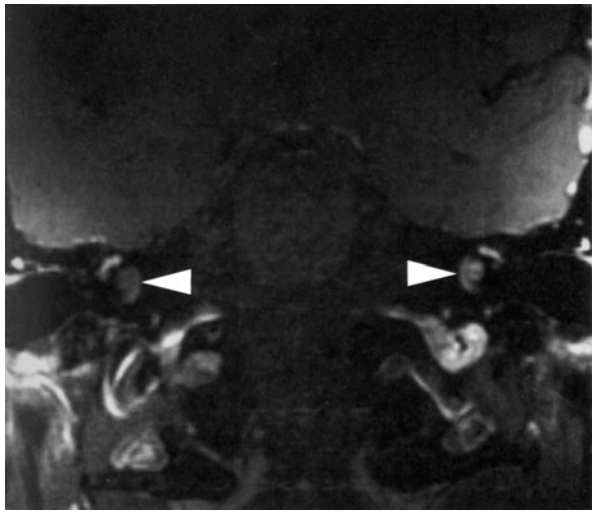
Glastonbury CM, Davidson HC, Harnsberger HR, Butler J, Kertesz TR, Shelton C. Imaging findings of cochlear nerve deficiency. *AJNR Am J Neuroradiol* 2002;23(4):635 [PMID: 11950658]. (Exquisite imaging of anatomy and cochlear deficiency in the internal auditory canal.)

Inanli S, Tutkun A, Ozturk O, Ahyskaly R. Endolymphatic sac tumor: a case report. *Auris Nasus Larynx* 2001;28(3):245 [PMID: 11489369]. (Presentation of a 50-year-old man with endolymphatic sac tumor with a left-sided sensorineural hearing loss.)



A B

▲ **Figure 3–162.** Labyrinthitis ossificans. **(A)** Axial CT scan viewed in bone window demonstrates ossification and therefore poor visualization of the middle and apical turns of the cochlea (arrowhead) as well as narrowing and subtle sclerosis of the base turn of the cochlea (arrow). **(B)** Axial T2-weighted image in the same patient shows absence of expected fluid signal in the middle and apical turns of the cochlea (expected position indicated by arrowhead), consistent with ossification. The base turn is narrowed, but still has some fluid signal within it (arrow). The information about patency of fluid spaces that is obtained on MRI can be useful to determine if a patient is a candidate for cochlear implantation.



▲ **Figure 3–163.** Radiation-induced labyrinthitis. A patient with bilateral hearing loss who had received radiation therapy 10 years earlier after the resection of a medulloblastoma in the posterior fossa. Postgadolinium T1-weighted image with fat saturation shows mild enhancement in the right cochlea (notched arrowhead) and intense enhancement in the left cochlea (arrowhead).

Lemmerling M, Vanzieleghem B, Dhooge I, Van Cauwenberge P, Kunnen M. CT and MRI of the semicircular canals in the normal and diseased temporal bone. *Eur Radiol* 2001;11(7): 1210 [PMID: 11471615]. (A description of the normal and abnormal imaging of the semicircular canals.)

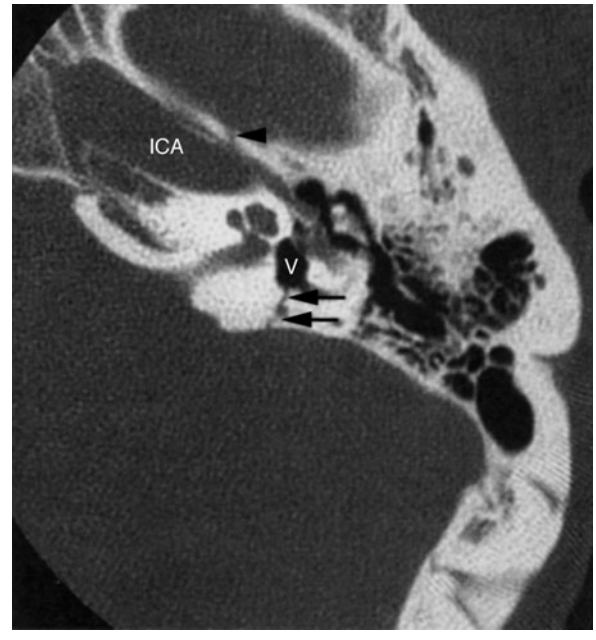
Naidich TP, Mann SS, Som PM. Imaging of the osseous, membranous, and perilymphatic labyrinths. *Neuroimaging Clin N Am* 2000;10(1):23 [PMID: 10658153]. (This article provides a detailed review of the neonatal anatomy and development of these structures, knowledge of which derives in great part from advances in CT scanning and sophisticated MR imaging.)

Swartz JD. Temporal bone trauma. *Semin Ultrasound CT MR* 2001;22(3):219 [PMID: 11451097]. (Temporal bone trauma is subdivided into fractures and pseudofractures, fistulous communication, hearing loss, and facial nerve involvement.)

CEREBELLOPONTINE ANGLE & INTERNAL AUDITORY CANAL

Anatomy

The cerebellopontine angle (CPA) is the region where the pons and the cerebellum meet and form an obtuse angle; the adjacent subarachnoid space is referred to as the cerebellopontine cistern. Lesions at the CPA are usually centered near the level of the middle cerebellar peduncle.



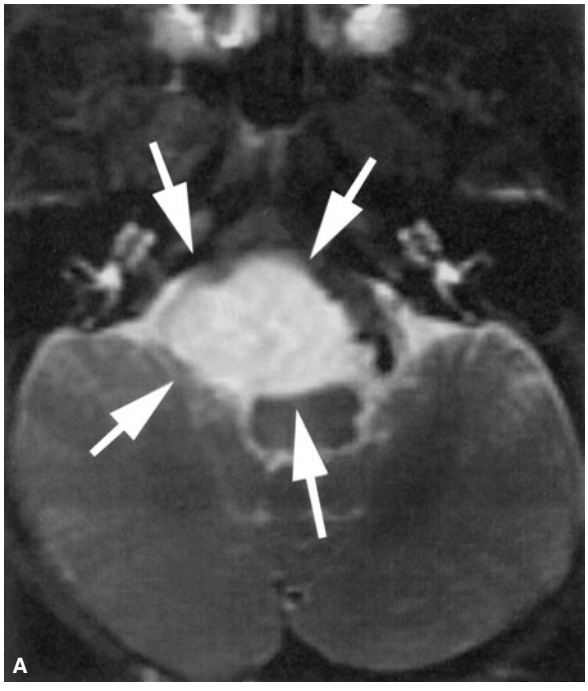
▲ **Figure 3–164.** Fracture. Axial CT scan viewed in bone window demonstrates a transverse fracture (black arrows) traversing the vestibule and causing pneumolabyrinth. The fracture also traversed the carotid canal (black arrowhead), and this finding should raise a clinical suspicion of a vascular injury. ICA, internal carotid artery; V, vestibule.

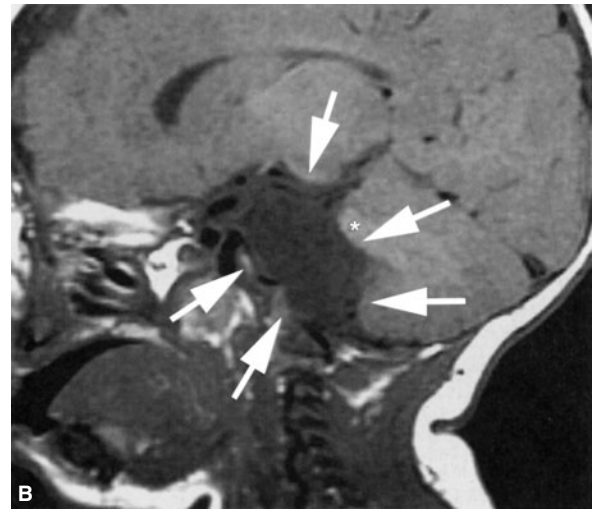
Pathology

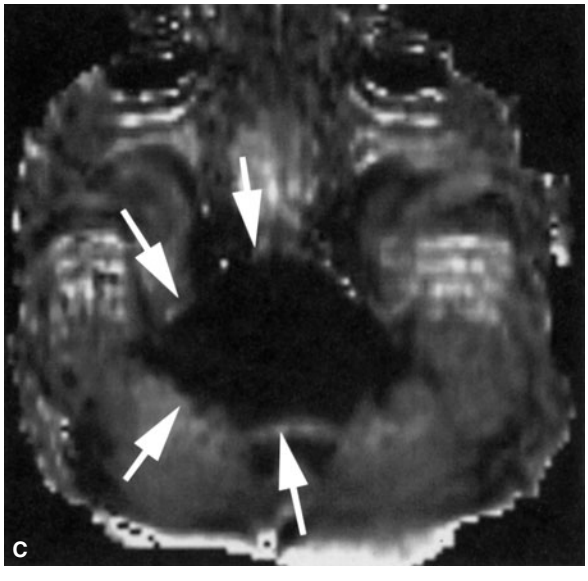
Some of the more common abnormalities that may be encountered on imaging studies of the CPA are listed in Table 3–15, and a number of these entities are illustrated in Figures 3–165 through 3–169. Imaging characteristics of four of the most common CPA tumors are summarized in Table 3–16.

Table 3–15. Selected Abnormalities of the Cerebellopontine Angle and Internal Auditory Canal.

Schwannoma
Meningioma
Arachnoid cyst
Epidermoid
Vascular loop
Lipoma
Superficial siderosis



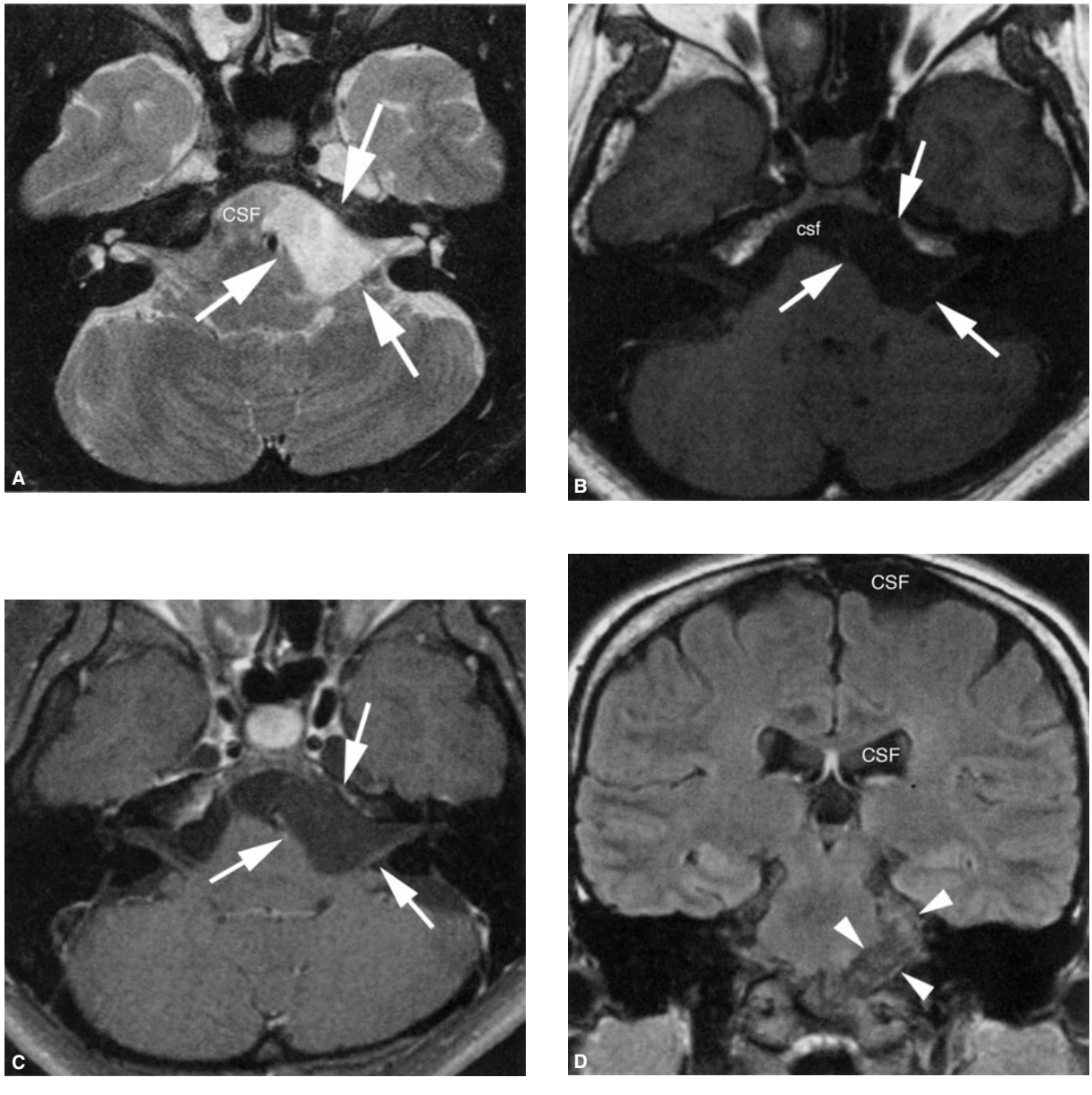




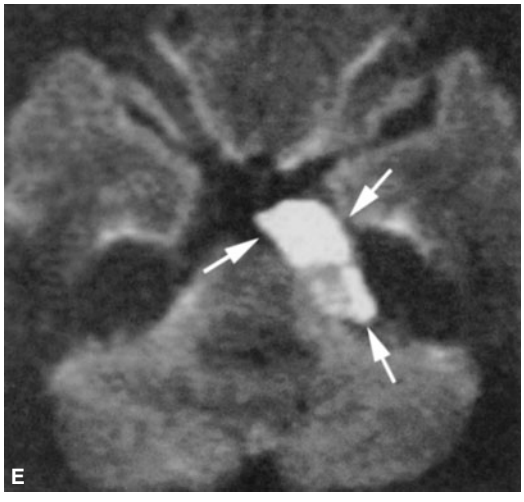
▲ **Figure 3–165.** Arachnoid cyst. **(A)** Axial T2-weighted image shows a hyperintense extra-axial lesion (arrows) causing a mass effect on the medulla and cerebellum. Note the signal intensity is the same as cerebrospinal fluid. **(B)** Sagittal T1-weighted image shows the extra-axial mass (arrows) causing a mass effect on the cerebellum, notably, the middle cerebellar peduncle (*). Again, the signal intensity is the same as cerebrospinal fluid. Following gadolinium administration (not shown), there was no enhancement of the lesion. **(C)** Axial diffusion-weighted image shows a low signal intensity consistent with increased diffusion in the lesion (arrows). Diffusion-weighted imaging is very useful to separate purely cystic lesions from solid masses. In this case, the imaging characteristics on conventional MRI sequences and diffusion-weighted imaging paralleled CSF exactly, confirming the diagnosis of an arachnoid cyst.

A. Vestibular Schwannomas

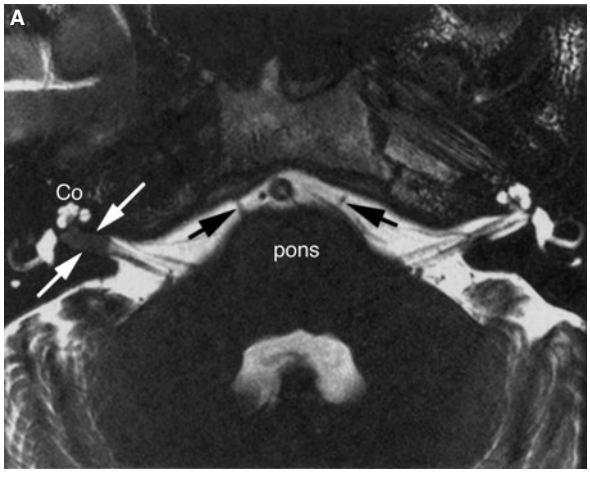
Vestibular schwannomas (Figure 3–167) are also known as acoustic neuromas or eighth nerve schwannomas. These lesions typically present with asymmetric sensorineural hearing loss, but they may also present with tinnitus or may be noted incidentally on imaging studies obtained for other purposes; if large, then they may present with symptoms of hydrocephalus or compression of intracranial structures. These lesions appear as well-circumscribed, round, or ovoid masses that are relatively dark on T2-weighted images compared with the high signal intensity of surrounding CSF. They typically enhance intensely and homogeneously, except in areas of cyst formation or hemorrhage. These lesions may be small and completely confined to the internal auditory canal, but as they grow, they tend to widen the internal

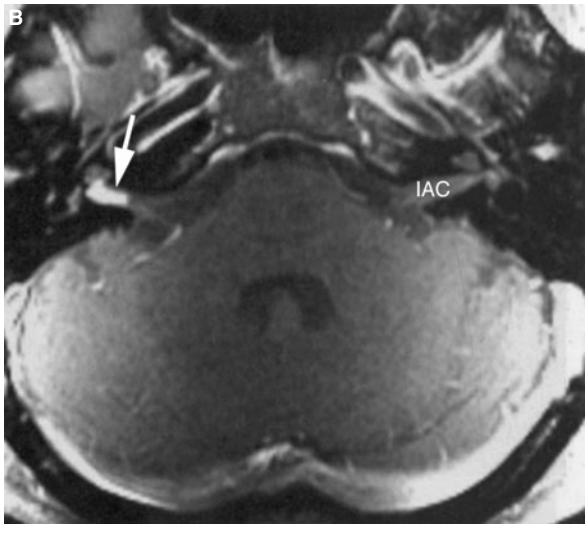


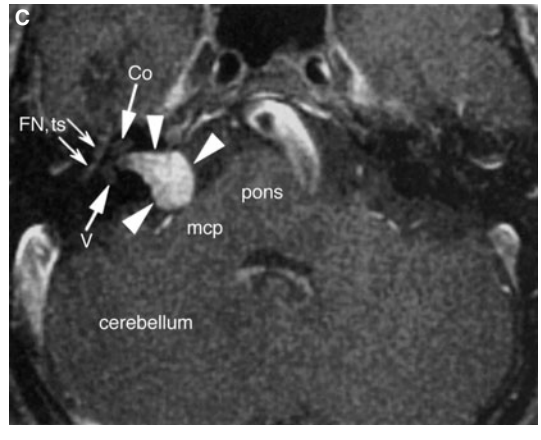
▲ **Figure 3–166.** Epidermoid. **(A)** Axial T2-weighted image shows an extra-axial hyperintense mass (arrows) in the left cerebellopontine angle that displaces the left seventh and eighth cranial nerve complex posteriorly and slightly compresses the brainstem. Note the slightly darker signal in the CSF to the right of the lesion. This is due to CSF pulsation artifact that causes a signal loss in the normally flowing CSF. **(B)** Axial T1-weighted image shows the lesion (arrows) to be of low signal intensity, though it is actually slightly hyperintense to CSF on this T1-weighted image. **(C)** Axial postgadolinium Tl-weighted image with fat saturation shows no enhancement of this lesion (arrows). At this point, it is still not possible to distinguish between an arachnoid cyst and an epidermoid, as an arachnoid cyst that has slightly increased protein content compared with normal CSF may be slightly brighter than CSF on a T1-weighted image. **(D)** A coronal FLAIR image (fluid-attenuated inversion recovery) shows an increased signal intensity in the lesion (arrowheads) compared with CSF in the subarachnoid space and ventricles, now strongly suggesting the diagnosis of epidermoid. The FLAIR sequence is a heavily T2-weighted image with the signal from CSF suppressed. *(continued)*



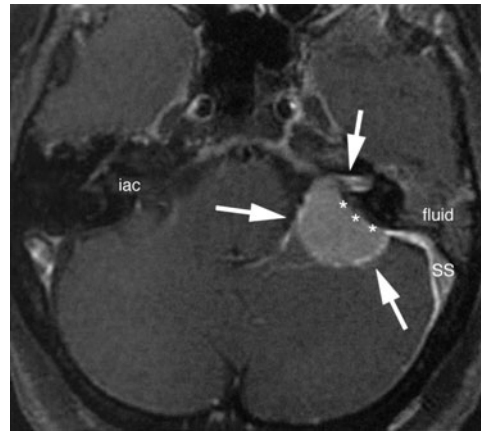
▲ **Figure 3–166.** *(continued)* **(E)** Axial diffusion-weighted image shows a markedly increased signal intensity of the lesion, consistent with reduced diffusion. This signal is very different from CSF (which is dark on diffusion-weighted images), and the diffusion-weighted image is very useful in distinguishing an arachnoid cyst (Figure 3–165) from an epidermoid.



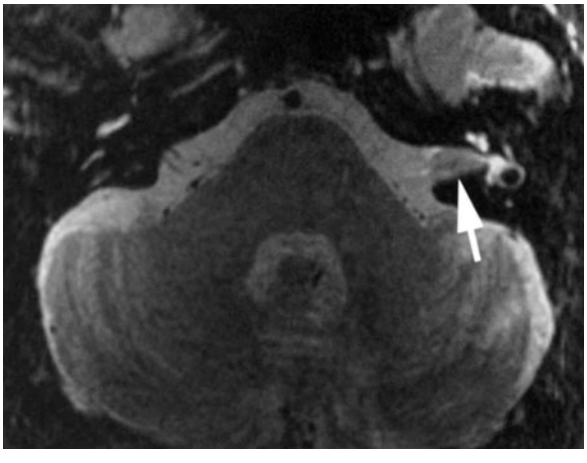




▲ **Figure 3–167.** Vestibular schwannoma. **(A)** Axial thin-section heavily T2-weighted image shows a right intracanalicular vestibular schwannoma (white arrows) in stark contrast to the high signal of normal CSF. The lesion extends to the fundus of the internal auditory canal (IAC). Note the subtle extension of the lesion into the cochlea. Also indicated on this thin-section, high-resolution image are the bilateral sixth cranial nerves (black arrows). **(B)** An axial postgadolinium T1-weighted image with fat saturation in the same patient demonstrates intense and homogeneous enhancement of the intracanalicular lesion (white arrow) and also demonstrates the subtle extension into the cochlea. **(C)** Axial postgadolinium T1-weighted image with fat saturation in a different patient shows the classic "ice cream cone" or "mushroom" appearance of a vestibular schwannoma that has both IAC and cerebellopontine angle components. Indicated are the pons, cerebellum, and middle cerebellar peduncle (mcp), as well as the cochlea (Co), vestibule (V), and the tympanic segment of the facial nerve (FN,ts; white arrows). FN,ts; facial nerve, tympanic segment.



▲ **Figure 3–168.** Meningioma. Axial postgadolinium T1-weighted image with fat saturation shows a homogeneously enhancing left cerebellopontine angle mass (arrows) that has a broad dural base (***) against the back of the petrous bone. Dural enhancement extends into a nonwidened internal auditory canal, and also posteriorly over the sigmoid sinus (SS) and occipital bone. Fluid is present in the left mastoid air cells, probably unrelated to the presence of the tumor.



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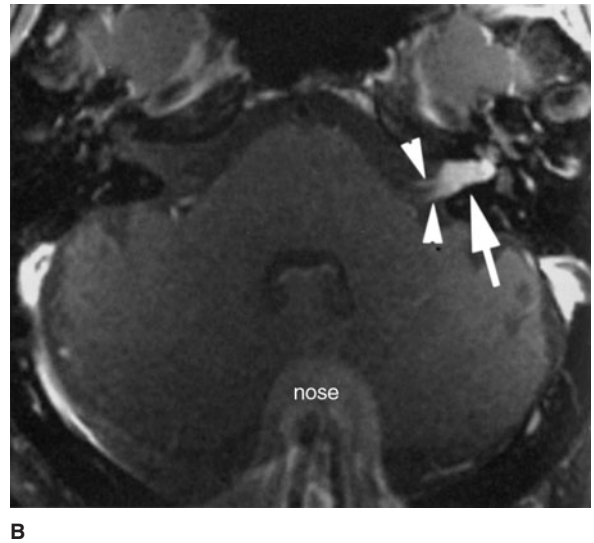

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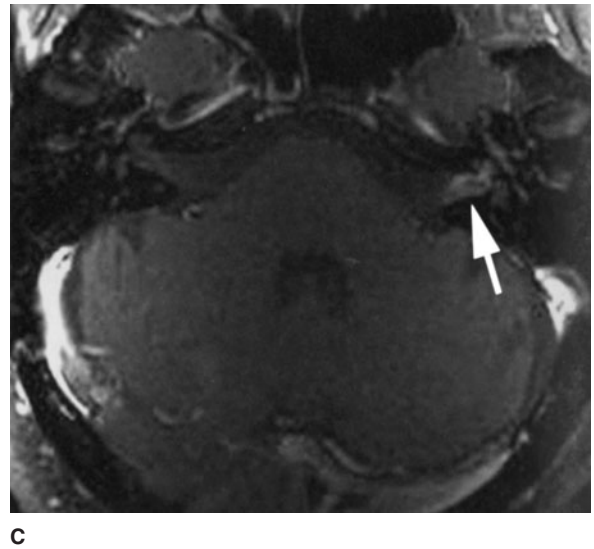


C

▲ **Figure 3–169.** Inflammatory pseudotumor. **(A)** Axial T2-weighted image shows an apparent internal auditory canal (IAC) mass (arrow) that has an intermediate signal intensity. This could be a vestibular schwannoma in this patient with sensorineural hearing loss. **(B)** Axial postgadolinium T1-weighted image shows intense enhancement of the lesion (arrow). Note, however, the linear enhancement extending more proximally along the cisternal segments of the cochlear and vestibular nerves (arrowheads). This indicates that this may be an inflammatory or infiltrative lesion (such as sarcoid or lymphoma) and not a typical vestibular schwannoma. Note also the nose "wrapping around" into the posterior fossa; this is a common MRI artifact related to selection of the field of view. **(C)** After several months of steroids, a follow-up axial postgadolinium T1-weighted image shows decreased enhancement (arrow) in the IAC and the lack of more proximal enhancement. The T2-weighted image (not shown) appeared essentially normal. The diagnosis in this case was considered to be an inflammatory neuritis of uncertain etiology.

Table 3–16. Imaging Characteristics of Common Cerebellopontine Angle Tumors ("SAME").

"SAME"	General Characteristics	CT Scan	MRI, T1-Weighted Imaging	MRI, T2-Weighted Imaging	MRI, FLAIR	MRI, DWI	MRI, Gadolinium
Schwannoma	Typically expands internal auditory canal (IAC); may be cystic; infrequently calcifies	Intermediate density on ST window; wide IAC on bone window	Intermediate (cysts may be low, hemorrhage high)	Intermediate (cysts high, hemorrhage variable)	Intermediate (cysts low)	No reduction	Avid, homogeneous enhancement (unless cyst or hemorrhage is present)
Arachnoid cyst	Follows CSF on all sequences	Fluid density	Low	High	Low	Increased diffusion, decreased signal	No enhancement
Meningioma	Look for broad dural base; may calcify	Intermediate density, ± adjacent hyperostosis	Intermediate	Intermediate (low if calcification)	Intermediate	No or mild reduction	Avid, homogeneous (unless calcification is present)
Epidermoid	Use FLAIR and DWI to differentiate from arachnoid cyst	Low density	Low	High	Intermediate	Reduced diffusion, increased signal	No enhancement

DWI, diffusion-weighted image; FLAIR, fluid-attenuated inversion recovery.

auditory canal and to expand medially into the cistern of the CPA. Large lesions may compress the brainstem and result in obstructive hydrocephalus, in which case the patient may present with headache or gait ataxia.

B. Facial Nerve Schwannomas

Facial nerve schwannomas can also occur in the CPA but are far less common than those arising from the eighth nerve. It can be helpful to know preoperatively if a presumed schwannoma arises from the facial nerve. Identifying abnormal enhancement extending along the labyrinthine segment of the facial nerve, or even more distally along the tympanic or descending mastoid segments, may be a helpful clue on MRI.

Bonneville F, Sarrazin JL, Marsot-Dupuch K et al. Unusual lesions of the cerebellopontine angle: a segmental approach. *Radiographics* 2001;21(2):419 [PMID: 11259705]. (Using CT and MRI to distinguish among the many cerebellopontine angle lesions.)

Curtin HD, Hirsch WL Jr. Imaging of acoustic neuromas. *Otolaryngol Clin North Am* 1992;25(3):553 [PMID: 1625865]. (A negative high-quality, high-resolution, contrast-enhanced MRI is excellent evidence that a patient does not have an acoustic neuroma.)

Heier LA, Communale JP Jr, Lavyne MH. Sensorineural hearing loss and cerebellopontine angle lesions. Not always an acoustic neuroma—a pictorial essay. *Clin Imaging* 1997;21(3):213 [PMID: 9156313]. (There are many etiologies of sensorineural hearing loss other than acoustic neuroma, with characteristic imaging features.)

Lalwani AK. Meningiomas, epidermoids, and other nonacoustic tumors of the cerebellopontine angle. *Otolaryngol Clin North Am* 1992;25(3):707 [PMID: 1625871]. (The preoperative differentiation among cerebellopontine angle lesions based on the clinical history, physical examination, and audiovestibular testing is difficult. CT scanning and gadolinium-enhanced MRI reveal the characteristic appearance of these tumors and make an accurate diagnosis possible.)

Tsuruda JS, Chew WM, Moseley ME, Norman D. Diffusion-weighted MR imaging of the brain: value of differentiating between extra-axial cysts and epidermoid tumors. *AJNR Am J Neuroradiol* 1990;11(5):925 [PMID: 2120997]. (Diffusion-weighted MRI can be useful in distinguishing between arachnoid cysts and epidermoid tumors.)

PETROUS APEX

Pathology

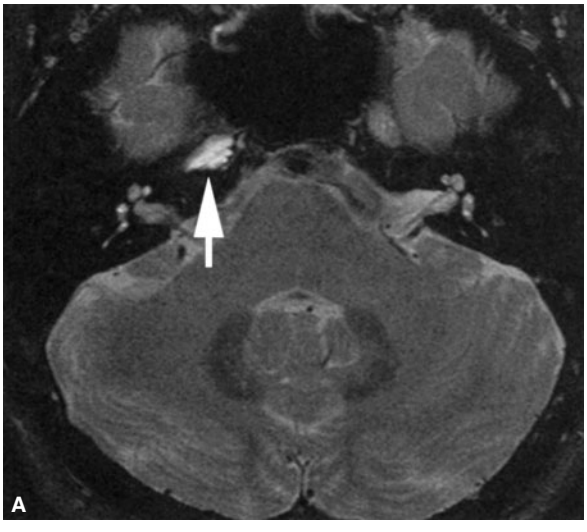
Some of the more common abnormalities that may be encountered on imaging studies of the petrous apex are listed in Table 3–17 and are shown in Figures 3–170 through 3–172.

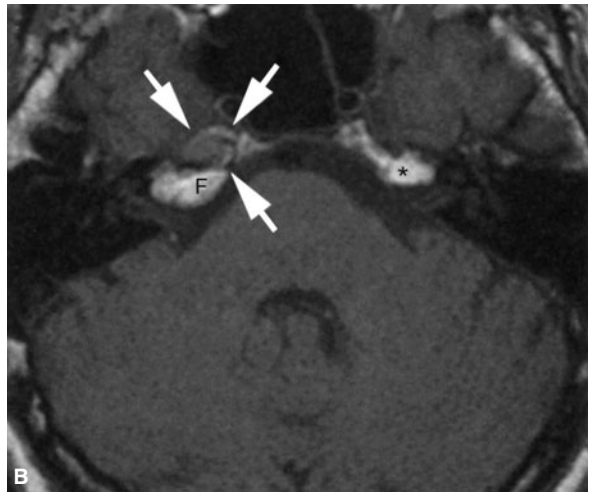
Table 3–17. Abnormalities of the Petrous Apex.

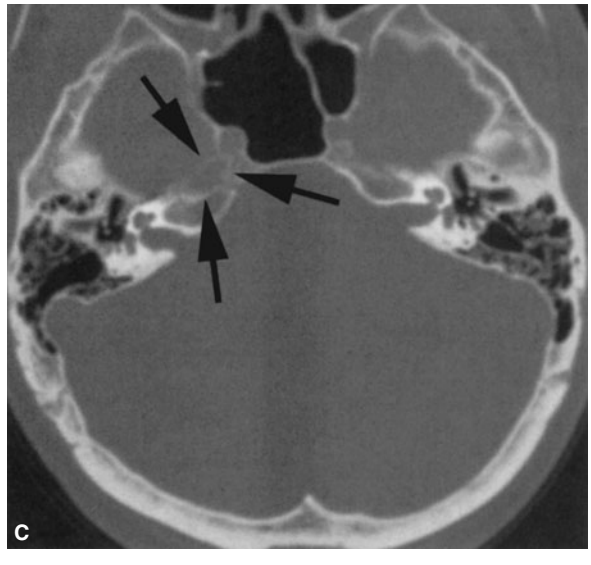
Fluid in aerated apex
Mucocele
Cholesterol granuloma
Arachnoid cyst or meningocele
Cholesteatoma, congenital or acquired
Chondrosarcoma
Metastasis

Imaging characteristics of selected petrous apex lesions and pseudolesions are reviewed in Table 3–18. Note that it is very important to distinguish "don't touch" lesions such as simple fluid in an aerated apex or a simple meningocele from lesions that might require operative intervention such as cholesterol granulomas, cholesteatomas, or neoplasms.

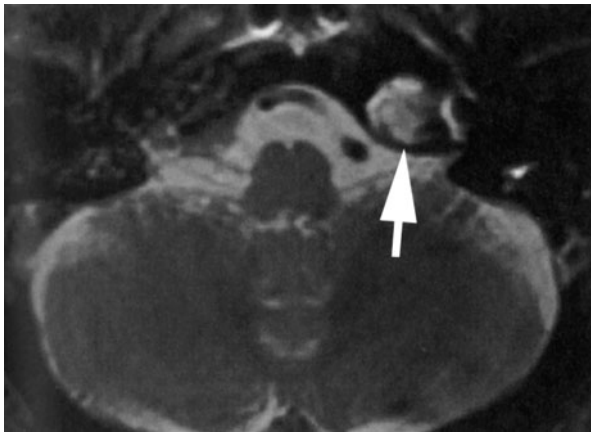
Curtin HD, Som PM. The petrous apex. *Otolaryngol Clin North Am* 1995;28(3):473–496 [PMID: 7675465]. (Description and distinguishing features of petrous apex lesions.)







▲ **Figure 3–170.** Fluid in aerated petrous apex. **(A)** Axial fast spin-echo T2-weighted image with fat saturation shows hyperintense material (arrow) at the petrous apex, with preservation of apical septa and no apical expansion. **(B)** Axial T1-weighted image shows this "lesion" (arrows) has intermediate signal intensity, consistent with slightly proteinaceous fluid. The high signal intensity posterior to the lesion represents normal apical marrow fat (F). Fat is also present in the left petrous apex (*). Postgadolinium (not shown), there was no enhancement of this lesion. At this point, the differential includes fluid in a petrous air cell, mucocele, and epidermoid, with both a mucocele and an epidermoid seeming unlikely given the apparent preservation of apical septa and a lack of expansion. In some cases, a CT scan can help differentiate among these possibilities and a follow-up scan may also be useful. **(C)** Axial CT scan viewed in bone window demonstrates a nonexpanded but opacified petrous apex air cell (arrows). CT scanning is useful to show that there is no bony destruction, which would suggest an epidermoid or a cholesteatoma, or expansion, which would suggest a mucocele or cholesterol granuloma. Follow-up imaging at 6 months showed resolution of this fluid.



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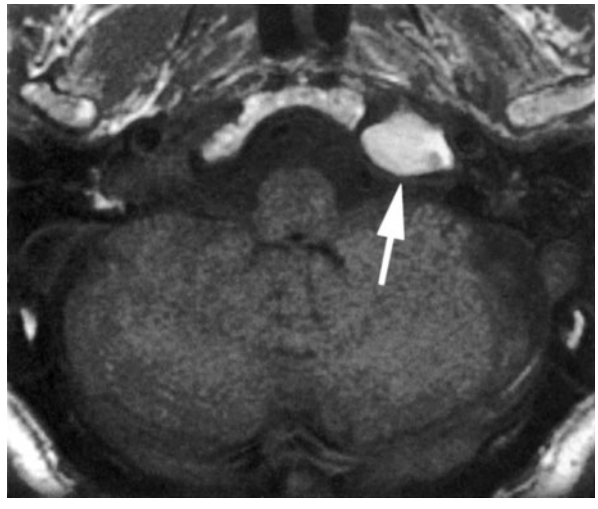
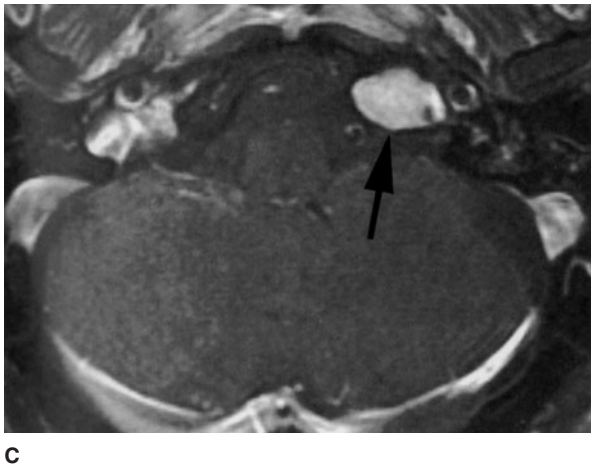


B



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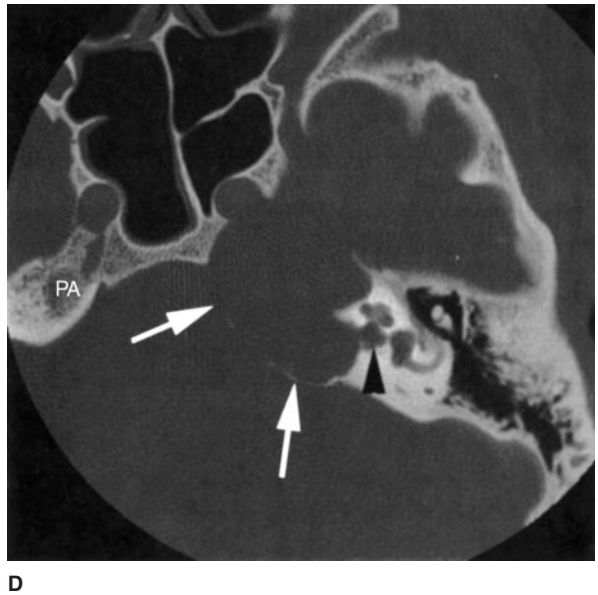
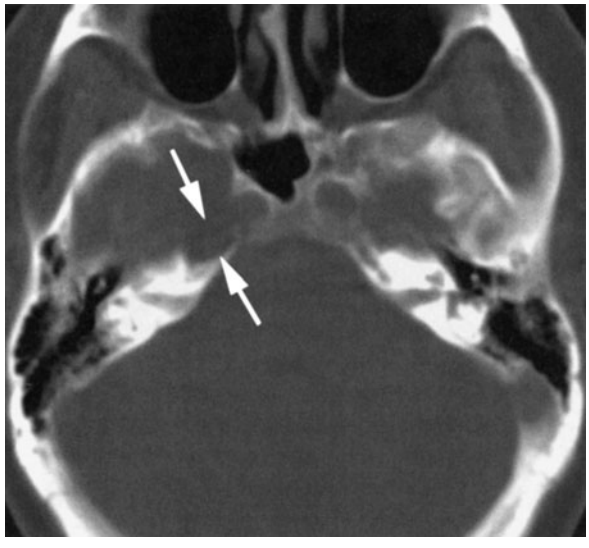


D

▲ **Figure 3–171.** Cholesterol granuloma. **(A)** Axial T2-weighted image shows an expansile hyperintense lesion (arrow) in the inferior aspect of the petrous apex. **(B)** Axial T1-weighted image shows the lesion (arrow) to be intrinsically hyperintense. This could represent hemorrhagic debris, proteinaceous material, or fat. **(C)** Axial postgadolinium T1-weighted image with fat saturation shows the lesion (arrow) remains hyperintense and is therefore not fatty in nature. **(D)** Axial CT scan viewed in bone window in a different patient with a large left petrous apex cholesterol granuloma demonstrates an expansile lesion (arrows) that has eroded and remodeled the left petrous apex as well as parts of the adjacent clivus and otic capsule. The internal auditory canal (black arrowhead) has been partly eroded. Note the normal right petrous apex (PA) for comparison.



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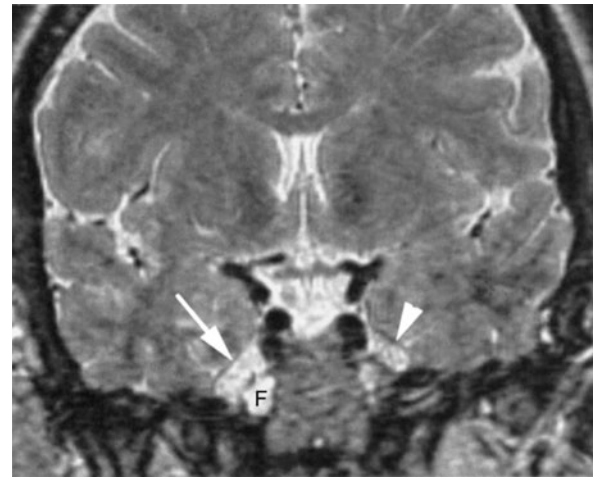

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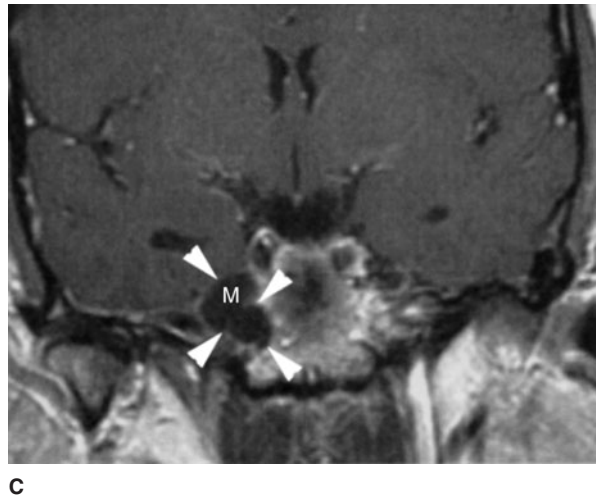

C

▲ **Figure 3–172.** A young woman underwent CT scanning with a complaint of headache, and a skull base lesion was incidentally noted. **(A)** Axial CT scan viewed in bone window demonstrates a right petrous apex lesion (arrows) that has smoothly eroded and remodeled adjacent bone. This appearance suggests a benign lesion but is nonspecific. **(B)** A thin-section coronal fast spin-echo T2-weighted image demonstrates that the lesion is fluid-filled (F) and appears to communicate with a slightly enlarged Meckel cave (arrow). The normal left Meckel cave (arrowhead) is shown for comparison. **(C)** Coronal postgadolinium T1-weighted image demonstrates the fluid-filled lesion (arrowheads) clearly in communication with the Meckel cave (M). The imaging characteristics are consistent with a meningocele that has remodeled the petrous apex. This is a "don't touch" lesion. CT cisternography would confirm free communication between this "lesion" and the subarachnoid space, but is not necessary. In some cases these lesions can result in a CSF leak, with complicating meningitis or intracranial hypotension, and in that setting may require confirmation with CT cisternography and operative intervention.

Table 3–18. Imaging Characteristics of Selected Petrous Apex Lesions and Pseudolesions.

Lesion or Pseudolesion	CT Scan	MRI, T1-Weighted Image	MRI, T2-Weighted Image	MRI, Gadolinium T1-Weighted Image
Normal marrow	Normal nonaerated bone; diagnostic	High because of normal marrow fat	Low on fat saturated image	No enhancement; low if fat saturation used
Fluid-filled air cell	No destruction No expansion	Intermediate to low intensity	High	No enhancement
Mucocele (can mimic cholesterol granuloma)	Expansile No bony destruction	Variable, typically low unless proteinaceous	High	No enhancement
Acute petrous apicitis	Air-fluid levels in air cells without bony destruction	Low	High	May be mild, peripheral
Acute petrous apicitis with osteomyelitis (Gradenigo syndrome)	Opacified air cells with bony breakdown; nonexpansile	Low	High	Can show rim enhancement or enhancement of adjacent meninges
Cholesterol granuloma	Expansile	High (fat saturation does not reduce signal)	Variable, but classically high	No enhancement
Cholesteatoma	Bony erosion, remodeling	Intermediate to low intensity	High	No enhancement
Chondrosarcoma	Look for bony erosions and mineralized matrix	Intermediate to low intensity	High ± some heterogeneity if calcified matrix	Avid enhancement

Moore KR, Fischbein NJ, Harnsberger HR et al. Petrous apex cephaloceles. *AJNR Am J Neuroradiol* 2001;22(10):1867 [PMID: 11733318]. (Presents the clinical and imaging features of petrous apex cephaloceles.)

Moore KR, Harnsberger HR, Shelton C, Davidson HC. "Leave me alone" lesions of the petrous apex. *AJNR Am J Neuroradiol* 1998;19(4):733 [PMID: 9576664]. (Asymmetric fatty marrow in the petrous apex and petrous air-cell effusions have characteristic MRI and CT scanning features that facilitate their correct diagnosis.)

Muckle RP, De la Cruz A, Lo WM. Petrous apex lesions. *Am J Otol* 1998;19(2):219 [PMID: 9520060]. (The clinical features, diagnostic evaluation, imaging, and treatment outcomes of patients with petrous apex lesions are reviewed.)

4 Principles of Radiation Oncology

Ryan J. Burri, MD & Nancy Lee, MD

INTRODUCTION

Radiation oncology is the discipline of medicine involving the use of ionizing radiation to treat malignant neoplasias. The radiation oncologist aims to deliver a precise dose of ionizing radiation to a defined tumor volume while minimizing damage to the surrounding normal structures. Due to the increasingly multidisciplinary nature of oncology, an understanding of radiation therapy is crucial to the surgeon involved in the combined-modality treatment of the patient with head and neck cancer.

External Beam Radiation Therapy (Teletherapy)

Therapeutic ionizing radiation can be divided into two categories: high-frequency electromagnetic radiation (X-rays and γ-rays) and particulate radiation (electrons, neutrons, protons). The amount of radiation absorbed per unit mass of tissue is known as the absorbed dose. The most commonly used unit for absorbed dose is the gray (Gy), which is equivalent to one joule of energy absorbed per kilogram of tissue. One Gy is also equal to 100 cGy, or 100 rads (the previously used unit of absorbed dose).

In the head and neck, primary radiotherapy is most frequently delivered via a linear accelerator with 6-megavolt (MV) photons. Anatomic location and desired depth of penetration are the main criteria used in choosing which type and energy of external beam to employ. Less commonly employed forms of external beam radiotherapy (EBRT) include 6–20 MeV electron beams, ^{60}Co γ-rays, and superficial (40–100 kV) or orthovoltage (250 kV) X-rays.

The past several decades have seen great advances in external beam treatment delivery schemes. Traditionally, radiotherapy was often delivered with a single field using superficially penetrating X-rays. The development of machines capable of deeper delivery of radiation (ie, linear accelerators) allowed centrally located tumors to be treated with parallel opposed radiation portals. During the early 1990s, with advances in computer and imaging technology, 3D conformal radiotherapy was introduced. This allowed for noncoplanar beam arrangements that conform to the target in three dimensions. The more recent development of intensity-modulated radiotherapy (IMRT) permitted the intensity of each beam to fluctuate in complex ways across the field. This further improved the ability of the radiation oncologist to cover irregularly shaped tumor volumes, facilitating a higher degree of dose conformality and minimization of damage to surrounding normal tissues, most importantly the parotid glands and spinal cord. Recently, image-guided radiotherapy (IGRT) has emerged as a way to ensure accurate daily tumor localization during the delivery of IMRT treatment plans.

Brachytherapy

Brachytherapy is a form of radiotherapy in which a radioactive source is placed inside or adjacent to the area requiring treatment. Selected radioisotopes contained within specialized instruments deliver radiation to the tumor or tumor bed at a short distance. The treatment may involve permanent implantation of the radiation source, or a temporary placement after which the source is withdrawn. Brachytherapy treatment can be delivered via interstitial implants (eg, base of tongue, neck, or tumor bed), intracavitary applicators (eg, recurrent nasopharyngeal cancer), or molds (eg, skin, hard palate). Treatments are also defined by the dose rate, and can be divided into low/medium-dose rate (LDR), high-dose rate (HDR), and pulsed-dose rate (PDR) techniques.

The advantage to brachytherapy is the short distance between radiation source and desired target volume. The radiation dose decreases with the inverse square of the distance from the source, and exposure of normal tissues to radiation is therefore reduced. Brachytherapy is frequently combined with EBRT. This allows the areas at risk for subclinical disease to be irradiated with external beams to a dose sufficient to sterilize microscopic metastases, while

brachytherapy is reserved as a boost for the gross tumor or high-risk tumor bed.

RADIOBIOLOGY

Ionizing radiation deposits energy at a constant rate as it travels through matter. This rate is defined as the linear energy transfer (LET). X-rays and γ rays are considered low LET or sparsely ionizing radiation and deposit their energy less densely per unit length of tissue. Energetic neutrons, protons, and heavy charged particles are high LET (densely ionizing) radiations. Equal doses of radiation of differing LET produce distinct biological responses. The relative biological effectiveness (RBE) is a measure of the ability of radiation with differing LET to produce the same biological effect under the same conditions. Radiation with higher RBE causes greater biological damage for equivalent radiation exposure. For example, if 800 cGy of 250 kV X-rays and 200 cGy of neutrons result in the same surviving fraction of cells under the same conditions, the RBE of the neutrons would be 4.

The fraction of cells surviving a given dose of radiation is dependent on many factors, including: the radiation type (high LET vs. low LET), dose size, cell type, oxygenation, and cell cycle phase. Some cells, and by extension, some tumors are more sensitive to radiation than others. The fraction of cells able to survive a low LET dose of 200 cGy varies between 20% and 80% depending on histology.

The presence of molecular oxygen in the tissue environment also influences the biological effect of ionizing radiation. Cells in a 100% oxygen environment are approximately three times more radiosensitive than completely anoxic cells. Malignant cells in the relatively hypoxic center of a bulky tumor therefore tend to be relatively radioresistant. Nevertheless, as the better oxygenated cells are preferentially killed and removed, relatively hypoxic cells are brought in closer proximity to blood vessels and reoxygenated.

In general, cells in the M and G_2 phases are the most radiosensitive, and those in late S phase are the most resistant. Prior to irradiation, malignant cells are present in all phases of the cell cycle. Following exposure to radiation many cells are arrested in late G_2 phase, thereby synchronizing cells in a more radiosensitive phase.

Fractionation

Fractionation refers to the division of total dose into a number of separate fractions. Most normal tissues are better equipped to repair genetic damage than malignant cells. As a result, fractionation generally allows for preferential sparing of normal tissue. The conventional fractionation scheme, which was arrived at empirically, is 180–200 cGy per fraction, one fraction per day, 5 days per week, to a total dose of 6500–7000 cGy. Based on several decades of both laboratory and clinical research, it is now evident that the conventional fractionation scheme may not be the best approach for all malignancies, especially for many in the head and neck region.

Tissues can be broadly divided into early and late responding tissues. Early responding tissues tend to be rapidly proliferating (skin, mucous membranes, most malignant cells) and poorly equipped to repair sublethal injury. These acutely responding tissues are spared less by dose fractionation and are instead more affected by the overall treatment duration. Late responding, slowly proliferating tissues (spinal cord, brain, muscle, bone) are spared more than early responding tissues by dose fractionation and are less affected by treatment duration.

The effect of treatment duration is largely due to the issue of repopulation. When squamous cell carcinomas of the head and neck are irradiated, for example, radioresistant clonogens can undergo a rapid burst of repopulation approximately 3–5 weeks after the start of treatment. *Accelerated fractionation* schedules, which reduce the treatment duration, were developed to help prevent this tumor proliferation from contributing to increased rates of local failure.

PRETREATMENT REQUISITES

Comprehensive pretreatment evaluation is required in all patients undergoing radiation therapy. Dental, nutritional, and ophthalmologic care is crucial to help prevent the development of complications, especially in patients receiving combined-modality treatment.

Patient Evaluation and Prevention of Complications

A. Dental care

Evaluation and treatment of preexisting dental pathology is crucial to preventing mild problems of the oral cavity from developing into severe complications. Pretreatment dental care should include radiologic studies, fluoride prophylaxis, extraction of nonsalvageable carious teeth, and treatment of other preexisting oral pathology prior to radiotherapy. Patients with significant dental fillings should be fitted with a customized mouth guard to avoid adjacent mucositis from back scatter radiation. If the patient is to receive postoperative radiotherapy, dental extractions may be carried out on the same day the definitive surgical procedure in order to avert the need for additional anesthesia and to avoid possible delay in the initiation of adjuvant radiotherapy.

B. Nutritional support

Adequate nutritional guidance is crucial to helping patients maintain their weight during and after treatment. Patients should meet with a dietician prior to the onset of treatment to evaluate nutritional status. Dietary consultation may result

in prescription of dietary supplements, and in select patients, placement of a percutaneous endoscopic gastrostomy tube. Nutritional guidance and support should continue through treatment so that problems such as weight loss, odynophagia, dysphagia, and trismus may be addressed.

C. Ophthalmologic/other

A baseline ophthalmologic examination is indicated in patients whose radiation portals include a portion of the orbit. Such patients include those with tumors of the nasopharynx, nasal cavity, and paranasal sinuses. Patients receiving radiotherapy to the neck are at high risk for developing hypothyroidism and should have thyroid function monitored at both baseline and post-treatment.

TREATMENT SELECTION

Postoperative Radiation Therapy

In patients with resected head and neck cancer, postoperative radiation therapy (PORT) is generally reserved for patients whose risk for local-regional recurrence is ≥ 20%. Pathologic poor-risk prognostic factors include close or positive margins of resection, extracapsular extension of nodal disease, perineural extension, involvement of two or more lymph nodes, lymphovascular space invasion, and involvement of lymph nodes at levels 4 or 5 from carcinoma arising in the oral cavity or oropharynx.

The optimal PORT dose using conventional fractionation consists of 180–200 cGy fractions, 5 days per week, to a total dose of 6000–6600 cGy to the high-risk volume, and 5000–5400 cGy for elective nodal irradiation.

In general, PORT should be initiated within 6 weeks of surgery in order to maximize the benefits on local–regional control. The total treatment time from surgical procedure until completion of radiotherapy has been shown to be a significant predictor of local–regional control.

Two randomized controlled trials conducted in parallel in the United States and Europe demonstrated that the addition of concurrent chemotherapy to PORT significantly improves local–regional control compared to PORT alone. This improvement comes at the cost of significantly increased high-grade acute toxicity and decreased patient compliance to treatment protocol. The fitness of the patient and availability of supportive care should therefore be carefully evaluated prior to initiating postoperative chemoradiotherapy. In general, postoperative concurrent chemoradiotherapy should be offered to fit patients with positive resection margins and/or extranodal extension.

Definitive Radiation Therapy

The efficacy of radiation therapy as definitive treatment has been well established for malignancies at many sites of the head and neck. Although disease control and cure should be of paramount importance in the selection of treatment modality, functional outcome and impact on quality of life must be taken into consideration. Treatment paradigms have shifted toward organ preservation with the aim to preserve speech and swallowing, when possible.

While single modality treatment is usually sufficient for early lesions, multimodal treatment is required for advanced stage disease. A meta-analysis of studies involving patients with head and neck cancer showed an absolute overall survival benefit of 6.5% at 5 years associated with the use of definitive concurrent chemoradiotherapy when compared to radiotherapy alone. In selected patients, the increased use of definitive chemoradiotherapy has allowed for organ preservation without compromise of treatment outcomes. Further information regarding definitive radiotherapy is discussed in each respective chapter.

Preoperative Radiation Therapy

The rationale behind the use of preoperative radiation is that tumor cells are in their maximal state of oxygenation and are therefore more sensitive to radiation. The most commonly used scheme involves delivery of 180–200 cGy fractions, 5 days per week, to a total dose of 5000 cGy.

A randomized trial (RTOG 73-03) comparing preoperative versus postoperative radiotherapy for advanced operable squamous cell carcinoma of the head and neck found improved local–regional control in favor of postoperative radiotherapy, with no difference in complication rates between the two approaches.

Currently, preoperative radiotherapy is administered in only selected cases. Indications include borderline resectable tumors where vital structures are at risk, or patients with poor nutritional status who require several weeks of nutritional support prior to surgery.

SEQUELAE OF RADIATION THERAPY

Acute Sequelae

Adequate management of acute treatment-related toxicities is pivotal to reducing discomfort and avoiding interruption in radiotherapy. Early responding tissues to radiation include the skin, mucous membranes, and salivary glands.

In the skin, ionizing radiation primarily affects the basal proliferating layer. At lower levels of exposure, erythema and hyperpigmentation result. Dry desquamation, with xerosis and hyperkeratosis, is seen as the accumulated dose increases. At higher doses, the basal layer is no longer able to repopulate, resulting in wet desquamation and ulceration. Small areas of wet desquamation need cleaning to prevent secondary infection, with larger areas requiring hydrogel dressings and thorough wound care.

Like the skin, mucous membranes consist of rapidly proliferating cells that show dose-dependent acute toxicity. The buccal mucosa, soft palate, tonsillar pillars, and pharyngeal

walls are especially prone to developing acute mucositis. With increasing radiation dose, areas of mucositis often become confluent. At doses over 7000 cGy, soft tissue or laryngeal necrosis may occur. Treatment of acute mucositis is mainly symptomatic, and includes pain management and oral irrigation with a baking soda/salt solution.

The salivary glands are relatively radiosensitive, with the threshold mean dose of radiation causing irreversible xerostomia thought to be approximately 2000–2500 cGy. Xerostomia often requires significant adaptation in lifestyle and eating habits, and can significantly impair quality of life. The availability of IMRT has opened up the possibility for parotid sparing in selected patients.

Late Sequelae

The physiologic mechanisms underlying late toxicities in most tissues have yet to be fully elucidated. Nevertheless, a combination of fibrosis, vascular endothelial damage, and muscle atrophy are though to be at work in many instances.

Chronic dysphagia is a frequently encountered issue, especially in patients treated with high-dose chemoradiotherapy. Oral, pharyngeal, and/or esophageal strictures may develop, requiring dilatation. Clinical swallowing evaluation with modified barium swallow and/or video fluoroscopy may help identify patients at risk for silent aspiration.

Trismus occurs secondary to fibrosis of the muscles of mastication, and in some unfortunate cases, due to tumor recurrence/persistence. Treatment includes regular daily jaw exercises and physical therapy.

Chronic xerostomia is a frequent late complication of radiotherapy treatment. Reduction in salivary output predisposes patients to developing caries, and excellent oral hygiene is required to prevent dental deterioration. Patients require routine fluoride prophylaxis and frequent dental evaluation. Moreover, patients receiving radiotherapy are at risk for the development of osteoradionecrosis, and any mandibular or dental pain should prompt thorough examination, including radiologic evaluation.

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5 Anesthesia

Errol Lobo, MD, PhD & Francesca Pellegrini, MD

INTRODUCTION

Head and neck surgery requires a cooperative relationship between surgeon and anesthesiologist. This is especially true in surgical procedures involving the airway. In fact, in most situations a common bond exists between otolaryngologist and anesthesiologist. In critical situations, where airway compromise is anticipated, it is the anesthesiologist and the otolaryngologist who have the best appreciation for the severity of the situation. In this chapter we will discuss briefly the pharmacology of some of more commonly used drugs in anesthesia. While a majority of these drugs are used by anesthetists in monitored conditions, these drugs may also be used in procedures requiring conscious sedation. It is hence of great importance for the physician or nurse involved on conscious sedation to be knowledgeable about the use and limitations of drugs used in conscious sedation.

This is followed by an overview of anesthesia equipment as pertains to the needs of the otolaryngologist. Quite often, surgery of the head and neck will involve the use of special equipment for endotracheal intubation. The otolaryngologist must have some knowledge of the available equipment for optimum operating conditions. This section is followed by a review of the difficult airway and suggested methods for control of the difficult airway. In the final section, an outline of the presurgical evaluation for patients with coexisting cardiovascular and pulmonary disease is presented, and anesthetic considerations for some common head and neck surgical procedures are presented. These procedures are discussed in greater detail in other parts of the text.

PHARMACOLOGY OF SOME COMMONLY USED ANESTHETIC DRUGS

ANALGESICS, SEDATIVES & HYPNOTICS

OPIOIDS

Opioids mediate analgesia through a complex interaction of opioid receptors in the supraspinal central nervous system (CNS). They produce reliable analgesia as well as provide some sedation and euphoria. There is no significant impairment of myocardial contractility, but sympathetically mediated vascular tone is reduced. Ventilation is depressed due to elevation of the carbon dioxide threshold for respiration. Opioids given at recommended doses do not reliably produce unconsciousness. They may, however, cause decreased bowel motility, biliary spasm, nausea, and pruritus. A brief review of some of the pharmacology of some of the more common opioids is presented below.

1. Morphine

Morphine is relatively hydrophilic and thus has a slower onset with a longer clinical effect. Only a small amount of administered morphine gains access to the CNS, but it accumulates rapidly in the kidneys, liver, and skeletal muscles. Profound vein vasodilatation may be induced due to the effects of histamine release and reduction of sympathetic nervous system tone.

2. Fentanyl

A synthetic opioid, fentanyl has similar effects, but is more lipid soluble and has more rapid onset and shorter duration

of action. This reflects faster entrance into the CNS and prompt redistribution. Elevated doses may lead to progressive saturation in adipose tissues. When this occurs, plasma concentrations do not decline promptly. Thus, pharmacodynamic effects, including ventilatory depression, may be prolonged.

3. Remifentanil

Remifentanyl was recently introduced and has a much more rapid onset and offset than fentanyl. With an initial dose, anesthesia may be achieved in 30–60 seconds, and offset of the drug can occur within 5–10 minutes after the discontinuation of an infusion. Because remifentanil is metabolized in blood and skeletal muscle, it can be administered as a single dose or in infusion. Due to the potency of this opioid and since chest wall rigidity may occur, this drug should be administered by an anesthesiologist or an anesthetist.

4. Meperidine

Commonly known as Demerol, meperidine has one-tenth the potency of morphine and a shorter duration of action. In low doses it has been shown to decrease the shivering associated with rewarming after surgery and after amphotericin administration. Several metabolites are excreted by the kidney and may accumulate in the presence of renal disease. The major metabolite, normeperidine is a proconvulsant and may cause seizures in renal compromised patients.

Opioids may be given by intermittent intravenous (IV) or intramuscular (IM) routes. Plasma level peaks and valleys may lead to variations in desired analgesia or excessive side effects. Continuous infusions or **patient-controlled analgesia** with smaller, more frequent doses has been shown to lead to better analgesia, with fewer side effects and less total drug use. Fentanyl and morphine may also be administered by an **intrathecal** or **epidural** route. This allows placement of opioids in the vicinity of receptors in the spinal cord. A growing body of information supports the use of these routes in high-risk patients to provide superior analgesia, less sedation, and less decrement in pulmonary function.

Tolerance developed by induction of hepatic microsomal enzymes may occur over the course of days to weeks. The effects of narcotics may be reversed with a variety of antagonists (ie, naloxone). Acute reversal may be accompanied by agitation, pulmonary and systemic hypertension, and pulmonary edema.

BENZODIAZEPINES

Benzodiapines produce anxiolysis and sedation by facilitation of the inhibitory actions of GABA on nerve conduction in the cerebral cortex. They may be used to produce sedation and amnesia, facilitate cooperation with care, attenuate alcohol withdrawal syndrome, treat seizures, and relieve muscle spasm.

Benzodiapines have no analgesic properties. They may cause transient decreases in blood pressure, due to decreased catecholamine levels and systemic vascular resistance, but with little effect on contractility. Respiratory depression is usually well tolerated in clinical doses, but may be accentuated in the elderly and those with COPD. Titration to a cooperative, oriented, and tranquil state (level 2 on Ramsey Scale) is the desired effect. Patients with a history of heavy alcohol or sedative use may require considerably more drug to achieve this response. Diazepam, midazolam, and lorazepam are three of the more commonly used benzodiapines.

1. Diazepam

Diazepam has a long clinical duration due to the long half life of several active metabolites. It is not water soluble and the parenteral suspension of propylene glycol is irritating when given intravenously or intramuscularly. Because diazepam requires microsomal nonconjugative pathways for degradation and elimination, it should not be used for patients with acute hepatitis.

2. Midazolam

Midazolam is the most commonly used benzodiazepine in the intensive care unit (ICU). It is water soluble, with short clinical duration, and few active metabolites. Midazolam offers a more rapid onset and a greater degree of amnesia, which makes it a good choice for brief procedures such as EGD and bronchoscopy.

3. Lorazapam

Lorazepam is another frequently used long-acting benzodiazepine. There is no pain on injection and no active metabolites. This agent has become a popular choice for patients with liver disease because its metabolism is not dependent on microsomal enzymes.

Tolerance to benzodiapines develops as with prolonged alcohol and opiate use. Withdrawal may result in profound sympathetic autonomic response. Replacement of benzodiazepine plasma levels and transient autonomic control would be indicated for control of withdrawal symptoms.

Reversal of benzodiazepine-induced sedation has been reported with physostigmine and aminophylline. **Flumazenil**, a specific benzodiazepine receptor antagonist, provides consistent reversal of sedation within 2 minutes of IV administration. The duration of reversal is short; thus resedation is a possibility in cases of benzodiazepine overdose. Flumazenil has also been reported to transiently reverse the somnolence of hepatic encephalopathy. Therapy with this agent should be gradual, to avoid excitatory symptoms. Convulsions have been reported in seizure-prone and benzodiazepine-dependent patients.

ALPHA$_2$-AGONIST

The α_2-agonist Dexmedetomidine is a class of sedative drug that has been approved by the FDA for use as a sedative and analgesic in the operating room and in the ICU. Dexmedetomidine has similar pharmacologic actions as clonidine except that its affinity for the α_2-receptor is 8 times greater, making Dexmedetomidine 5–10 times more potent than clonidine. In the past few years, the use of Dexmedetomidine for the management of sedation and analgesia in the perioperative setting has increased significantly. Dexmedetomidine also possesses several properties that may additionally benefit to postoperative patients who have an opioid tolerance or who are sensitive to opioid-induced respiratory depression. In spontaneously breathing volunteers, IV Dexmedetomidine caused marked sedation with only mild reductions in resting ventilation at higher doses. Head and neck surgeons will find this drug useful for conscious sedation cases, for augmented sleep studies, and for fiberoptic intubations and tracheostomy placement.

The drug does cause some cardiovascular instability, although this can be avoided when the drug is titrated carefully. Nevertheless, it should be appreciated that Dexmedetomidine does cause some moderate reductions in blood pressure and heart rate.

ANESTHESIA INDUCTION DRUGS

1. Barbiturates

Once a mainstay in sedation management, barbiturates now seem to have fallen out of favor, mainly due to availability of more titratable alternatives. They have numerous sites of action, but most likely promote the inhibitory effects of GABA on neuronal function. They have no analgesic effect and cause dose-related CNS, cardiac, and respiratory depression. Short-acting agents such as **methohexital** and **thiopental** are useful to produce unconsciousness for very short procedures such as cardioversions and intubations. Both agents can also be used for short-term procedures such as examination of the oropharynx in a noncooperative patient. As with most anesthetic induction drugs, patients should be adequately monitored (heart rate, blood pressure, electrocardiogram [ECG], and pulse oximetry), and supplemental oxygen should be given. Emergency endotracheal intubation equipment should be readily available together with emergency medications. Doses must be judicious due to the increased likelihood of respiratory and hemodynamic depression, especially in elderly patients.

Medium-acting (**pentobarbital** IV/PO) and long-acting (**phenobarbital** PO) agents have been used for violent agitation refractory to other agents, status epilepticus, andthe induction of barbiturate coma to treat increased intracranial pressure.

2. Propofol

Propofol is an ultra-short-acting IV anesthetic agent. Unconsciousness may be induced in less than 30 seconds followed by awakening in 4–8 minutes. It has potent sedative hypnotic activity, but unlike other agents, awakening is markedly rapid from even deep sedation with minimal residual sedative effects, and good antiemetic qualities. Hepatic metabolism is rapid, but rapid redistribution also plays a role in early awakening. It has no pharmacologic active metabolites. Propofol has been shown to decrease systemic blood pressure as a result of myocardial depression and vasodilatation. When used in low doses (10–50 mcg/kg/min) as a continuous infusion for sedation, these effects are minimal. It has no analgesic effects but has been shown to decrease narcotic requirements.

One of the disadvantages is that propofol is only slightly water soluble. It must be formulated in an oil/water emulsion of soybean oil, egg lecithin, and glycerol. This is similar to 10% Intralipid. Thus, this agent is contraindicated in patients with potential for allergic responses to the emulsion components. Pain is frequent on injection. This is often attenuated by pretreatment of the vein with a 20- to 40-mg lidocaine bolus prior to infusion. Blood chemistries should be assessed because prolonged use may result in hypertriglyceridemia.

Propofol should be treated with the same degree of caution as parenteral nutrition solutions. Multiple reports of bacterial contamination due to manipulations of the emulsion medium demonstrate that it supports rapid bacterial growth. Recent formulations of propofol have included bacteriostatic agents, such as EDTA or sulfites, which have made this issue less of a clinical concern. Nonetheless, clinical guidelines still limit handling opened vials to less than 24 hours and, when used as an infusion, advocate line changes at regular (usually 12-hour) intervals.

A soluble cousin of propofol marketed as Aquavan (fospropofol disodium) is currently awaiting FDA approval. The drug is described to have similar properties as propofol without the pain experienced during injection. The drug has been used for conscious sedation for colonoscopies with success in several phase III studies. Aquavan does have the respiratory depression function of propofol.

3. Ketamine

Ketamine is a phencyclidine derivative (similar to LSD) that produces a dossal, dissociative state that may be exploited as a sedative. Agitated patients may be given IM injection (3–5 mg/kg) or titration of 10-mg IV boluses in order to produce a cataleptic state in which the eyes remain open with a slow nystagmic gaze. Amnesia is present and analgesia is intense. Additional advantages include maintenance of airway reflexes, cardiovascular stimulation, and bronchial relaxation. Disadvantages include increased airway secretions, transient increases in intracranial pressure, and an association with unpleasant visual or auditory illusions.

Addition of benzodiazepines may attenuate these untoward sensory effects. Examples of clinical utility include conscious sedation for burn wound dressing changes and facilitation of endotracheal intubation in the hypotensive patient.

INHALED ANESTHETICS

In the operating room, general anesthesia is commonly maintained with inhaled anesthetics. These agents also provide some analgesia, amnesia, and muscle relaxation. In pediatric cases where there is no IV access, anesthesia may be induced by inhalation. All of the inhaled anesthetics with the exception of nitrous oxide are bronchodilators and may be useful in patients with reactive airways. Most inhaled agents will reduced blood pressure due to direct cardiac depression (eg, halothane), or by vasodilation (eg, isoflurane, sevoflurane, or desflurane). The rapidity of induction of anesthesia as well as emergence from anesthesia is based on the lipid solubility characteristics of the inhaled anesthetic. Hence, the more insoluble the anesthetic agent, the faster the induction of anesthesia. Also, the agents with high lipid solubility prolong the emergence from anesthesia.

1. Nitrous Oxide

Nitrous oxide produces general anesthesia through interaction with the cellular membranes of the CNS. It is the only nonorganic inhaled anesthetic in clinical use. Although it is nonvolatile, it does support combustion, and caution should be taken in the event of airway fires. Uptake and elimination of nitrous oxide are relatively rapid compared with other inhaled anesthetics, primarily as a result of its low blood-gas partition coefficient. Elimination of nitrous oxide is via exhalation. It produces analgesia, amnesia (with a concentration greater than 60%), mild myocardial depression, and mild sympathetic nervous system stimulation. It does not significantly affect heart rate or blood pressure. Nitrous oxide is a mild respiratory depressant, although less than the volatile anesthetics.

2. Isoflurane

Until recently isoflurane was the most commonly used inhaled anesthetic in the United States of America. Isoflurane is noted for its minimal cardiac depression. Like other volatile, isoflurane causes respiratory depression with a fall in minute ventilation. The ventilatory response to hypoxia and hypercapnia are diminished. Another characteristic in common with other volatile anesthetics is the ability of isoflurane to cause bronchodilation. This effect occurs despite its ability to cause airway irritation.

Isoflurane increases skeletal muscle blood flow, decreases systemic vascular resistance, and lowers arterial blood pressure. High concentrations of isoflurane may increase cerebral blood flow (CBF) and intracranial pressure. These effects are effectively reduced by hyperventilation. At even higher concentrations isoflurane reduces cerebral metabolic oxygen requirements and provides cerebral protection. Isoflurane decreases renal blood flow, glomerular filtration rate, and urinary output.

3. Desflurane

The structure of desflurane is very similar to isoflurane except for substitution of a fluorine atom for a chlorine atom. This makes desflurane highly insoluble. Its low solubility in blood and body tissues causes a very rapid wash-in and washout of anesthetics. Wake-up times are approximately half as long as those observed following isoflurane administration. Desflurane has cardiovascular and cerebral effects similar to those of isoflurane.

4. Sevoflurane

Sevoflurane has begun to replace halothane as a primary inhaled anesthetic agent used in the induction of anesthesia where an IV induction cannot be performed. It is used primarily in pediatrics where IV access is not available and induction has to be achieved by other means. Nonpungency and rapid increase in alveolar anesthetic concentration make it an excellent choice for smooth and rapid inhalation induction of anesthesia. Sevoflurane's solubility in blood is slightly greater than that of desflurane. Sevoflurane mildly depresses myocardial contractility. Systemic vascular resistance and arterial blood pressure decline slightly less than with isoflurane or desflurane. As with isoflurane and desflurane, sevoflurane causes slight increases in CBF and intracranial pressure at normocarbia. Sevoflurane is reported to have potential for nephrotoxicity and hence should be used with a gas flow of greater than 2 L.

5. Halothane

Halothane is a halogenated alkane that is used primarily for induction of anesthesia in patients where an IV induction is not possible. Halothane's nonpungent and sweet-smelling odor makes it especially suitable for this purpose. Halothane causes a dose-depression reduction in arterial pressure by myocardial depression. It also causes respiratory depression. Halothane has been associated with a drug-induced hepatitis known as halothane hepatitis. This condition is extremely rare (1 in 35,000) and has an increased incidence in patients exposed to multiple halothane anesthetics within short intervals, in middle-aged obese women, and in patients with a genetic predisposition to halothane hepatitis.

ANTIEMETICS

1. Droperidol

Droperidol has greater antiemetic and sedative effects, but may also produce respiratory depression. If administered alone, dysphoria can happen; at clinical doses it is used in combination with a narcotic or benzodiazepine for sedation.

Table 5–1. Pharmacokinetics of the More Commonly Used Neuromuscular Blockers. Only Vecuronium is Used as an Infusion.

Clinical Pharmacology of Neuromuscular Blocking Agents				
Agent	Intubation Dose (mg/kg)	Time to Onset (minutes.)	Time to Recovery (minutes.)	Infusion Rate (mcg/kg/min)
Vecuronium	0.1	2–3	25–30	1–2
Cisatracurium	0.2	1–2	50–60	NA
Pancuronium	0.1	5	80–100	NA
Rocuronuim	1.2	1–2	40–150	NA

More recently, the FDA has discouraged the use of droperidol in an unmonitored setting.

2. Ondansetron and Dolasetron

Ondansetron and dolasetron are selective antagonists of serotonin 5-HT_3 receptors with little or no effect on dopamine receptors. Unlike droperidol they do not cause sedation, extrapyramidal signs, or alteration of the GI motility and lower esophageal sphincter tone. 5-HT_3 receptors are found in the chemoreceptor trigger zone of the area postrema, in the nucleus tractus solitarius, and also along the gastrointestinal tract. The most common reported side effect is headache. Dolasetron can prolong the QT interval.

3. Newer Antiemetics

In the last few years, two new medications have been approved for the treatment of nausea and vomiting. Palonosetron, a 5-HT_3 antagonist, has been shown to be effective in delayed emesis and has been shown to be superior to other the 5-HT_3 antagonists ondansetron and dolasetron. In most studies, however, the efficacy has been best when the 5-HT_3 antagonist was given with 20 mg of Dexamethasone. Another new antiemetic is aprepitant, an NK1 receptor antagonist. The scientific basis of aprepitant is based on its antagonism of substance P, a pro-emetic, which exerts its biological effect (emesis), by binding to the tachykinin neurokinin NK1 receptor. Aprepitant antagonizes this binding. The antiemetic effects of Aprepitant had added efficacy when given with Dexamethasone.

NEUROMUSCULAR BLOCKERS

Neuromuscular blocking agents are used in most cases for endotracheal intubation and in the operating room when patient movement is detrimental to the surgical procedure. The most prominent side effect of giving neuromuscular blockers is that they cause paralysis of the muscles of respiration. Hence, ventilation of the patient is in the hands of the anesthesiologist and can be achieved with a mask or with a secured endotracheal tube.

Most muscle relaxants induce paralysis by blocking acetylcholine receptors at the neuromuscular junction of skeletal muscle. They have no intrinsic sedative or analgesic properties and must be used in concert with other medications. At a minimum, these agents should be used in conjunction with an anxiolysis agent. Inadequate sedation and hypnosis during use of neuromuscular blockers can produce unpleasant recall by patients with long-term side effects. Neuromuscular blockers can be classified as depolarizing neuromuscular blockers, such as succinylcholine, which bind to the acetylcholine receptor and produces a "persistent" depolarization of the neuromuscular junction. Muscle relaxation is achieved because propagation of action potentials is prevented by the area of inexcitability that occurs around the acetylcholine receptors. The second type of neuromuscular blockers is termed nondepolarizing neuromuscular blockers, which directly bind the acetylcholine receptor and prevent the binding of acetylcholine. All drugs described belong to the nondepolarizing neuromuscular blocker group (Table 5–1).

Vecuronium is a popular relaxant due to its short clinical duration (30–60 minutes) and lack of hemodynamic side effects. It may be given as a bolus or continuous infusion. It is metabolized by the liver and excreted by the kidney.

Cisatracurium undergoes degradation in plasma at physiologic pH and temperature by organ-independent Hofmann elimination. Metabolism and elimination appear to be independent of renal or liver failure. It does not affect heart rate or blood pressure, nor does it produce autonomic effects.

Pancuronium has a longer duration of action (60–90 minutes) and is eliminated primarily by renal mechanisms. The major limiting factor to its use is tachycardia, especially after bolus administration, resulting from a vagolytic effect.

Rocuronium has an onset of action similar to but slightly longer than succinylcholine, making it suitable for rapid-sequence inductions, but at the cost of a much longer duration of action. This intermediate duration of action is comparable to Vecuronium. It undergoes no metabolism and is eliminated primarily by the liver and slightly by the kidneys, so its duration of action is modestly prolonged by severe hepatic failure and pregnancy.

OTHER DRUGS OF VALUE TO THE OTOLARYNGOLOGIST

NSAIDS—KETOROLAC

Ketorolac is a recently released potent parenteral nonsteroidal analgesic without opioid-related side effects such as respiratory depression. IM doses of 60 mg are reported to be equivalent to 10 mg morphine for up to 3 hours. Clinical dosing is every 8 hours, and it appears to be most effective in situations where swelling contributes to pain (ie, dental, gynecologic, and orthopedic surgery). There is minimal impact on ventilation, hemodynamics, and bowel motility. Disadvantages include a limited analgesia effect beyond recommended doses and impaired platelet function. Substantial gastrointestinal mucosal breakdown may occur with use over periods as short as one week.

ANTICHOLINERGICS

Anticholinergic agents are sometimes used to produce sedation and amnesia. They also have an antisialogue effect and prevent reflex bradycardia. **Atropine** and **scopolamine** are tertiary amines that cross the lipid barrier protecting the CNS. Scopolamine has 10 times the potency of atropine in terms of centrally induced sedation and amnesia. Because scopolamine produces tachycardia as its major hemodynamic side effect, it is a popular choice as an urgent amnestic for the hemodynamically unstable or hypovolemic patient (ie, trauma victim).

Undesirable side effects include toxic delirium (known as central cholinergic syndrome), tachycardia, relaxation of lower esophageal sphincter tone (with associated potential for regurgitation), mydriasis, and potential elevation of temperature via suppression of sweat gland function.

ANESTHESIA EQUIPMENT

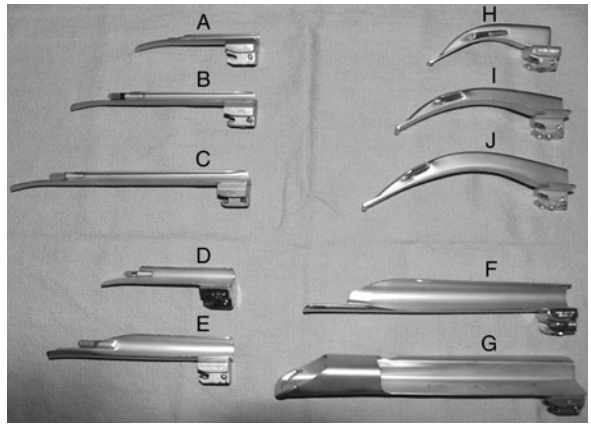
The basic equipment for airway management used by the anesthesiologist should be familiar to the otolaryngologist. This includes laryngoscope blades, endotracheal tubes, and breathing circuits.

LARYNGOSCOPE BLADES

In general laryngoscope blades may be classified as either straight or curved. With proper head positioning, both types of blades provide a direct pathway to the vocal cords for tracheal intubation. There are several designs of laryngoscope blades, and these are shown in Figure 5–1. Some blades like the Bainton blade may be used in special situations where redundant tissue or airway edema is present and the vocal cords are not easily visible.

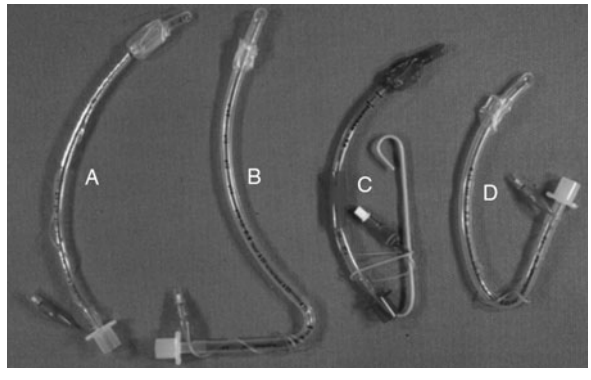
ENDOTRACHEAL TUBES

Otolaryngologists often require specialized endotracheal tubes depending on the procedure performed (Figure 5–2).



▲ **Figure 5–1.** Laryngoscope blades used by anesthesiologists. Blades are usually classified as straight such as the Miller blades **(A–C)**, the Wisconsin blades **(D–F)**, and the Bainton blade **(G)**, or curved such as the Macintosh blades **(H–J)**. The Bainton blade was designed especially for situations where edematous or redundant tissue obstructs a view of the cords.

The standard endotracheal tube is made of polyvinyl chloride and is disposable. Endotracheal tubes can also be made from clear silicon material. Reusable rubber tubes are also available. These tubes have to be cleaned and autoclaved prior to reuse. Endotracheal tubes come in various sizes and may be cuffed or uncuffed. Uncuffed endotracheal tubes are used in neonates, infants, and children usually up to the age of 12 years. A suggestion of tube size in children is shown in



▲ **Figure 5–2.** Tracheal tubes used in ENT procedures. Included are a cuffed endotracheal tube **(A)**, a nasal RAE, and an oral RAE tube (**B** and **D**) used for tonsillectomies and procedures in the oral cavity, an armored tube **(C)**. Armored tubes are commonly used in laryngectomies.

Table 5–2. Recommended Endotracheal Tubes Sizes for Pediatrics. A Leak Around the Tube is Preferred to a Snug Fitting Tube in the Pediatric Population.

Age	Weight (Kkg)	Size (ID in mm)	LENGTH (cm)
Newborn (Neonate)	2–4	2.5–3.5	10–12
1–6 months	4–6	4.0–4.5	12–14
6–12 months	6–10	4.5–5.0	14–16
1–3 years	10–15	5.0–5.5	16–18
4–6 years	15–20	5.5–6.5	18–20
7–10 years	25–35	6.5–7.0	20–22
10–14 years	40–50	7.0–7.5 (cuffed)	22–24

Table 5–2. The tracheal end is usually beveled and may contain a Murphy eye. Endotracheal tube cuffs may be of either the high-volume variety or the low-volume variety. Both types of cuffs may cause tracheal necrosis with long-term intubation. Endotracheal tubes have gradations usually in centimeters to allow for the clinician to keep track of correct position of the tube and prevent endobronchial migration or extubation. It should be noted that for common procedures of the larynx, use of a small-diameter endotracheal tube allows for better exposure. The recommended size is 5.0-mm ID for women and 5.5-mm ID for men.

For a variety of head and neck procedures, specially designed endotracheal tubes may be required. The otolaryngologist should be familiar with these tubes. These tubes are designed to provide optimal exposure for the surgeon working in the oral and nasal cavities. Their anatomical design prevents kinking of the tubes during surgery.

Three of the more commonly used endotracheal tubes for head and neck procedures are the RAE tracheal tubes, the armored tracheal tubes, and the laser resistant tracheal tubes. RAE tubes, named after the inventors of the tube (Ring, Adair, and Elwyn), have a preformed shape to fit the mouth or nose. The tubes are available in a variety of pediatric and adult sizes and may be cuffed or uncuffed. Nasal RAE tubes are commonly used in surgery of the oral cavity as they do not obstruct the surgical field. Oral RAE tubes are commonly used for surgeries of the oral cavity, particularly those involving the tonsils. A drawback to RAE tubes is that their shape may cause them to cause an endobronchial intubation, particularly in patients with short necks.

Armored tracheal tubes are commonly used in surgery of the head and neck. The primary advantage of using these tubes is that they can withstand the constant moving of the head without kinking. Laser resistant tracheal tubes are used in laser surgery, as in the treatment of vocal cord papillomas. Regular endotracheal tubes can be converted to laser resistant tubes by wrapping the ends with aluminum foil.

THE DIFFICULT AIRWAY

A high percentage of cases involving the head and neck involve patients with "difficult airways." A patient with a difficult airway is one who may pose a challenge for both manual ventilation and placement of an endotracheal tube. Patients with difficult airways should be identified prior to surgery, more specifically prior to the induction of general anesthesia, particularly with use of neuromuscular blockade. Preoperative evaluation by the otolaryngologist either by direct vision of the airway or by other diagnostic tools such as a CT scan and an MRI may provide invaluable information to the anesthesiologist, particularly if a difficult airway is involved.

IDENTIFICATION OF PATIENTS WITH POTENTIALLY DIFFICULT-TO-MANAGE AIRWAYS

With the improvement in record keeping and patient–physician communications, patient history should provide important information with regards to the patient's airway and potential problems for securing the airway in the operating room. Knowledge of prior history of difficult intubation, prior surgery of the head and neck, immobility of cervical vertebrae, and radiation therapy to the airway should be basic alert items for a potential difficult airway. Other alert items should include dysphagia, trauma to the head and neck, and hoarseness or stridor (see Table 5–3).

PHYSICAL EXAM OF AIRWAY

EXAMINATION OF THE HEAD AND NECK

In most cases involving head and neck surgery, a detailed preoperative assessment of the airway may be performed by the otolaryngologist. This is extremely helpful in determining which patients are going to be challenged for tracheal intubation. The preoperative exam should thus include:

- a detailed frontal and a profile view to assess mandibular size and mobility;

Table 5–3. Basic Alert Items That May Help in Identification of the Difficult Airway.

Basic "Alert" Items
Prior difficulty with endotracheal intubation
Cervical immobility (limited or no range of motion of neck)
Neck circumference greater than 50 cm and morbid obesity
Hoarseness or stridor
Trauma
Radiation therapy
Prior surgery of the head and/or neck
Dyspnea or dyspnea on exertion
Dysphagia
Shortness of breath

- examination and assessment of mental-alveolar process and mental-hyoid bone or mental-thyroid cartilage distance;
- assessment of neck rotation and flexion-extension mobility;
- examination of the neck for evidence of masses, tracheal deviation, size of tracheal and cricoid cartilage, and tissue plasticity.

In patients classified as morbidly obese, a neck circumference greater than 50 cm may be used as a predictor of increased difficulty of endotracheal intubation.

Recognition of certain breathing pattern and phonation may also provide with important clues about airway patency and potential difficulty with endotracheal intubation.

In addition an intraoral examination should be performed as part of the preoperative assessment. This would include an assessment of tongue size, protrusive occlusion, and degree of overbite, (see Table 5–4). Recognition of a potentially difficult airway can be done by examining the oral cavity and assessing the structures that can be seen with a wide open mouth. The classification of these views, shown in Figure 5–3, is called the Mallampati classification. At the bottom of the figure are shown graded laryngoscopic views.

The American Society of Anesthesiologists has provided stepwise guidelines for dealing with patients who present with problematic intubation of the trachea (Figure 5–4).

Table 5–4. Examination of the Mouth Can Provide Important Information Regarding Potential Airway Difficulties.

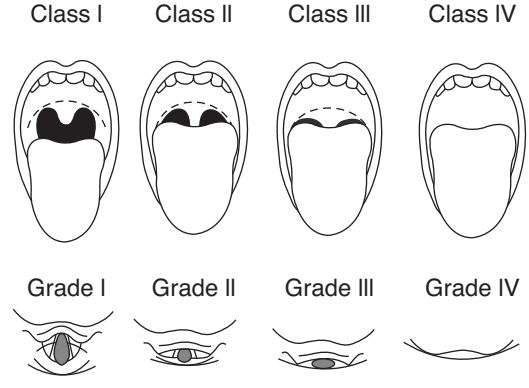
Examination of the Intraoral Cavity
Examine for loose, missing, or overly large teeth
Degree of overbite or protrusive occlusion
Size of the tongue
Visibility and size of faucial structures
Patency and size of the nares, or deviation of nasal septum

AWAKE INTUBATIONS

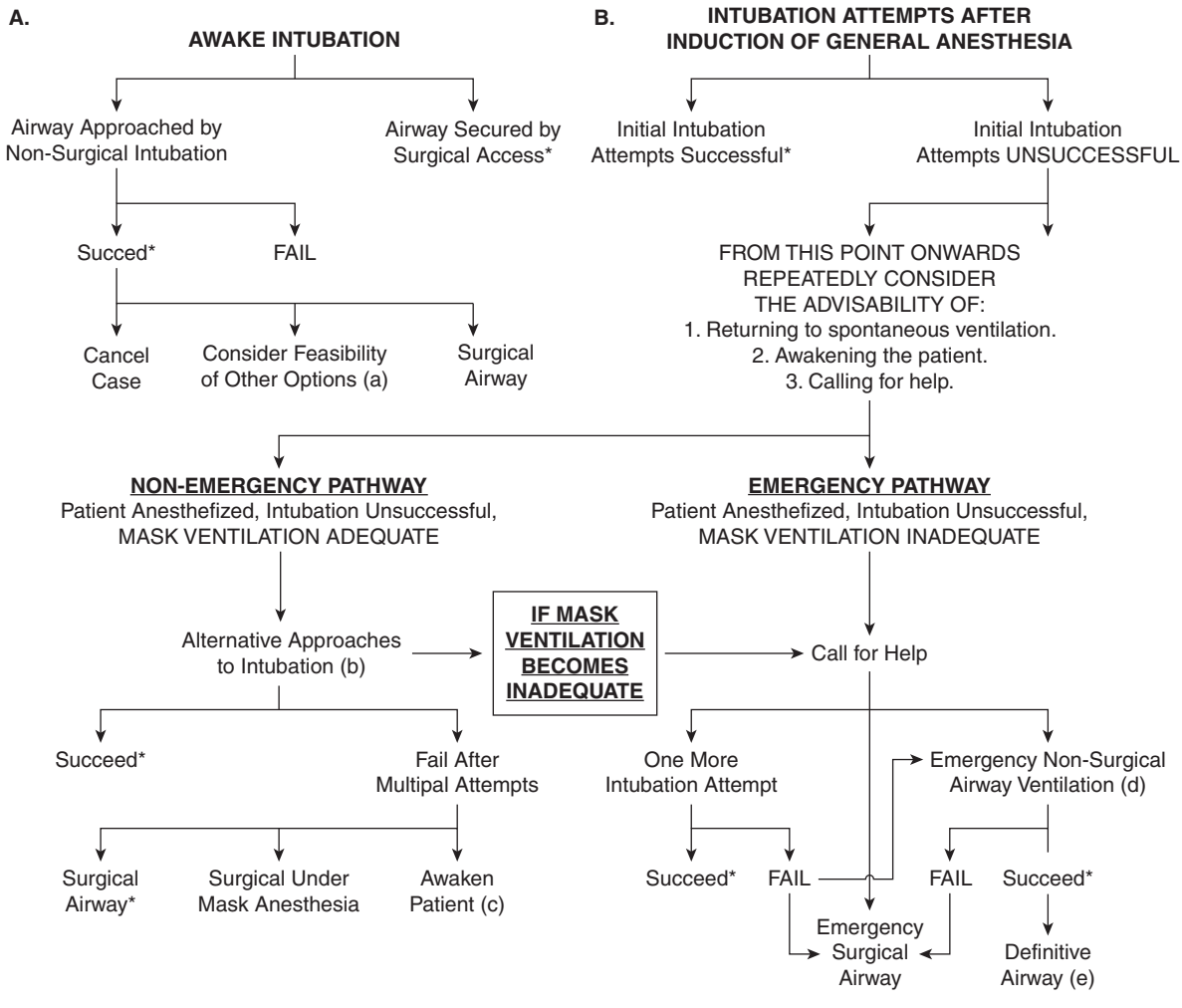
Preparation of the Patient

In patients with anticipated difficult airways or patients who are unable to open their mouths or have cervical spine precautions, an awake intubation is often necessary. This can be done by anesthetizing the oropharynx with a local anesthetic. The use of 2% lidocaine sprayed in the mouth and throat may cause the loss of a gag reflex and allow for awake laryngoscopy (see below). In other situations tracheal intubation either via the oral or via nasal route should be done awake using a fiberoptic scope. In this latter situation, facilitation of fiberoptic intubation may **require blockade of specific nerves**.

- In the mouth, sensation to the anterior aspect of the tongue is innovated by the *lingual nerve*. In contrast, the posterior third of the tongue and the oropharynx are innovated by *pharyngeal braches* of the *glossopharyngeal nerve* and by the *vagus nerve*. These nerves can be easily anesthetized by spraying the oral cavity with local anesthetic and asking the patient to gargle and swallow the spray medication. Alternatively, these nerves are easily blocked by bilateral injection of 2 mL of local anesthetic into the base of the palatoglossal arch with a 25-gauge spinal needle. The inferior aspect of the larynx to the level of the vocal cords is innervated by the *superior laryngeal nerve*, a branch of the *vagus nerve*. This nerve can be blocked by placement of local anesthetic-soaked gauze in the pyriform sinuses. Also this nerve may be blocked externally by locating the hyoid bone and injecting 3 mL of 2% lidocaine 1 cm below each greater cornu, where the internal branch of the superior laryngeal nerves penetrates the thyrohyoid membrane.
- The *recurrent laryngeal nerve* innervates the mucosa below the cords. This nerve may be blocked by transtracheal injection of local anesthetic. A transtracheal block is performed by identifying and penetrating the cricothyroid membrane while the neck is extended. After confirmation of an intratracheal position by aspiration of air, 4 mL of 4% lidocaine is injected into the trachea at the end of expiration. A deep inhalation and cough immediately following injection distributes the anesthetic throughout the trachea.



▲ **Figure 5–3.** Correlation between views obtained prior to laryngoscopy with the naked eye and views with laryngoscopy. In about 80% of oral view Class 1, a Grade 1 laryngoscopic view is observed. For Mallampati Class II, only the posterior vocal cords may be visualized in about 50% of cases. Class III and IV merit special attention as intubation of the trachea in these patients may be difficult and may merit an awake intubation. The degree of vigilance should also be increased in Class III and IV patients, as manual ventilation may be a challenge.

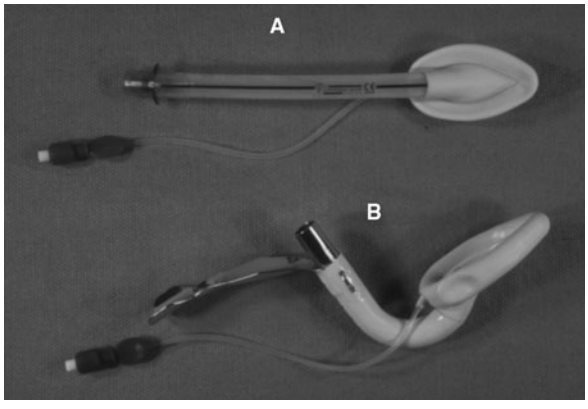


▲ **Figure 5–4.** An algorithm suggested by the American Society of Anesthesiologists for dealing with the difficult airway.

Use of local anesthetic to block the above nerves may facilitate awake intubation of the trachea by depressing the protective cough reflex and the swallowing reflex. Special precaution should be taken with those patients at high risk for aspiration. In some patients the use of anesthesia may be limited to the nasal passages with either a blind-nasal intubation being used or a fiberoptic nasal intubation. Using local anesthetics in the nares will allow patients who are high risk for aspiration to protect their airway.

OTHER HELPFUL TOOLS FOR THE PATIENT WITH A DIFFICULT AIRWAY

In cases where a difficult airway was not anticipated and patients may be already medicated with anesthetic induction drugs and neuromuscular blockers and cannot be awoken, a patient airway and ventilation is essential. If manual ventilation with a mask is adequate, then this is less of a life-threatening situation, and the patient may be ventilated until he or she wakes up and can be intubated by an alternative technique. In cases where manual ventilation is difficult, even with use of oral or nasal airways, then aggressive intervention including a surgical airway may become imperative. The introduction of the laryngeal mask airway (LMA) and fast-track LMA has added to the available options when conventional methods of tracheal intubation with a laryngoscope are unsuccessful and respiratory compromise is imminent. The LMA was designed in 1981 and is a compromise between the face mask and the tracheal tube. It is used extensively throughout the world and has been included in the American Society of Anesthesiologist algorithm for the difficult airway. It requires no direct visualization of the cords. The one



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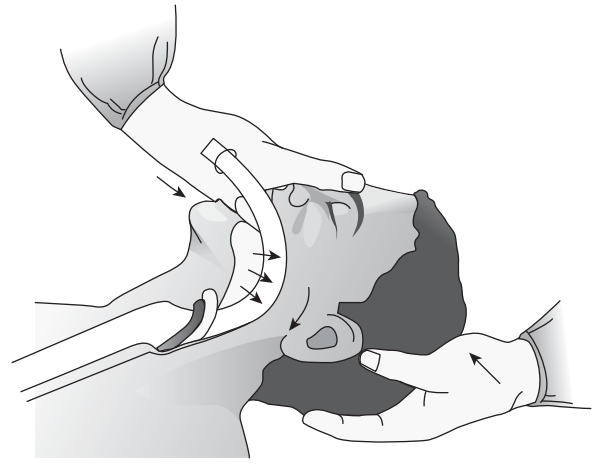

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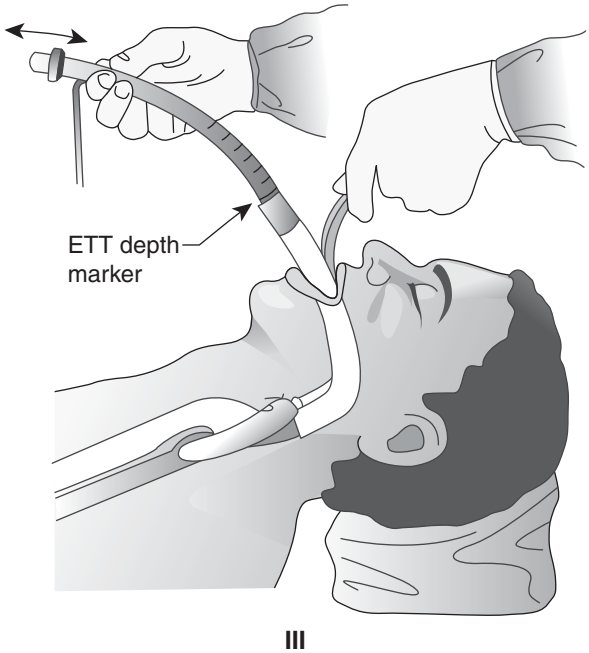
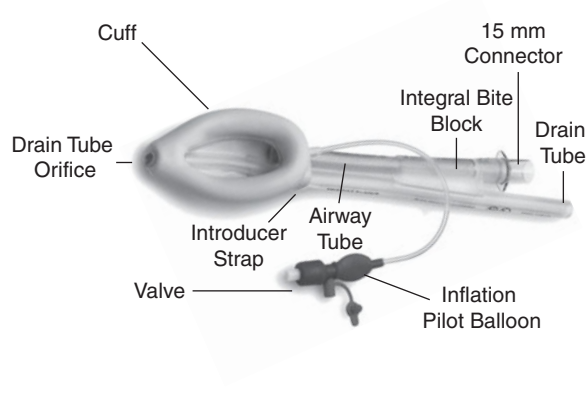


III



IV

▲ **Figure 5–5.** In part **I** of the figure, the laryngeal mask airway (LMA) (A) and the fast-track LMA (B) are shown. The LMA is commonly used for short procedures in patients who are aspiration risks **(II)**. It can also be used for emergency situations for ventilation when a laryngoscope is not available or when the vocal cords are not visualized. In situations where the patient may be an aspiration risk, a small tracheal tube can be placed through an LMA with confirmation by fiberoptic bronchoscopy. The fast-track LMA **(III)** was designed specifically for placement of an endotracheal tube in emergency situations. The ProSeal LMA **(IV)** consists of a special lumen that allows for aspiration of stomach contents.

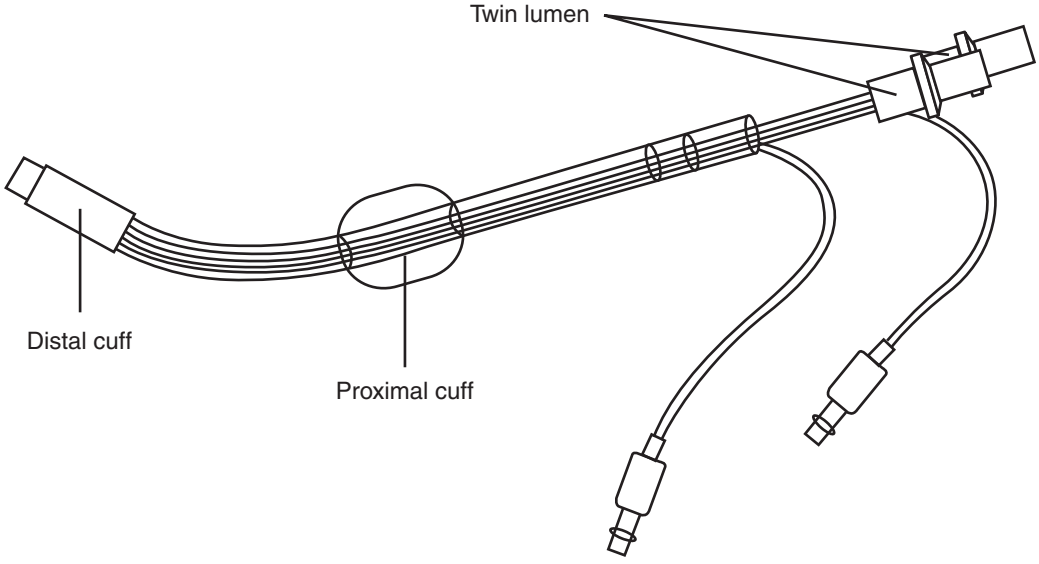
setback of this device is that it does not prevent aspiration. Hence in patients with high aspiration risk, a small endotracheal tube can be placed under fiberoptic guidance. More recently two new laryngeal masks have been introduced: the fast-track LMA and the ProSeal LMA. The fast-track LMA can be used as a regular LMA. Its main advantage is that it allows the placement of endotracheal tubes without direct laryngoscopy (see Figure 5–5). The ProSeal LMA is very similar to the LMA, but with an extra-lumen for suction of stomach and intestinal contents. It should be emphasized

that all three types of LMA do not protect against aspiration of gastrointestinal contents if the patients vomits.

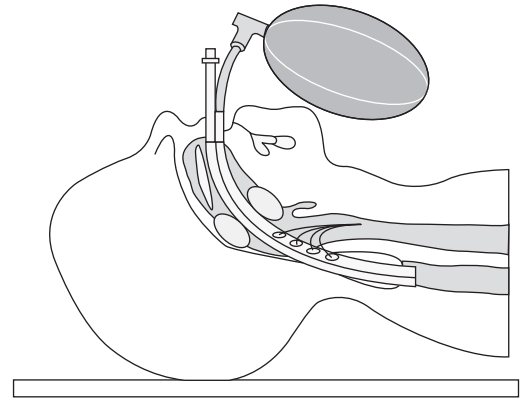
The esophageal-tracheal combitube is another device that can be used in emergency situations. The combitube is a hybrid of the traditional endotracheal tube and the old esophageal obturator airway. This device can prevent aspiration because of the presence of a tracheal cuff (see Figure 5–6).

The Glidescope

The GlideScope® (Saturn Biomedical Systems Inc., Burnaby, British Columbia, Canada) is a new video laryngoscope that can be a useful alternative to the conventional fiberoptic scope for placement of an endotracheal tube in the trachea when confronted with a difficult airway. The GlideScope has a high-resolution digital camera incorporated in the blade, which displays a view of the vocal cords on a monitor. The blade is fashioned after the Macintosh blade with a 60° curvature to match the anatomical alignment. The blade is made of a soft plastic material and has a thickness of 18 mm. The blade also has an embedded antifogging mechanism. The GlideScope can be used with minimal treatment of the oropharynx with local anesthetic and is useful for not only endotracheal intubation but also as a diagnostic tool. Currently, there are several other video laryngoscopes on the market that improve our ability to deal with the difficult airway.



A



B

▲ **Figure 5–6.** The combitube is one of the more recently developed airways that can be placed without laryngoscopy and in emergency situations. The airway contains two lumens, a distal lumen which sits in the esophagus and a proximal lumen for ventilation. There are two inflatable, one in the esophagus and one in the oropharynx **(A)**. Placement of the combitube is illustrated in **(B)**.

PREPARING THE PATIENT FOR ANESTHESIA AND SURGERY

Patients who are scheduled for surgery should have a preoperative evaluation by the surgeon and the anesthesiology, especially if general anesthesia is to be administered. These patients should have some baseline laboratory assessment that should include at a complete blood count. In patients with coexisting disease, an evaluation of other function is necessary. Patients over the age of 50 years should also have an ECG as should patients with heart disease. A preoperative pulmonary function assessment in patients with pulmonary disease is also warranted. These tests may determine postoperative care requirements and assess if preoperative treatment may reduce the perioperative risks. In this section a review of the current functional tests for cardiac and pulmonary function is presented. While in a high percentage of cases a cardiac or pulmonary consultant will be involved with the assessment of the patients, it is important for the otolaryngologist to understand some of the functional tests that will be ordered.

Table 5–5. Sensitivity and Specificity of Noninvasive Testing.

Test	Sensitivity (%)	Specificity (%)	Cost ($)
Ambulatory ECG (24 hours)	70	85	280
ECG stress test	65	80	450
Stress echo	80	85	600
Thallium (planar)	90	80	1200
Thallium (SPECT)	90	90	1200
Dipyridamole thallium	90	90	1200
Cardiac catheterization	95	95	2500

Adapted from Fleisher LA, Hulyalkar A. Cardiovascular testing for the 1990s. In Lake CL, Barash PG, Sperry, RJ (editors): *Advances in Anesthesia*, Vol. 11. St. Louis, Mosby-Year Book, 1994.

Assessment of Patient with Cardiac Disease

Patients over the age of 50 years and patients with cardiac disease should have an ECG prior to surgery. The preoperative ECG can provide important information on the status of the patient's cardiac and coronary circulation. Patients with abnormal Q waves seen on their ECG suggest a past myocardial infarction. These patients may be at increased risk of a perioperative cardiac event and may need further preoperative assessment. In fact about 30% of infarctions are silent and only detected on routine ECG, most notably in patients with diabetes or hypertension. In addition to the ECG, history taking can provide important information with regards to the patient's cardiac status. Assessing the patient's functional status by knowing the patient's exercise tolerance may determine the need for a cardiac evaluation. The information from cardiovascular testing may allow for optimization of preoperative medications, provide information on perioperative monitoring, or determine the need for coronary revascularization. There are several tests for assessing functional status (Table 5–5). These include the following:

A. 24-Hour Ambulatory ECG

This ECG requires the placement of a Holter monitor, which records a continuous 12-lead ECG for 24 hours. This will detect arrhythmias and ischemic changes during a 24-hour period. This test will often require further testing, particularly if ischemic changes are noted.

B. Exercise Stress Test

Essentially, in an exercise ECG stress test where a patient is asked to exercise with the ECG, heart rate and blood pressure monitored. The presence of ECG signs of myocardial ischemia and/or the patient complaints of chest pain or dyspnea, and clinical signs of left ventricular dysfunction, are considered positive. Even more important is a decrease in blood pressure in response to exercise. This may be associated with global ventricular dysfunction. Syncope during the test also signifies decreased cardiac output. A positive exercise ECG stress test should alert the anesthesiologist that the patient is at risk for ischemia, within a wide range of heart rates, which may occur during surgery. These patients may require further workup and optimization of medical management.

C. Thallium Exercise Test

The sensitivity and specificity of the noninvasive stress test can be increased by nuclear imaging techniques. Thallium-201 (Tl-201) is a radioactive compound that mimics potassium uptake by viable myocardial cells. The sensitivity of exercise Tl-201 imaging depends upon the imaging technique. Qualitative visual Tl-201 imaging has an average sensitivity of 84% and specificity of 87% for detecting coronary artery disease (CAD), although these numbers are improved with better imaging techniques. The drawback is that patients have to remain stationary for imaging to avoid artifact. Thallium defects are reported as normal, fixed, and/or reversible. Other measures of importance, particularly during stress Tl-201 imaging, are size of defect, lung uptake, and left ventricular cavity size. A large lung uptake of isotope has been associated with myocardial ischemia that produces left ventricular dysfunction that may result in pulmonary edema. The presence of a distended left ventricular cavity on the immediate post-stress image is another marker of severe CAD, presumably as a result of myocardial ischemia.

D. Thallium Imaging in Patients Who Cannot Exercise

The use of pharmacologic agents to induce cardiac stress in patients who cannot exercise can also detect CAD. These agents can be divided into two categories: those that result in coronary artery vasodilatation, such as dipyridamole and adenosine, and those that increase myocardial oxygen demand, such as dobutamine and isoproterenol. Coronary artery vasodilators are useful for defining myocardium at risk by causing differential flows in normal coronary arteries compared with those with a stenosis. The use of dolbutamine is an alternative method of increasing myocardial oxygen demand without exercise. The goal is to increase heart rate and blood pressure.

E. Echocardiography

The use of echocardiography for preoperative cardiac evaluation has increased in the last few years. Left ventricular function, pulmonary vascular pressures, and valvular competence can be evaluated. In most cases, a transthoracic approach has been used. Transesophageal echocardiography may provide better measurement of valvular abnormalities and left ventricular function. Echocardiography can also be performed with exercise, and in patients unable to exercise, dolbutamine has been used to mimic the stress effects of exercise.

F. Coronary Angiography

Coronary angiography has been called the gold standard for defining coronary anatomy. In addition, angiography also can assess valvular function and hemodynamic indices, including ventricular pressure and gradients across valves. In most cases, angiography is performed after a positive stress test to determine if coronary revascularization will improve cardiac function and reduce perioperative cardiac morbidity after noncardiac surgery. One major difference between stress tests described previously and coronary angiography is that the latter provides the clinician with anatomic, not functional, information. It is also an expensive test with potential complications.

G. Patient with Drug-Eluting Stents (DES)

In the last several years, percutaneous vascular interventions have replaced open surgical procedures (coronary artery bypass graft [CABG]) in a number of situations. One such situation is percutaneous placement of DES for coronary revascularization in patients with CAD. DES, unlike their counterparts, the bare metal stents (BMS), are coated with slow-release chemicals that prevent thrombus formation with the help of antiplatelet drugs such as clopidogrel. As the number of patients with DES who present for head and neck surgery increases, it is imperative that surgeons and anesthesiologists be aware of guidelines for stopping antiplatelet medications. The current recommendation for patients with DES is that elective surgery should be postponed if the duration between stent placement and noncardiac surgery is less than 6 months. For semi-emergent procedures, both aspirin and clopidogrel should be continued during surgery unless clearly contraindicated by the nature of the surgery. If the risk of bleeding is high, then modification of antiplatelet medications should be considered on a case-by-case basis.

H. Patients with Pacemakers and AICDs

With the advances in pacemaker technology, the placement of pacemakers in patients with both cardiac conduction defects and arrhythmias has dramatically increased. Hence some basic knowledge of pacemakers must be known. In addition to patients with pacemakers, some patients who present for surgery may have automated implantable cardioverter defibrillators (AICDs). Both groups of patients benefit from a careful preoperative evaluation and device interrogation by a cardiologist specializing in electrophysiology. It is important to know the type of the device; in the case of the pacemaker, the configuration should be known and then also the reaction of either device to "inhibition" by placing a magnet over the implanted device. Most of the problems encountered with pacemakers and AICD devices are due to electrocautey. Several measures can be made to avoid potential adverse effects. These include the use of bipolar cautery. If unipolar cautery is needed, then the grounding pad should be placed away from the pacemaker and close to the operative site. It is recommended that electrocautery not be used at a distance less than 15 cm from the pacemaker or AICD device; if this is unavoidable, then use of cautery with short bursts and long pauses will reduce adverse events. The pacemaker may be programmed to an asynchronous mode by a magnet or by a programmer. The magnet will place the pacemaker in a backup-pacing mode. Reprogramming of the device should be instituted after the surgery.

I. Patients with Drug-Eluting Stents

In the last few years, percutaneous coronary intervention by placement of coronary stents has surpassed CABG for revascularization due to CAD. This is due primarily to the introduction of DES. In the past, patients with multi-vessel CAD requiring revascularization would often undergo CABG surgery instead of stent placement because of concerns regarding re-stenosis with BMS. Nevertheless, patients with DES merit special consideration if they are scheduled for surgery. Because of the risk of thrombus formation during the period of re-endothelialization of the stent, antiplatelet drugs are given particularly in the first 6 months to prevent thrombus formation. Aspirin and clopidogrel are the two most common drugs used. In most patients with DES, antiplatelet drugs should be used in the first 6 months, and stopping these medications puts patients at risk for thrombus formation in the stents. Hence, in patients with a DES, a preoperative cardiology consultation is essential. **Elective**

surgery should be postponed if the duration between DES placement and noncardiac surgery is less than 6 months. For semi-emergent procedures, both aspirin and clopidogrel should be continued during surgery unless clearly contraindicated by the nature of the surgery. If the risk of bleeding is high, then modification of antiplatelet medications should be considered on a case-by-case basis.

J. Preoperative Pulmonary Evaluation

Patients scheduled for head and neck surgery may present with coexisting pulmonary diseases. For patients with acute pulmonary disease scheduled for elective surgery, the surgery may be postponed until the pulmonary disease resolves. Postoperative pulmonary complications include atelectasis, pneumonia, respiratory failure, and exacerbation of chronic pulmonary disease. Patients with chronic pulmonary disease may merit from a preoperative pulmonary workup that includes an arterial blood gas, chest X-ray, and pulmonary function tests. The presence of pulmonary disease may increase perioperative morbidity and mortality. Preoperative pulmonary function tests measure the severity of lung disease, measure the efficacy of bronchodilator therapy to improve the pulmonary function, and can predict the need for the patient for postoperative mechanical ventilation.

In general, disease of the pulmonary system may be classified as obstructive or restrictive.

1. Obstructive Pulmonary Diseases—Obstructive pulmonary disease includes asthma, emphysema, chronic bronchitis, bronchiectasis, and bronchiolitis. These disorders are characterized by an increase in expiratory airflow resistance that results in an increase in the work of breathing. The most typical finding noted on pulmonary function tests is that both forced expiratory volume in 1 second (FEV1) and the FEV1/FVC (forced vital capacity) ratio are less than 70% of the predicted values. The expiratory airflow resistance results in air trapping. In addition, the residual volume (RV) and the total lung capacity (TLC) are increased. Wheezing is a common clinical finding and represents turbulent airflow. In mild obstructive disease, wheezing may be absent but can be elicited by prolonged exhalation.

2. Restrictive Pulmonary Diseases—Restrictive lung diseases may be acute or chronic intrinsic disorders that include pulmonary edema, ARDS, infectious pneumonia, or the interstitials lung diseases. Restrictive pulmonary disease may also represent extrinsic disorders involving the pleura, chest wall, diaphragm, or neuromuscular function.

The hallmark of this group of disorders is decreased lung compliance that increases the work of breathing due to a characteristic rapid-shallow breathing pattern. Lung volumes are typically reduced as well as the FEV1 and the FVC. There is a normal FEV1/FVC ratio. The expiratory flow rates are unchanged.

Management of Patients with Chronic Anticoagulation

As noted above, some patients who present for elective surgery often require chronic anticoagulation for conditions such as venous thromboembolism, mechanical valve implants, or chronic atrial fibrillation. The management of these patients requires careful consideration. Common medications used include vitamin K antagonists such as Coumadin and antiplatelet agents such as aspirin and clopidogrel. For patients undergoing a major surgical or invasive procedure, if the intent is to eliminate any effect of antithrombotic therapy, it should be stopped at a time before the procedure. Coumadin (warfarin) should be stopped approximately 5 days if the patient's INR is maintained between 2 and 3, with the goal of bringing the INR to 1.5 prior to surgery. If the INR persists between 1.8 or higher, then the option of administering a small dose (1 mg, subcutaneously) of vitamin K is an option for antagonism of anticoagulation. If the INR is maintained at greater than 3.0, then Coumadin should be stopped 10 days prior to surgery. In patients in whom there is concern for thrombus formation if the vitamin K antagonist is stopped, then "bridging therapy" with lower molecular weight Heparin given via subcutaneous means or unfractionated heparin given intravenously, can be used as bridging therapy.

In patients receiving an antiplatelet drug, clopidogrel, medication should be stopped 7–10 days prior to surgery. In patients who are receiving antiplatelet drugs alone, bridging anticoagulation is not typically administered.

SPECIAL CONSIDERATIONS FOR THE ANESTHESIOLOGIST AND OTOLARYNGOLOGIST FOR COMMON HEAD AND NECK SURGERIES

Ear, nose, and throat surgery often requires special anesthetic considerations and equipment. These concerns are important to both the surgeon and the anesthesiologist. In this section, concerns that merit attention are outlined in brief. A more detailed description of the procedures can be found elsewhere in the text.

SURGERY OF THE ORAL CAVITY AND AIRWAY

1. Tonsillectomy and Adenoidectomy

Preoperative Considerations

- Most patients are usually young and healthy.
- A few may present with symptoms of obstructive sleep apnea (OSA). Patients with OSA are often obese, with potentially difficult airway. They may have a short, thick neck, large tongues, and redundant pharyngeal tissue, so

they may require an awake tracheal intubation. Sedative premedication may be avoided in children with OSA, intermittent obstruction, or very large tonsils.

- Patients may present with upper respiratory tract infections (URI). Surgery for these patients should be postponed until resolution of the URI (usually 7–14 days). These patients may develop laryngospasm with airway manipulation. This is an undesirable complication with potential for significant morbidity and even mortality.

Intraoperative Considerations

- Tracheal intubation in some patients may be significantly difficult; hence the presence of an otolaryngologist may be helpful at the time of intubation.
- The use of an oral RAE tube for tracheal intubation may optimize visualization of the surgical field.
- In younger children in whom an uncuffed tracheal tube is used, in order to avoid inhalation blood from the pharynx area, the supraglottic area may be packed with petroleum gauze tube provided an appropriate leak around the endotracheal tube is obtained.
- Patients should be extubated awake when protective airway reflexes have returned. In patients with reactive airway disease, including asthma, deep extubation of the patients may be warranted to prevent airway reactivity, including bronchospasm and laryngospasm.
- The use of LMAs for tonsillectomies has been increased in the last few years. With a well-trained team, adenotonsillectomy on children can be carried out safely in an office-based setting with LMA and a short postoperative stay.

Postoperative Complications

- Retention of throat pack.
- Pulmonary edema. Acute airway obstruction such as laryngospasm can lead to pulmonary edema. This occurs as the patient breathes against a closed glottis, creating a negative intrathoracic pressure. This pressure is transmitted to the interstitial tissue, increasing the hydrostatic pressure gradient and enhancing fluid out of the pulmonary circulation into the alveoli.
- Hemorrhage from bleeding tonsil. Often re-intubations may be difficult. Care should be taken not to over-sedate the patient who may aspirate large quantities of blood. If bleeding is not controlled, then the patients should be returned to the operating room for exploration and surgical hemostasis.
- In the last few years, the performance of tonsillectomies in morbidly obese patients has come under much scrutiny due to postoperative respiratory complications due to opioid use for analgesia. It is clear that morbidly obese patients and patients with OSA merit special consideration and may not be ideal candidates for same-day surgery.

2. Laser Surgery of the Airway

Laser surgery for lesions in the airway provides precision in targeting lesions, minimal bleeding and edema, as well as preservation of surrounding structures and rapid healing. The carbon dioxide laser has particular applications in the treatment of laryngeal or vocal cord papillomas and laryngeal webs, resection of redundant subglottic tissue, and coagulation of hemangiomas.

Preoperative Considerations

Appropriate equipment should include a laser-resistant endotracheal tube, and other endotracheal tubes for emergency situations should be available. Anesthesia during laser surgery may be administered with or without an endotracheal tube. All standard PVC endotracheal tubes are flammable and can ignite and vaporize when in contact with the laser beam. Some surgeons may prefer using a Dedo or Marshall laryngoscope and intermittent ventilation with a Sanders ventilator. The Sanders ventilator is a jet ventilator that delivers oxygen under 50 psi directly through a port in the laryngoscope.

Intraoperative Considerations

- The eyes of a patient must be protected by taping them shut, followed by the application of wet gauze pads and a metal shield in order to prevent laser penetration of eyes. All operating room personnel should wear special protective glasses.
- Airway fires are a risk with laser surgery, and a plan of action is necessary. In some centers the tracheal balloon is filled with methylene blue; hence rupture of the balloon is an early indication of a hazard. Both oxygen and nitrous oxide support combustion, and hence a mixture of 30% oxygen and nitrogen may be used. If a fire occurs, ventilation should be discontinued, oxygen turned off, and the tube removed. If the flame persists, the field should be flooded with normal saline. Direct examination of the pharynx and larynx will evaluate the extent of the burn.
- If a Dedo or Marshall laryngoscope is used, then maintenance anesthesia can be accomplished with an IV anesthetic to prevent anesthetizing the surgeon.
- The patient should be reintubated with a regular endotracheal tube after the bronchoscope is removed.
- Use of the Sanders jet ventilator is associated with the risk of pneumothorax and pneumomediastinum due to rupture of alveolar blebs or a bronchus.

Postoperative Considerations

- In the event of an airway fire, the patient should be monitored for at least 24 hours. Steroids and antibiotics should be considered for severe burns.
- If respiratory problems are encountered, then patients should be observed in an intensive care setting.

EPIGLOTTITIS

Acute epiglottitis is one of the most feared upper airway disease in children and adult. It is an infectious disease caused by *Haemophilus influenzae* type B. It can progress rapidly from sore throat to airway obstruction to respiratory failure and death if proper diagnosis and treatment are delayed. Patients are usually between 2 and 7 years of age, although epiglottitis has been reported in younger children and adults. Characteristic signs and symptoms of acute epiglottitis include:

- sudden onset of fever, dysphagia, drooling, thick muffled voice, and preference for the sitting position with the head extended and leaning forward;
- retractions, labored breathing, and cyanosis, which may be observed in cases where respiratory obstruction is present.

Preoperative Considerations

- Do not attempt direct visualization of the epiglottis in the unanesthetized patient. This could lead to airway compromise and death.
- Do not attempt excessive blood draws that will excite the patient. Keep the patient calm. The differential resulting from negative pressure inside and atmospheric pressure outside the extrathoracic airway results in slight narrowing during normal inspiration. During inspiration the pressure differential is exaggerated in the patient with airway obstruction. This dynamic collapse of the airway may become **life-threatening in the struggling and agitated patient.**

Intraoperative Considerations

- If the patient is a child, then a parent should be allowed into the operating room to keep the patient calm.
- An emergency airway cart and tracheostomy tray should be available and open.
- Induce anesthesia with halothane or sevoflurane maintaining spontaneous ventilation. **Secure the airway.**

Postoperative Considerations

- Postoperative care should be in the ICU for continued observation and radiographic confirmation of tube placement.
- Tracheal extubation is usually attempted 48–72 hours later when a significant leak around the endotracheal tube is present and visual inspection of the larynx by flexible fiberoptic bronchoscopy confirms reduction in swelling of the epiglottis and surrounding tissues.

PAROTID GLAND SURGERY

Parotid gland surgery is usually performed for tumors but can also be performed for infectious disorders. Some diseases of parotid gland have been associated with the use of alcohol; hence these patients may exhibit the signs and symptoms of alcohol-related diseases. The surgeries are performed under general anesthesia, and in most cases, the facial nerve will need to be preserved and hence nerve monitoring is necessary. When a radical parotidectomy is done, the facial nerve may be sacrificed and reconstructed with a graft from the contralateral greater auricular nerve.

Special Considerations

- Muscle relaxants should be avoided if nerve monitoring is used.
- Nasal intubation may be necessary if mandible has to be dislocated.

NASAL SURGERY

A significant percentage of nasal surgery is performed for cosmetic purposes, although a large percentage is performed for functional restoration of the airway. Functional restoration is usually performed for either congenital or posttraumatic deviations of the septum. Nasal surgery is office based and performed with local anesthesia and IV sedation. Patients with nasal polyps and asthma often have a hypersensitivity to aspirin, which can precipitate bronchospasm.

Intraoperative and Postoperative Considerations

- The most important consideration is achieving profound vasoconstriction in the nares to control bleeding. This can be achieved with cocaine packs, local anesthetics, and epinephrine infiltration.
- Since these drugs have a profound effect on the cardiovascular system, a careful evaluation of the cardiovascular system is essential, especially for older patients or patients with known cardiac disease. A vasoconstrictor can also precipitate dysrhythmias.
- A moderate degree of controlled hypotension combined with head elevation decreases bleeding in the surgical site.
- Blood may passively enter the stomach. The placement of an oropharyngeal pack or suctioning of the stomach at the conclusion of surgery may attenuate postoperative retching and vomiting.

EAR SURGERY

The ear and its associated structures are target organs for many pathological conditions. Perhaps most common is the placement of myringotomy tubes. Also on the rise are placement of cochlear implants and tympanoplasties. The surgeries usually require general anesthesia and, in some cases, rely on neuromonitoring. When nerve monitoring is necessary, muscle relaxants should not be used. In most cases of ear surgery, there is nausea and adequate pretreatment with antiemetics, and the use of anesthetics such as propofol and sevoflurane have been shown to reduce the incidence of nausea and vomiting.

MYRINGOTOMY AND TUBE INSERTION

Special Considerations

- Premedication is not recommended because most sedative drugs will far outlast the duration of surgical procedure.
- Anesthesia may be effectively accomplished with a potent inhalation drug, oxygen, and N_2O administered by mask.
- Pretreat for nausea and vomiting.

MIDDLE EAR AND MASTOID SURGERY

Tympanoplasty and mastoidectomy are two of the most common procedures performed on the middle ear and accessory structures.

Special Considerations

- An oral or nasal RAE tube may be helpful in avoiding intrusion into the surgical field.
- Although not totally contraindicated, N_2O should be discontinued at least 30 minutes before placement of a tympanic membrane graft to avoid pressure-related displacement.
- Extubation should be smooth to avoid straining, which may unseat the tympanic membrane graft or disrupt other repairs.

Postoperative Considerations

Postoperative nausea and vomiting are the most common postoperative problems. This can be reduced by:

- decompressing the stomach after induction of general anesthesia, thereby emptying the stomach of gas and fluid;
- limiting the use of opioids;
- using antiemetics.

NECK SURGERY

Neck dissection may be complete, modified, or functional. The primary muscle involved is the sternocleidomastoid muscle, the primary nerve is cranial nerve XI, and the primary vascular structures are the internal and external jugular veins and the carotid artery. Often a neck dissection is performed for removal of a tumor and may also involve a partial or total glossectomy. Patients who present with such tumors may have a history of tobacco use and pulmonary disease and may need a preoperative pulmonary workup. In a high percentage of cases, the dissection may be bilateral and a tracheostomy may be performed to maintain a patent airway.

Special Considerations

- These patients may be a challenge to intubate if they have a history of radiation treatment to the larynx and pharynx or if they have a significant mass in the oral cavity.
- If nerve monitoring is used, then muscle relaxants should be avoided.
- Dissection around the carotid bulb may precipitate bradycardia, which may be treated with an injection of local anesthetic into the bulb or with IV atropine or glycopyrrolate.
- Laryngeal edema can be a significant problem if no drains are placed.

Postoperative Considerations

- Nerves injured include the facial nerve, resulting in a facial droop. In addition, injury to the recurrent laryngeal nerve can cause vocal cord dysfunction. If the injury is bilateral, this can lead to airway problems. Since the phrenic nerve also traverses through the operative field, paralysis of the hemidiaphragm can occur. If injury is bilateral, that breathing will be impaired.
- With low neck dissection, a pneumothorax can occur.
- Excessive coughing or agitation can result in hematoma formation and airway compromise.

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6 Lasers in Head & Neck Surgery

Bulent Satar, MD & Anil R. Shah, MD, FACS

DEFINITIONS

The word "laser" is an acronym for light amplification by stimulated emission of radiation. A laser is a device that produces an intense beam by amplifying light.

Radiation

The radiation produced for surgical lasers is in the electromagnetic spectrum with a wavelength that ranges from 200 to 400 nm (near-UV radiation), 400 to 700 nm (visible radiation), 700 to 1000 nm (near-infrared radiation), and more than 1000 nm (infrared radiation). The most prominent physical feature of the radiation is its wavelength, which determines its visibility. The three most commonly used types of surgical lasers are (1) the argon laser, which is within the visible portion of the electromagnetic spectrum; (2) the neodymium:yttrium–aluminum–garnet (Nd:YAG) laser; and (3) the carbon dioxide (CO_2) laser.

Amplification

Stimulated emission is the main source of laser energy. However, the energy of stimulated emission needs to be amplified to produce an intense beam. When the laser pump activates the active medium, the active medium starts having more atoms in an excited state. As atoms in the excited state release photons, this induces the emission of the photons from other atoms through a chain reaction.

Light

One of the distinctive features of the light is its highly concentrated energy per unit area. Beams forming the light synchronously occur parallel with each other, which makes it possible for the laser to travel a certain distance without divergence. It is monochromatic. The wavelength of the light is one of the factors determining the physical characteristics of the laser and its interaction with tissue.

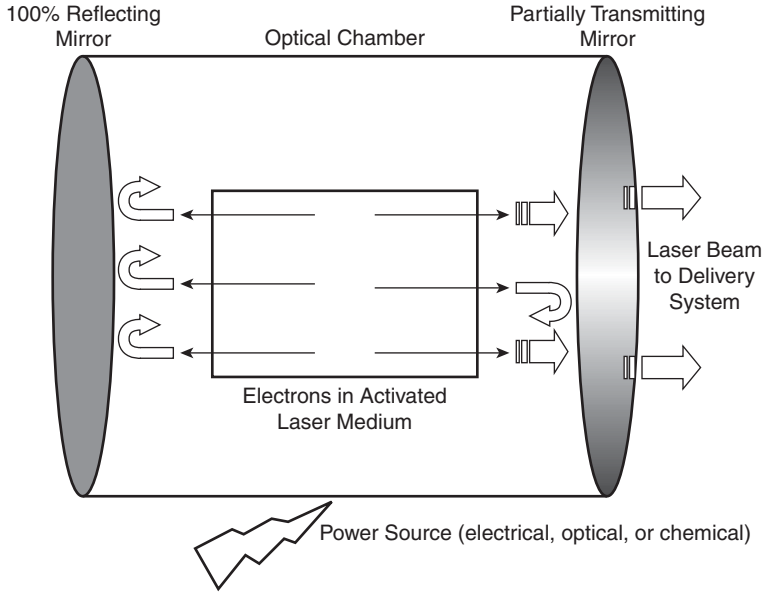
Stimulated Emission

The current model of stimulated emission is described by quantum physics, which defines different energy levels of electrons while revolving around the nucleus in different levels of orbit. In this model, a stable electron in a normal state makes a transition to a higher but unstable energy level by absorbing a photon (absorption). This unstable electron with high energy ultimately may return to the original stable level spontaneously (spontaneous emission). Alternately, this emission can be induced by a forced interaction between one photon and the unstable electron to release a new photon (stimulated emission), which is the basis of laser energy.

LASER COMPONENTS

A laser primarily consists of three main components: (1) an active medium; (2) a stimulation (excitation) mechanism, which is the power source or a laser pump; and (3) an optical chamber (feedback mechanism) (Figure 6–1). The active medium is the component where the laser radiation is generated. The function of the active medium is to supply a source of stimulated atoms, molecules, and ions. It may be in a solid, gaseous, or liquid state. Different types of lasers are named based on what is used as an active medium. Lasers with a solid state of active medium are the Nd:YAG, ruby, and diode lasers. Lasers using a gaseous active medium are the CO_2, argon, and helium-neon lasers. The helium-neon laser is used as an aiming beam in lasers with an invisible beam (as in the CO_2 laser) in order to create a visible beam. A laser with a liquid active medium uses organic dye.

The activation status of the laser medium is operated by the operation mode of the laser device. Three operational modes are available currently. In the **continuous mode,** the active medium is kept in a stimulated mode, which provides constant and stable energy. In the **pulsed mode,** the active medium is intermittently activated for a very short time, which allows tissue to cool off between pulses,



▲ **Figure 6–1.** A simplified model of the primary laser components.

thereby decreasing thermal damage. However, a much higher maximum of instantaneous energy is delivered with pulses compared with that of the continuous mode in which average power output is greater. In **Q-switched mode,** very short pulses of the laser are produced in a controlled manner. The second component of the laser is the power source that is used to activate the medium. The optical chamber is used to direct the output and also to provide feedback from amplification and collimation. The optical chamber contains the active medium.

Besides these major components of the laser, it must contain a cooling system, a delivery system, a control unit, and a remote control. Delivery systems are important in the selection of a laser. They can be an articulated arm (for the CO_2 laser), optical fibers (for near-infrared and visible lasers), or a connection between the laser and the operation microscope (for the CO_2 laser).

COMMONLY USED LASERS

CO_2 Laser

The wavelength of the CO_2 laser is 10,600 nm, which is not visible. Its power is between 0.1 and 100 W. A cooling system is required to couple to the main system because of the high heat energy produced by the laser. Also, the helium-neon laser beam is used as an aiming beam to make it visible. Its delivery system may be a handpiece at the end of an articulated arm consisting of reflective mirrors, a wave guide, or a micromanipulator to be coupled to an operating microscope. Practically, its energy is absorbed by the tissue within a 0.2-mm depth. Any tissue with a high water content selectively absorbs the CO_2 laser. For an incision, a small spot size with a high power density is preferred. New CO_2 laser systems have a spot size as small as 160 μm. For vaporization purpose, a low power density is applied with a large spot size. This also creates a heat energy that coagulates blood and lymph vessels. However, its hemostasis capability is limited to vessels <0.5 mm. In skin resurfacing, the CO_2 laser ablates 20–60 μm of tissue and up to 150 μm of residual thermal damage per pass. Generally speaking, the CO_2 laser is used for excision of laryngeal lesions and deep skin resurfacing for rhytids and acne scarring.

Argon Laser

The argon laser is typically used for the coagulation of hemangiomas. Its beam emits a green-blue light, visible in the range of the electromagnetic spectrum (458–515 nm), and has a penetration depth of 1 mm. Because of its wavelength, it is almost completely absorbed by hemoglobin, melanin, and myoglobin.

Nd:YAG Laser

The Nd:YAG laser is a solid-state laser that delivers a 1060-nm beam (near infrared), thereby requiring an aiming beam. The penetration depth is 3–5 mm because of its low absorption by water and tissue pigments. This low absorption also causes scattering and reflection. Therefore, its use for coagulation purposes requires high power, making the thermal coagulation of vessels and hemangiomas possible. Its delivery system is a fiberoptic carrier, which provides

a hemostatic effect at contact. However, it can be used for ablation in a noncontact mode. The Nd:YAG laser is used for tracheobronchial lesions, particularly for its excellent hemostatic qualities; nonablative skin resurfacing; and hair removal in ethnic patient populations.

KTP-532 Laser

The KTP-532 (potassium titanyl phosphate) laser works by passing an Nd:YAG laser through a KTP crystal, resulting in the emission of half its wavelength (532 nm), which becomes visible. The delivery system is a fiberoptic carrier (for vaporizing and coagulation effects) or a contact quartz tip (for cutting). Since this laser is primarily absorbed by oxyhemoglobin, it is mainly used in the treatment of vascular lesions (including superficial skin lesions and telangiectasias) and the surgical reduction of turbinate tissue.

Erbium:YAG Laser

The erbium:YAG laser emits a 29–40 W, which is highly absorbed by water (12–18 times more efficiently than CO_2 laser). It has the advantage of precise tissue ablation, 5–20 μm per pass, a small zone of residual thermal damage compared with the CO_2 laser. The erbium:YAG laser has the disadvantage of poor hemostatic qualities and limited collagen tightening compared with the CO_2 laser. It is primarily used for superficial skin resurfacing for fine wrinkles, brown spots, and acne scars.

LASER–TISSUE INTERACTION

The effects of laser on tissue rely on one of the following interactions: absorption, scattering, transmission, or reflection (Figure 6–2). The type of interaction between a laser beam and any tissue is determined by the wavelength of the laser beam, the operation mode of the laser, the amount of energy applied, and tissue characteristics. The interaction of the laser on tissue can be summarized with the general statement that "the shorter the wavelength, the greater the effect on the tissue." Table 6–1 shows lasers with their electromagnetic spectrum and penetration depth. Lasers whose wavelengths are within 0.1–0.8 μm (UV and visible region of the spectrum) cause minimal water absorption but considerable hemoglobin-melanin absorption. Lasers with a wavelength >3 μm absorb water.

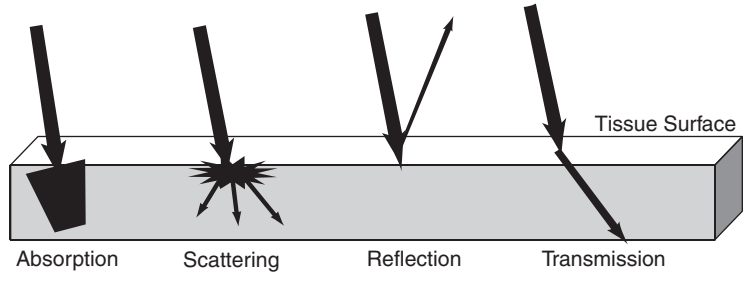
The visible lasers penetrate into tissue at approximately 1 mm. However, the Nd:YAG laser goes into tissue at 4 mm and absorbs minimal water. In contrast, the penetration depth of the CO_2 laser is only 30 μm, which makes it superb as a cutting tool.

Changes in tissue exposed to a laser relate to the temperature created by the laser. In temperatures higher than 50°C, enzymatic activity decreases. Protein denaturation occurs at temperatures over 60°C, the point at which physical changes are seen. However, tissue can still recover with the healing process. Over 80°C, the collagen degrades; 100°C is the temperature at which the water vaporizes, which results in expansion of the steam and finally tissue ablation. Although providing perfect hemostasis, a laser incision causes a delay in wound healing. Collateral thermal damage, although inevitable, can be minimized by using infrared lasers. Lasers can be used for incision, vaporization, or coagulation. Laser beams can be focused to spot sizes <1 mm in diameter or defocused. A focused beam is used for cutting and a defocused beam for ablation and coagulation.

LASER SAFETY RULES

Currently, there are two main federal regulations regarding the safe use of lasers in the United States. These are the American National Standard for Safe Use of Lasers (ANSI Z 136.1), which regulates the laser industry, and Safe Use of Lasers in Health Care Facilities (ANSI Z 136.3), which regulates the installation, operation, and maintenance of lasers in health care units. There is another standard, Safe Use of Lasers in Educational Institutions, which regulates safe use during educational activities (ANSI Z 136.5).

Lasers can harm not only the patient but also the surgeon and other personnel in the operating room. Laser system hazards can be related either directly to the effect of the beam on tissue, such as the retina, the corneas, or skin, or



▲ **Figure 6–2.** Types of laser–tissue interaction.

Table 6–1. Currently Used Lasers with Their Electromagnetic Spectrum and Penetration Depth.

Electromagnetic Spectrum	Laser Type	Wavelength	Penetration Depth
Visible lasers	Argon	514 nm	0.8 mm
	KTP-532	532 nm	0.9 mm
	Flashlamp-excited dye	577 nm	0.9 mm
Near-infrared lasers	Nd:YAG	1060 nm	4.0 mm
Infrared lasers	Ho:YAG	2100 nm	0.4 mm
	Er:YAG	2940 nm	3.0 μm
	CO_2	10,600 nm	30.0 μm

secondary conditions such as fire, electrocution, toxic waste, and plume radiation.

Beam Hazards

A primary concern of unsafe laser use is eye injury. It can occur as a result of direct exposure to either a laser beam or a reflected beam. The best protection is for all personnel to wear approved laser safety glasses. If possible, the patient also needs to wear the same eyewear. If it interferes with the operation field or the procedure, moistened sterile cotton eye pads with moistened towels or metallic eye protectors are needed to cover the eyelids. All operating room windows must be covered with an opaque material at the wavelength of the laser used. An ANSI-approved warning sign at the entrance to all operating rooms should be placed with protective eyewear for those who enter the operating room.

Plume Hazards

Plume hazards relate to plume radiation and plume content. Plume radiation occurs when the laser beam contacts the smoke plume, which is a by-product of laser beam use. The smoke plume results from heat effect of the laser beam. Some of the energy may shift in wavelength, resulting in secondary emission and often in the visible portion of the spectrum. This secondary emission can cause temporary blindness. Continuous or frequent smoke evacuation is the only solution. Plume content biohazard relates to the direct toxic effect of the plume. In addition to laser smoke elimination, a surgical mask can minimize this risk.

Fire Hazards

Laser systems may cause airway burns from an endotracheal tube fire when the laser beam strikes an endotracheal tube, which is made of PVC. Therefore, tubes wrapped with reflective tape or made of reflective metals are preferred. Likewise, surgical drapes made of flame-retardant material are advised. The immediate surgical field should be covered with saline-soaked towels.

Precautions in Anesthetic Procedures

These precautions for anesthetic procedures are important when the operation is performed on the larynx or trachea. A closed ventilatory system that is provided with a small-cuff endotracheal tube is preferred unless the tube obstructs the surgical view. This type of system reduces the possibility of an anesthetic gas leak into the operative field, where the laser beam is present. The cuff may be filled with methylene blue. Ventilation with a high concentration of O_2 and nitrous oxide should be avoided. Jet ventilation is often necessary for glottic and subglottic lesions.

American National Standards Institute. For the safe use of lasers. ANSI Z 136.1;2000. (Provides guidance for the safe use of lasers and laser systems.)

American National Standards Institute. For the safe use of lasers in health care facilities. ANSI Z 136.3;1996. (Provides guidance for the safe use of lasers and laser systems in health care facilities.)

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WEB SITES

Laser Institute of America. www.laserinstitute.org. (Aims at fostering lasers, laser applications, and laser safety worldwide, offering technical information.)

LASERS IN OTOLOGY–NEUROTOLOGY

Ear Canal

Ear canal lesions that are treatable with lasers include chronic infections, tumors, atresia, scar tissue, and webs. Chronic skin infections of the ear canal may require surgical

intervention if medical treatment fails. If the full removal of canal skin is necessary, the argon or KTP-532 laser with low power is used to spot weld the edges or corners of the skin graft, which holds them in position. If whole-skin removal is not required, weeping areas of canal skin can be cauterized under local anesthesia with the argon or KTP-532 laser. Either laser is set at 1.5–2.0 W with a 1-mm spot size.

Polyps or other suspicious soft tissue in the ear canal can be biopsied with the same laser systems. Currently, there is no benefit to using lasers in canal skin carcinoma. Subcutaneous fibrous tissue in acquired ear canal atresia or stenosis can be dissected and vaporized with good hemostasis. This helps to keep the skin of the ear canal intact. In transcanal tympanoplasty, skin incision of the ear canal can be made with the laser without compromising visibility.

Tympanic Membrane

Fenestration of the tympanic membrane can be performed with a laser (laser-assisted myringotomy) under local anesthesia as an alternative to cold-knife myringotomy under general anesthesia. A CO_2 laser is set at 3–18 W with a single 100-ms pulse through a handheld otoscope or 200-mm objective of the microscope. A spot size of 2.0–2.6 mm is preferred. Diode laser was reported to be effective in this application as well. Myringotomy opening made by either laser may be used for endoscopic examination of the middle ear. Patients with a single attack of otitis media with effusion may be candidates for laser-assisted myringotomy instead of ventilation tube placement. However, a short duration (average 15 days) of myringotomy patency and recurrence should be kept in mind for chronic cases.

A minimally invasive treatment option called "laser contraction myringoplasty" was described for tympanic membrane atelectasis. In this technique, CO_2 laser set at 0.1–1 W with a spot size of 0.2 mm is applied to the perimeter of the atelectasis. It has been reported that the laser causes tightening of tympanic membrane tissues, which reduces or eliminates atelectasis.

Repairing a tympanic membrane perforation with a laser by spot welding is still far from a routine clinical practice. Nonetheless, in recurrent perforations with unresponsiveness to tympanoplasty, welding the temporalis fascia into the anterior canal skin may be effective.

Middle Ear

The KTP-532, argon, and CO_2 lasers are useful in middle ear surgery. The CO_2 laser has a small spot size (0.1–0.2 mm), which provides precision and safe handling.

Controversy exists as to which laser system is optimal; each has advantages and disadvantages. Visible lasers ensure the accurate aiming of the laser light. A handpiece eases the manipulation. The light of these lasers can pass through the overlying fluid environment. The spot size and power can vary by changing the distance between the tissue and the probe. The disadvantages of these lasers include the fact that their absorbency depends on pigment, which necessitates cautious work on white bones and tendons because of the possible inner ear damage. Therefore, in revision stapedotomy, visible lasers should not be used. In contrast, there is no inner ear damage risk in using the CO_2 laser, given its depth of penetration. However, with the CO_2 laser, the aiming and treatment beams need to be accurately aligned. The lack of penetration through liquid may cause the beam to be weakened if fluid is overlying the target tissue. Visible lasers have better optical precision but less ideal tissue characteristics, and the CO_2 laser has better tissue characteristics but less ideal optical precision.

Recently, the Er:YAG laser was found safe in middle ear procedures, given its high absorption rate by water, weak penetration through the otic bone, and weak transmission through the perilymph. Laser applications in middle ear surgery are not without complications. Facial nerve injury, severe vertigo, chorda tympani burn, and hearing loss can occur.

Small glomus tympanicum tumors can be vaporized with good hemostasis. Visible lasers are advantageous in this application. Although not commonly used, granulation tissue in the mastoid cavity can be removed with the argon laser at 4–6 W on continuous mode.

Laser stapedotomy was first introduced in 1979. Since then, it has gained growing acceptance. Although there are studies showing no difference in the hearing gain between classic and laser stapedotomy, laser stapedotomy appears to be advantageous over classic stapedotomy. Laser stapedectomy eliminates mechanical trauma to the inner ear as well as minimizing the prerequisite fine-hand skills. It provides precision in surgery. Postoperative vertigo is also diminished. Its benefits become more obvious in revision surgery and obliterative otosclerosis. Laser stapedotomy can be performed under local or general anesthesia. The laser is first used on the stapes tendon, and then the posterior crus of the stapes is vaporized. The latter should be done as close to the footplate as possible. Either a rosette pattern of spots with a series of laser shots or 0.6-mm fenestra with a single shot is used in the center of the footplate. After every shot, the char is wiped away. If a series of shots is to be used, the firings of the laser beam should be a few seconds apart. Recommended laser settings are as follows: (1) the spot size is 0.15 mm for the CO_2 laser and 0.20 mm for the KTP-532 and argon lasers; (2) the power is 1.5 W for the CO_2 laser and 1.6 W for the KTP-532 and argon lasers; and (3) the pulse duration is 0.1 seconds for each. With laser stapedotomy, closure of the air–bone gap within 10 dB is obtained in 90–95% of cases. No superiority of any laser system over another is mentioned.

For cases with otosclerosis confined to the fissula ante fenestram only, a novel technique has been described, laser stapedotomy minus prosthesis (STAMP). The technique simply includes vaporization of anterior crus first and later anterior one-third of the footplate with a handheld probe of argon laser. Use of a prosthesis is not needed. If the otosclerosis is limited to the fissula ante fenestram only, this

should free the remainder of the stapes. If so, the stapedotomy opening is sealed with adipose tissue. The technique may be converted to classic laser stapedotomy in appropriate cases. With this novel technique, it has been stated that high-frequency hearing (6–8 kHz) was better preserved compared with standard laser stapedotomy and also lasted as long as standard laser stapedotomy. Low incidence of refixation was also noteworthy.

In chronic ear surgery, a fixed malleus can be freed from the attic with a laser. Scar tissue, cholesteatomas, and adhesions close to the facial nerve or the stapes can be vaporized and removed. This is one of the most useful applications of the laser in otology. Diseased mucosa or granulation tissue in the mastoid bone can be removed by vaporizing with a defocused laser. A recent study showed that ancillary use of KTP laser significantly improved the rate of cholesteatoma eradication as evidenced in staged intact canal wall surgery.

Chronic intractable eustachian tube dysfunction is the new area of interest in laser use. For this condition, endoscopic transnasal laser-assisted surgery (laser eustachian tuboplasty) has been recently described with promising results. In this technique, mucosa and underlying soft tissue of the posterior wall (medial cartilaginous lamina) of the eustachian tube are vaporized through its free border using a 980-nm contact tip diode laser (7-W power, continuous-pulsed mode with 0.2 seconds on and 0.08 seconds off) or a wave guide of CO_2 laser (12-W power on superpulse mode and 0.05-second pulse).

An interesting area in which the laser is included is laser-Doppler vibrometry, which draws increasing attention in diagnostic otology. The system consists of a helium-neon laser and a joystick-controlled aiming prism, both mounted on a microscope; ear speculum–sound coupler assembly with nonreflective glass covering at back; sound generator; and probe-tube microphone. Details of how the system works is beyond the scope of this chapter. The resultant parameter is the umbo velocity, which has been stated to be a useful tool in patients with intact drum to differentiate causes of conductive hearing loss.

Inner Ear

Until recently, experiences in the inner ear have been limited to the CO_2 and argon lasers, which have been used for the treatment of benign paroxysmal positional vertigo (BPPV). Despite promising results, further clinical experience is necessary to prove the superiority of laser use to the current treatment modalities. A recent animal study was aimed to investigate whether there was any difference in hearing thresholds following cochleostomy that was performed with CO_2 laser, Er:YAG laser, or a microdrill. Comparative results showed that the safest method was microdrill cochleostomy. Some degree of hearing loss, more than with microdrill and less than with Er:YAG laser, resulted from CO_2 laser application. Thus, Er:YAG laser was found to have a greater potential to cause damage.

Even classic posterior canal occlusion is reserved for patients unresponsive to repositioning or liberating maneuvers. The occlusion with a laser still does not seem an alternative to these treatment modalities in routine practice.

The argon laser is one of the laser systems used in patients with BPPV with the aim of partitioning the posterior semicircular canal. In the procedure, after a mastoidectomy and blue-lining the posterior semicircular canal, the argon laser at 4–12 W and with a 0.1–0.5 pulse duration is applied 1–3 times to create a hole on the canal. The handpiece is held 1 mm away from the canal. After the application, the hole created is covered with the temporalis fascia. It is believed that this application occludes the membranous semicircular canal, which may prevent the cupular movement that results from gravity. The CO_2 laser is also applied directly to the endolymphatic space after removing the bone of the posterior semicircular canal; the opening is then occluded with bone wax.

Partial labyrinthectomy and labyrinthine ablation, with the preservation of hearing, have been tried in a very small group of patients with promising results. The argon and CO_2 lasers were used to either weld the open ends of the semicircular canals or ablate the macula. However, this procedure is still not an alternative to labyrinthectomy.

Tinnitus is another issue of interest in terms of investigating efficacy of low-power laser treatment. Despite inconsistent results reported, a recent placebo-controlled double-blind study showed that 60-mW laser was not effective in alleviating tinnitus in patients with Ménière disease, presbycusis, and sudden hearing loss.

Neurotology

Laser systems are not commonly used for tumors in the posterior fossa. The main concern is possible thermal injury of the surrounding structures (the facial nerve and cerebellum) and the transfer of the heat via the cerebrospinal fluid (CSF). However, when taking the necessary measures to protect these structures (ie, covering them with saline-soaked cottonoid), the laser can be used safely for hemostasis on the tumor surface and debulking of the tumor. The KTP-532 (3–15 W) or CO_2 laser (5 W) with a 1-mm spot size on continuous mode can be an alternative to the ultrasonic surgical aspirator to debulk tumors. Even experienced surgeons prefer accurately applied bipolar coagulation for hemostasis near critical neural structures.

Argon and Nd:YAG lasers have some promise for the treatment of vascular tumors. In a vestibular nerve section, the KTP-532 laser at 3 W or CO_2 laser at 1 W is an option to using a scalpel.

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LASERS IN HEAD & NECK

Paranasal Sinuses & Nose

The introduction of the laser into nasal surgery has resulted from a need for good hemostasis in a narrow operative field. In using the Nd:YAG, KTP-532, and argon lasers, neighboring structures (eg, the medial rectus muscle, anterior cranial fossa, and optic nerve) are at great risk of thermal damage. Therefore, the versatility of the CO_2 and Ho:YAG lasers in this setting has received much recognition.

Reducing turbinate hypertrophy and resecting polyps, papillomas, and synechiae can be performed with the CO_2 laser. The physician should be careful not to expose the turbinate bone secondary to thermal damage, which causes scarring, prolonged pain, and persistent crusting. In turbinate resection, the anterior part of the turbinate should always be preserved. The CO_2 laser can be used in superpulse mode to provide gradual vaporization. Using an optical wave guide, the laser beam can be directed at the posterior aspect of the turbinate. During the procedure, the laser plume should be vigilantly evacuated. Although the CO_2 laser provides good hemostasis and less thermal collateral damage in resecting the previously mentioned lesions, the lack of flexibility in its delivery system constitutes a serious problem. The Ho:YAG laser has tissue interaction characteristics similar to those of the CO_2 laser.

It is used on pulse mode. Since it can be transferred through a fiberoptic system, it is more advantageous than the CO_2 laser. Wedge resection of the inferior turbinate using consecutive interstitial and contact beams from an Nd:YAG laser is also efficient.

Holmium:YAG laser has been used to correct nasal septal cartilage without elevation of the mucoperichondrial flap. Under local anesthesia using a modified speculum, deviated septum was corrected, and then the laser via an optical fiber was applied through the mucosa. Hereditary hemorrhagic telangiectasia can be undergone with Nd:YAG laser therapy to reduce frequency of epistaxis. It should be noted that, overall, although laser systems offer some advantages, they have not replaced the classic surgical approaches.

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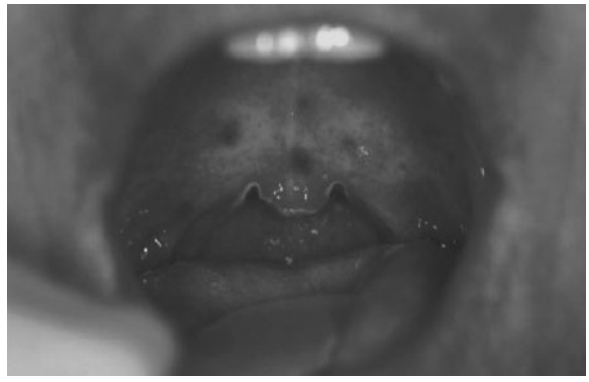
Oral Cavity & Oropharynx

A. Laser-Assisted Uvulopalatoplasty

The treatment of snoring and sleep apnea is one of the fields in which the laser has gained great popularity. The CO_2 laser has been shown to be an effective treatment instrument for snoring and sleep apnea when the obstruction is at the level of soft palate. Although no difference is found in the postoperative snore index between laser-assisted uvulopalatoplasty (LAUP) and conventional uvulopalatopharyngoplasty, LAUP helps avoid most of the postoperative morbidity, as well as providing a good hemostatic benefit during surgery. However, it has been reported that long-term results of snoring and respiratory disturbance index were not as satisfactory as short-term results and tended to deteriorate over time, which was explained with velopharyngeal narrowing and palatal fibrosis caused by the laser.



▲ **Figure 6–3.** Laser-assisted uvulopalatoplasty, immediately after the application of a CO_2 laser. (Photo contributed by Andrew N. Goldberg, MD, University of California, San Francisco, Department of Otolaryngology–Head & Neck Surgery.)

LAUP can be performed under local-topical or general anesthesia, even in an office setting. The operation can also be staged. The CO_2 laser is the laser most commonly used by otolaryngologists for this operation. Since the diameter of the vessels encountered during the procedure is smaller than 0.5 mm, the CO_2 laser is effective for hemostasis. Basically, in a LAUP, redundant soft tissue is either excised or ablated. In a typical CO_2 laser application, the system is set to a power of 15–20 W. A backstop is used to protect the pharynx from scattering the beam. The system is used in the focused mode for excision and in the defocused mode for vaporization. Bilateral incisions at both sides of the base of the uvula are made with a handpiece. The uvula is shortened to 15 mm, excising redundant soft tissue and preserving its curved shape. The wound then heals within 3–4 weeks. Figure 6–3 shows a postoperative view of immediately after LAUP (Figure 6–3).

B. Laser Tonsillotomy

Laser tonsillotomy is reserved for patients who are unable to tolerate general anesthesia or unwilling to undergo classic tonsillectomy. The technique requires ablation of tonsillar crypts and gross reduction of tonsillar tissue, which can be staged many times until the level of palatoglossus muscle is achieved. The CO_2 laser is set at 15–20 W on continuous mode and applied preferably with a handpiece.

C. Laser Tonsillectomy

Laser tonsillectomy is not indicated unless a coagulation disorder is diagnosed because of the cost of the laser. The KTP-532 laser is considered the instrument of choice for tonsillectomy because it provides adequate cutting with good hemostasis and little thermal damage. Its optical fiber is held very close to the tonsillar tissue. The first incision is made in

a curvilinear fashion along the anterior pillar from the superior pole to the inferior pole to define the dissection plane. Medially and inferiorly, the retracted tonsil is then dissected from the superior pole to the inferior pole.

D. Lingual Tonsillectomy

The excision of the lingual tonsil in the classic fashion is somewhat cumbersome owing to excessive bleeding, postoperative edema, and pain. The use of a laser offers resection with minimal edema, less bleeding, improved visibility during surgery, and less pain postoperatively. The need for a tracheostomy is therefore less likely. The CO_2, KTP-532, or Nd:YAG laser can be used along with a rigid laryngoscope. The operation can be staged.

E. Benign Lesions

CO_2 laser excision or ablation of gingival hyperplasias, pyogenic granulomas, and papillomas is possible with an excellent response rate, good hemostasis, and low morbidity. For especially vascular lesions, photocoagulation with an Nd:YAG laser is preferred. It is set at 32–48 W with a pulse duration of 0.3 seconds. A 2-mm spot size is used with a 2-mm separation between spots.

Oral mucositis associated with chemotherapy or radiation therapy may be prevented with low-level laser use. A few mechanisms underlie the healing effect of the laser. The low-level laser has been demonstrated to increase energy production in the mitochondria. It also facilitates conversion of fibroblasts into myofibroblasts from which fibroblast growth factors are released, and these play a role in epithelial repair. The last effect is that of reducing the formation of free oxygen radicals that are stomatotoxic. The most studied form of low-level laser therapy has been helium-neon laser. The CO_2 laser is an alternative. Studies have used low-level laser either prophylactically (before radiation therapy or chemotherapy) or after the appearance of mucosal lesions during the course of radiation therapy or chemotherapy. A recent review showed that even though there is not sufficient evidence to recommend laser use, evidence of its potential usefulness is accumulating.

F. Premalignant Lesions

The CO_2 laser is often used for premalignant lesions, including leukoplakia and erythroplakia. Because these lesions are confined to the epithelium, only the superficial layer of the mucosa is removed by leaving 2- to 3-mm margins of normal mucosa. The wound is left to granulate and be covered by a new mucosal layer. These lesions can also be ablated. For ablation, a defocused laser at 10–20 W with a 100-ms pulse is used.

G. Malignant Lesions

The oncologic literature related to head and neck procedures is encouraging with regard to laser use. Compared with traditional methods, the advantages obtained with laser systems are improved visibility, hemostasis, decreased postoperative edema and pain, and better functional results, including speech and swallowing functions. It allows the surgeon to protect the muscular support of the tongue and the floor of mouth. However, no inherent oncologic benefits result from the laser use. Transoral CO_2 laser resection is recommended for superficial T1 and T2 tumors, considering the difficulty in defining the depth of excision with lasers. It is generally accepted that deeply infiltrative tumors, tumors >4 cm, and tumors involving the maxilla or mandible are not suitable for laser resection. Transoral CO_2 laser excision of oral cavity carcinomas can be performed with the handpiece or a micromanipulator mounted to the operating microscope. Microscopically abnormal tissues can be detected by using 1% toluidine blue. Normal tissue margins generally measure 1–2 cm beyond the microscopically abnormal tissue.

Resection starts by outlining the margins with the CO_2 laser at 6 W and a 100-ms pulse duration. The incision is then made at 10 W on continuous mode. The defect is left for secondary healing or is sutured. The local control rates of T1 and T2 disease addressed with transoral CO_2 laser resection is 80–100% at a 2- to 5-year follow-up. The disease-free survival rate is 83–88% at a 5-year follow-up.

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Larynx

Laser surgery in the respiratory tract requires additional equipment and safety precautions. Microlaryngeal instruments have a black finish to prevent the reflection or misdirection of the laser beam. A microlaryngoscope with smoke evacuation channels is used. Platforms that act as a backstop have been developed to absorb the laser energy and to prevent the spread of the laser beam down into the trachea. In addition, vocal cord protectors are used to protect the other vocal fold.

The delivery systems of various lasers are important considerations in choosing the type of laser for laryngeal surgery. The CO_2 laser can be used through a rigid laryngoscope. The spot size of the CO_2 laser has been reduced to 160 μm in new systems when it is used at a distance of 400 mm. This offers better precision and prevents collateral damage. The argon, KTP-532, and Nd:YAG lasers can be transmitted through the laryngoscope to the tissue via a fiberoptic cable. They are not preferred for nonvascular glottic lesions because of excessive energy absorption by the surrounding tissue; however, good results are reported in glottic lesions with the contact Nd:YAG laser.

A. Bilateral Vocal Cord Paralysis

The current therapy for bilateral vocal cord paralysis focuses on static airway enlargement procedures at the posterior glottis; these procedures include posterior cordotomy, medial arytenoidectomy, and total arytenoidectomy. The laser provides better hemostasis compared to classic methods.

In a posterior cordotomy, laser can be used to incise the vocal cord anterior to the vocal process. The anterior vocal process is then excised or vaporized unilaterally or bilaterally. In a medial arytenoidectomy, the vocal process and the medial portion of the arytenoid body are vaporized, preserving the lateral arytenoid body and the aryepiglottic fold. A total arytenoidectomy can also be performed with the CO_2, KTP-532, and Nd:YAG lasers.

B. Benign Lesions

The use of laser for the excision of nodules, polyps, and cysts is not advantageous over microsurgical techniques in terms of preserving uninvolved mucosal layer and lamina propria. However, the surgical precision of the laser has been increased in new systems by adding a microspot manipulator. For these lesions, the laser is set at as low as 4 W of power in the focused mode. As small a spot size as possible should be used. Cautious excision of the lesion with the involved mucosa is necessary. For submucosal lesions, especially cysts and large sessile polyps, a mucosal incision can be made with the laser. The mucosa is then elevated and the lesion is removed in a standard fashion. However, the additional cost of the laser should be taken into account in these cases.

For vascular lesions, the laser is far superior to microsurgical interventions in terms of surgical precision and hemostasis. The CO_2 laser is preferred for small vascular lesions such as symptomatic dilated blood vessels and angiomatous clusters of capillaries. During laser surgery for these lesions, and after achieving endoscopic exposure, the defocused laser with a spot size of 300–400 μm and at 1–2 W is used with a single pulse of 0.1 seconds to coagulate the blood supply. This reduces the size of the capillary lesion. The main capillary lesion is then excised with a focused laser at the same level of power. Large vascular lesions are treated with the Nd:YAG laser for palliation. Under endoscopic exposure, a fiberoptic laser cable is introduced and secured. The lesion is then coagulated with the laser in a noncontact mode (a few millimeters away from the lesion) at 20 W and a 0.5-second pulse. The application can be staged in order to observe the response of the lesion and surrounding tissue.

Granulation tissue around the arytenoid cartilage, which arises from mucosal defects caused by gastric reflux or sustained mechanical trauma, can be excised with the CO_2 laser when surgery is warranted. The CO_2 laser can also be used to treat superior tracheal granulation tissue.

Recurrent respiratory papillomatosis can be ablated with the CO_2 laser, even though it does not provide a better recurrence rate than microlaryngeal surgery. Because the eradication of the virus is not possible, the area of active expression should be addressed. If possible, a 1-mm normal mucosal margin can be included. This intervention should be performed as infrequently as possible to avoid scarring. The laser permits a precise and bloodless excision with less scarring compared with other surgical options. The CO_2 laser can be used for either the excision of bulky disease or superficial vaporization. For excision, a focused laser is set at 4 W with 0.1-second pulse and a 0.5-second pulse interval. The same setting can be used in a defocused mode for superficial vaporization. Recurrences are addressed in the same manner. A comparative study showed that excision by microdebrider was less time consuming compared with CO_2 laser.

Laryngeal stenosis can be addressed with a laser for cutting or coagulating purpose. However, its only advantage over standard treatment methods (ie, scalpel incision and electrocoagulation) is good hemostasis. To prevent reformation, an anterior membranous or thick glottic web can be incised with a CO_2 laser before interposing the tissue flap, keel, or stent placement. In a posterior glottic web, a CO_2 laser is used to incise the arytenoid mucosa (the micro-trapdoor flap) and vaporize the submucosal scar tissue between the arytenoids. Subglottic stenosis <1 cm in vertical length can also be addressed with a laser to make radial incisions before bronchoscopic dilatation.

C. Malignant Lesions

The CO_2 laser offers surgical precision, minimal bleeding, less surgical trauma, and rapid healing in the endoscopic management of carcinoma in situ and early glottic carcinoma. For carcinoma in situ, the local control rate and the quality of life obtained in using the CO_2 laser are close to what is achieved with radiation therapy and better than with vocal cord stripping. Also, better ultimate laryngeal preservation is obtained with the CO_2 laser compared with radiation therapy. This holds true when laser CO_2 cordectomy is compared with open surgery. In a typical application, mucosal disease is excised with the CO_2 laser in the superpulse mode at a spot size of 0.5–0.8 mm. The output power is set to 2–3 W. If invasion is found in a histopathologic examination, the underlying vocal ligament should also be excised (subligamentous cordectomy), leaving a 1- to 2-mm normal tissue margin. Studies regarding the efficacy of endoscopic laser use for more aggressive disease and tumors invading the anterior commissure are not conclusive.

The transoral excision of the supraglottic carcinoma and selected piriform sinus carcinomas can be facilitated with a laser in the context of organ preservation. The neck is addressed in a staged manner. These techniques offer less postoperative morbidity, including the avoidance of tracheotomy and improved swallowing function.

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Tracheobronchial System

Laser use in the tracheobronchial system is limited to CO_2 and Nd:YAG lasers. In fact, use of the CO_2 laser in bronchoscopy remains restricted by the articulated arm. Another limitation of the CO_2 laser is its hemostatic capability. In contrast, an advantage of the Nd:YAG laser is the ability to use it with both rigid and flexible bronchoscopes. In addition, better hemostasis, even for deeper lesions, is obtained with the Nd:YAG laser.

Characteristics of the CO_2 laser confine its use to superficial lesions, including recurrent respiratory papillomatosis involving the tracheotomy site and the trachea, subglottic and tracheal stenosis, and capillary hemangiomas. The use of the CO_2 laser in these lesions is similar to what is described previously for laryngeal applications. For bulky lesions, the Nd:YAG laser is preferred for its vaporization and coagulation effects. In a typical application, the Nd:YAG laser is set at <30 W and exposure should be kept to <90 seconds. Laser use higher than these levels may cause necrosis and perforation in the tracheobronchial wall.

Debulking malignant disorders that obstruct the tracheobronchial system can be performed with the CO_2 or Nd:YAG laser for palliation purpose. Photodynamic therapy is useful only for patients with small lesions of squamous cell carcinoma and carcinoma in situ that can be reached with a flexible fiberoptic bronchoscope.

Esophagus

CO_2 laser has been introduced to endoscopic management of Zenker's diverticulum. The approach has been called "CO_2 laser-assisted diverticulotomy," and it is preferred in rather primary cases. With this approach, a specially designed

endoscope with double lips is introduced into the esophageal lumen. At the level of diverticulum, while the anterior lip of the endoscope is directed toward the esophageal lumen, the posterior lip remains at the bottom of the diverticulum, thereby leaving the common wall and cricopharyngeus muscle between the two lips of the endoscope. Then, through an operation microscope with 400-mm lens and CO_2 laser micromanipulator, the common wall is transected with a CO_2 laser set at 5–10 W on continuous mode. The transection is recommended to continue down to the distal-most part of the common wall. This procedure also transects the hypertonic cricopharyngeus muscle, which is thought to contribute to the pathogenesis of the diverticulum. Thus, both transecting the common wall and relieving the muscle prevent food entrapment. During the procedure, one should be cautious not to violate fascia that envelops the diverticulum. Compared with open technique, this technique reduces operative time. However, one should be aware of the greater possibility of repeated surgery in this approach.

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LASERS IN FACIAL SKIN SURGERY

Dermatology is one of the fields in which lasers are most commonly used. Cutaneous lesions present a wide spectrum from vascular lesions to malignant disorders. The use of the laser in dermatology offers surgical precision, improved hemostasis, good preservation of the lesion for histopathologic diagnosis, facilitation of postoperative wound care, and less scarring. The particular laser selection is based on the histologic nature of the lesion, the lesion site, and the laser characteristics. In dermatology, the cosmetic result is as important as the cure. Patients need to be well informed regarding possible drawbacks of the application, such as a temporary or permanent hypo- or hyperpigmentation, unsightly scarring, and the potential success rate.

Ablative Skin Resurfacing

Indications for laser surfacing include scars, rhinophyma, actinic cheilitis, superficial squamous cell carcinoma, and wrinkles. For a better result, the depth of thermal damage should be <100 μm. In a typical CO_2 laser application, the pulse duration and power density are adjusted to <10 ms and 5 J/cm^2, respectively. With hypertrophic scarring, the scar is ablated with nonoverlapping and intermittent pulses along the lesion. After the application, hyperpigmentation that lasts as long as a few months is expected and is usually reversible. In cases of deep thermal injury, hypopigmentation may occur and is permanent. Because of the significant risk of posttreatment skin dyschromias, CO_2 laser treatment should be limited to lighter-skinned patients. A major advantage of laser resurfacing over classic dermabrasion techniques is less crust formation. Er:YAG laser may be used for superficial resurfacing of fine rhytids and photodamage. Er:YAG laser offers less dramatic changes than CO_2 laser with less risk of significant sequelae. Newer variations of lasers are based on the principle of fractional resurfacing. Fractional resurfacing works by creating miniature columns of heat leaving adjacent skin undamaged and unaltered, limiting downtime and side effects. Both Er:YAG and CO_2 lasers can be found in fractional variants. Complications reported following laser surfacing are early and late infections by a wide spectrum of agents as well as eruption, prolonged erythema, acne, milia formation, contact dermatitis, hypertrophic scar formation, ectropion, delayed healing, pigmentary abnormalities, inflammatory reactions, and unusual granulomatous reaction.

Nonablative Skin Resurfacing

Nonablative resurfacing is the use of a laser to induce dermal remodeling without removal of the superficial layers of the epidermis and dermis. Currently, studies have shown minimal improvement in skin quality, tone, and rhytid formation with a variety of Nd:YAG lasers.

Rhinophyma

In rhinophyma, argon and CO_2 laser systems are alternate options to serial shave incisions and cryosurgery. Compared with serial shave incisions and cryosurgery, under local anesthesia, laser treatments have superior results with better hemostasis. Because the argon laser is absorbed by hemoglobin, the hypervascular form of the disease better responds to the argon laser. The argon laser is set at 1.0- to 2.5-W

power with a 2-mm spot size and a 0.5-second pulse. A total of 150 pulses is required to treat the entire nose. Treatment sessions should be at least 2 months apart. It takes 10 days to heal after the application.

Actinic Cheilitis

In actinic cheilitis, CO_2 laser systems with a pulse duration shorter than the thermal relaxation time of the epidermis and dermis provide a better outcome. A typical new CO_2 system for this superficial lesion is set at 250 mJ and 3 W of power at 12 Hz. Conventional CO_2 laser systems with a continuous mode cause thermal damage because they require a longer healing time and may cause more scarring.

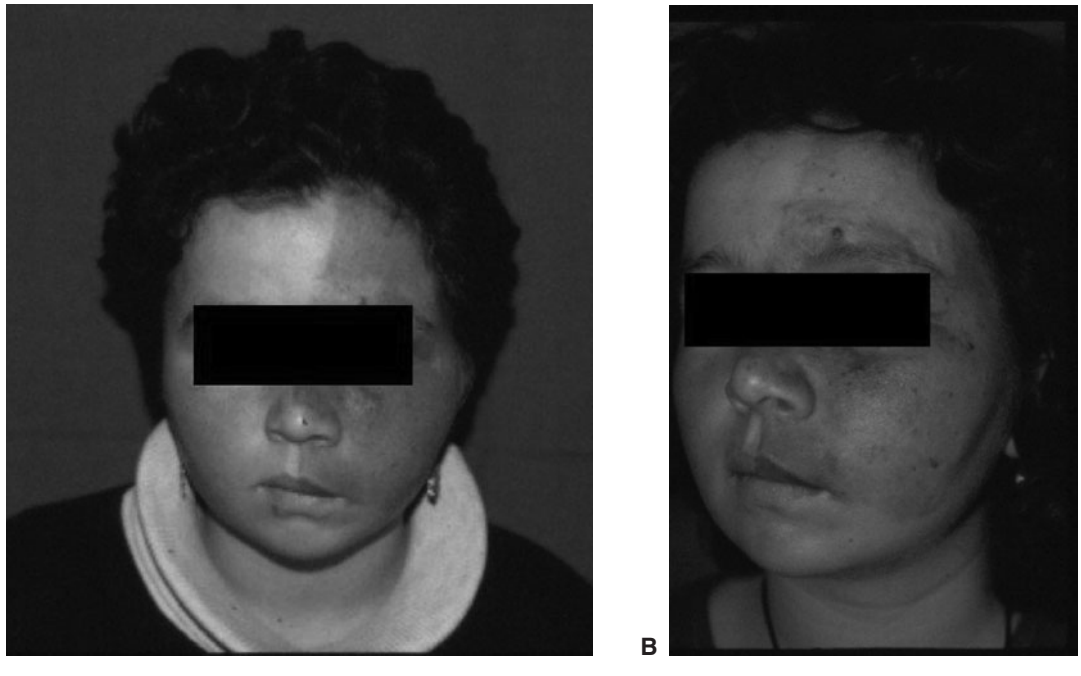
Vascular Skin Lesions

Port-wine stains are the most common vascular lesions. Laser systems are absolutely advantageous in the treatment of these lesions. The goal is to destroy the underlying blood vessels selectively without scarring. For light-colored skin, the flashlamp-excited dye laser is absorbed by red blood cells with minimal absorption in the skin, which causes only minimal thermal damage to epidermis. Its pulse duration is set at 450 μs. KTP laser is another alternative. It causes less purpura than flashlamp-excited dye laser. Figures 6–4A and B show pre- and postoperative views, respectively, of the patient with port-wine stains. The patient underwent three sessions of KTP laser treatment. For dark skin, thrombosis of the vessels is difficult to obtain without damaging the skin because of high melanin absorption. Therefore, infrared lasers are preferred. It should not be used in patients with dark skin or seizure disorders, or in patients receiving anticoagulant or photosensitizing therapy. However, purpura inevitably develops and lasts 10–14 days. Temporary or permanent hypopigmentation, transient hyperpigmentation, and scar formation may also develop.

In hemangioma and telangiectasia, flashlamp-excited dye is essential to treat the superficial component during both the proliferative phase and the phase of involution of the lesion. Nd:YAG, argon, and KTP-532 laser are other options. Superficial telangiectasias and spider capillaries can be treated effectively with either KTP-532 laser or an intense pulsed light source.

Benign Lesions

Controversy still exists about whether the CO_2 laser is superior to scalpel excision in treating keloids. However, the advantages of the CO_2 laser to the scalpel include hemostatic superiority and precision when used in the focused mode. In a typical application, a 1-mm spot handpiece is fitted. The



▲ **Figure 6–4.** **(A)** Port-wine stain involving the left side of the patient's face. **(B)** Postoperative view of the regressed lesion after three KTP laser treatment sessions. (Photos contributed by Mustafa Sengezer, MD, Gulhane Military Medical Academy, Ankara, Department of Plastic and Reconstructive Surgery.)

laser is set at 10 W in the continuous mode. Excessive tissue is excised with the laser, as with a scalpel. Debris should be cleaned off when necessary; otherwise, the resultant wound would be almost twice as large as the original lesion. The physician should avoid using sutures. However, until reepithelization occurs, the wound should be watched closely.

Café au lait maculas and lentigines are the most common benign lesions. With these lesions, cosmetically better outcomes are obtained with laser systems compared with scalpel excision. Shorter wavelength lasers are preferred because of the pigment content of the lesions. Q-switched laser systems (eg, the pulsed dye laser of 504 nm, or the ruby or Nd:YAG lasers) are ideal for targeting pigmented cells. The CO_2 laser is another option in spite of its much longer wavelength. In terms of scar formation and healing time, CO_2 laser systems with a short pulse duration (200-ms pulses at 250 Hz and 80-W power) provide slightly better outcomes compared with conventional continuous CO_2 systems.

Facial verrucae and rosacea are also successfully treated with flashlamp-excited dye laser.

Malignant Lesions

Basal cell carcinoma, squamous cell carcinoma, and melanoma are the three most common malignant lesions encountered. Laser use is one option among scalpel excision, Mohs micrographic excision, and radiation therapy. The CO_2 laser is ideal, especially for small to moderate lesions. It is also advantageous for use in patients with coagulation defects. In addition, the CO_2 laser is good in preserving margins. The recommended margin of excision is 4–7 mm for basal cell carcinoma, 3–4 mm for squamous cell carcinoma, and 1–3 cm for melanoma.

LASER-ASSISTED HAIR REMOVAL

Lasers in hair removal induce selective damage to hair follicles, while avoiding the competing chromophobe of melanin. Temporary hair reduction is a delay in hair growth, typically lasting 1–3 months. Permanent hair reduction reduces the number of terminal hairs after a given treatment, usually lasting 6 months. Complete hair loss is the reduction of number of regrowing hairs to zero. Lasers initially produce complete but temporary hair loss. Eventually, the laser creates partial but permanent hair loss (a permanent reduction in the total number of terminal hairs). In patients with light skin, the 694-nm ruby laser and the 755-nm Alexandrite laser are used. In patients with darker skin, the 800-nm diode laser, 1064-nm Nd:YAG laser (long-pulse and Q-switched), and intense pulsed lights are favored because of less competition with melanin.

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Hemangiomas of Infancy & Vascular Malformations

7

Joseph L. Edmonds, Jr., MD

Hemangiomas are true tumors with pathologic endothelial cell proliferation; vascular malformations are distinguished by this distinct absence.

HEMANGIOMA OF INFANCY

ESSENTIALS OF DIAGNOSIS

- Absent at birth or history of small premonitory mark at birth.
- Rapid neonatal growth of the lesion.
- Cutaneous lesions develop either a typical "strawberry" appearance or a bluish hue ("deep bruise" appearance).
- Magnetic resonance imaging (MRI) is diagnostic when the diagnosis is uncertain or when serial exam is not possible.
- Visceral involvement is suspected if there are more than three cutaneous lesions.
- Progressive stridor in the appropriate age group (2–9 months) is suspicious for airway hemangioma.

General Considerations

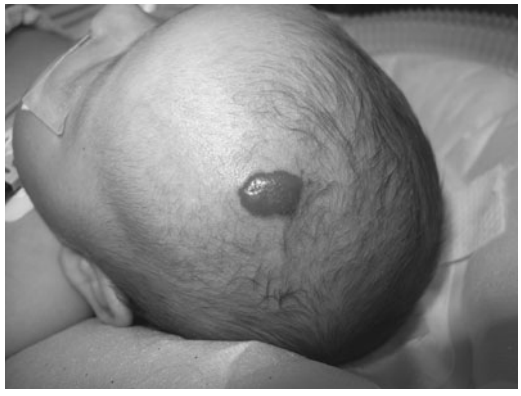
Hemangiomas are the most common tumors of infancy. They are more common in females than in males (3:1), in white populations, and in premature infants. Most of these neoplasms are located in the head and neck. Additionally, most are single lesions; however, about 20% of patients have multiple lesions. Hemangiomas exhibit a period of rapid postnatal growth. The duration of the proliferative period is variable, but is usually confined to the first year of life. The proliferative period rarely extends to 18 months. The involutional phase is also quite variable, occurring over a period of 2–9 years. After complete involution, normal skin is restored in about 50% of patients. In other patients, the skin may show evidence of telangiectasia, yellowish hypoelastic patches, sagging or fibrofatty patches, and scarring if the lesion has ulcerated.

Hemangiomas can be classified as superficial (Figure 7–1), deep (Figure 7–2), or combined. The term *superficial hemangioma* replaces the older terms *capillary hemangioma* and *"strawberry" hemangioma* and refers to hemangiomas located in the papillary dermis. The deep hemangioma, often slightly blue in color, originates from the reticular dermis or the subcutaneous space and, in the past, was referred to as a *cavernous hemangioma*. The combined hemangioma has elements of both the superficial and the deep hemangioma.

Pathogenesis

Proliferative hemangiomas have been shown to express high levels of indolamine 2,3-dioxygenase (IDO), basic fibroblast growth factors (β-fgf), proliferating cell nuclear antigen, type IV collagenase, urokinase, and, most recently, insulin-like growth factor 2. Involuting hemangiomas have been characterized by exhibition of tissue inhibitor of metalloproteinase 1 (TIMP1), thrombospondin, interferon-α, and decreased levels of other factors seen in the proliferative hemangioma.

In addition, it has recently been shown that endothelial cells are of clonal origin and the defect that leads to tumor growth and the altered expression of growth factors is intrinsic to the endothelial cell. These clonal endothelial cells have also been shown to have characteristics similar to placental endothelial cells, which may suggest that hemangiomas are of placental origin. There is a higher rate of hemangioma in children whose mother underwent chorionic villis sampling, giving additional weight to placental origin theories.



▲ **Figure 7–1.** A typical superficial hemangioma of infancy.

Clinical Findings

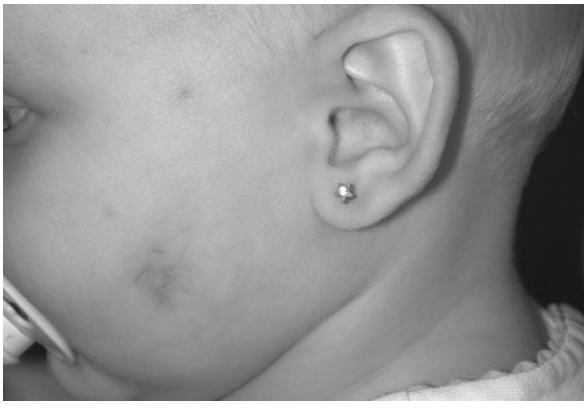
Most commonly, the diagnosis is determined by history and physical examination. The history will typically reveal that more than 50% of hemangiomas are seen at birth as a prominent cutaneous mark. This mark may manifest as a whitish patch, an anemic nevus, a faint telangiectasia, or a blue spot. The rapid proliferation of this initial lesion is highly suggestive of a hemangioma. A superficial hemangioma will assume the typical "strawberry" appearance, making the diagnosis obvious. In the case of a subcutaneous, intramuscular, or visceral tumor, the diagnosis may be uncertain. In these instances, various radiologic modalities can be very helpful. MRI is the most informative of the available modalities.

When an infant aged 2–9 months presents with progressive stridor or persistent croup-like symptoms, consideration should be given to the possibility of a subglottic hemangioma. This neoplasm is said to be more common in children with a cutaneous hemangioma in a facial or "beard" distribution. The diagnosis of a subglottic hemangioma should be made with a direct laryngoscopy and a bronchoscopy.

Special consideration should be given to children with three or more hemangiomas. In these children, abdominal ultrasounds should be obtained to evaluate for visceral hemangiomas and, most especially, hepatic hemangiomas. If the screening ultrasound is positive, MRI of the entire body is indicated to detect other internal hemangiomas.

Another special diagnostic situation arises when a child presents with extensive facial hemangiomas, sometimes referred to as segmental hemangiomas. The term segmental hemangioma relates to the approximate distribution that may correspond to sensory innervation patterns. The acronym PHACE can help the clinician recall the findings seen in these children, which include the following:

Posterior fossa malformations
Hemangiomas
Arterial anomalies
Coarctation of the aorta and cardiac defects
Eye abnormalities



▲ **Figure 7–2.** A deep hemangioma demonstrating the typical blue discoloration to the skin, similar to a bruise.

Differential Diagnosis

Congenital hemangiomas are rare vascular tumors that are fully developed at birth and in that way are distinguished from the more typical hemangioma of infancy. There are two types of congenital hemangioma. One does not involute, the non-involuting congenital hemangioma (NICH), and the other does involute quickly, rapidly involuting congenital hemangioma (RICH). These tumors are also pathologically distinguishable from the hemangioma of infancy, in that they are glucose transporter 1 protein (glut-1) negative.

A **vascular malformation** is another typical diagnostic alternative to consider when attempting to diagnose a potential hemangioma. The natural history of the hemangioma (not present at birth with rapid growth in the first months of life) is usually adequate evidence to support a confident diagnosis.

A **pyogenic granuloma**, which is neither a vascular malformation nor a hemangioma, is often confused with a hemangioma. A pyogenic granuloma is often the result of a minor trauma. The lesion is usually sessile, and as it grows it becomes pedicled, often bleeding impressively. The treatment is surgical excision.

Kaposiform hemangioendothelioma (KHE) is a rare vascular tumor with close association with Kasselbach–Merritt syndrome. Differentiation from hemangioma of infancy is typically based on recognition of aggressive behavior such as compression and invasion of surrounding tissue. These are large abnormal vascular tumors, and early recognition and treatment can be life saving.

Tufted angiomas (angioblastoma of Nakagawa) are benign erythematous plaques that grow slowly over several years. They will often stabilize after the slow-growth period. A pathologic specimen is usually diagnostic.

Magnetic resonance imaging with contrast is the most useful of all radiologic evaluations of hemangiomas. MRI can differentiate a hemangioma from a vascular malformation. A discussion of clinical suspicions with the radiologist may help determine the need for concomitant magnetic resonance angiography, which is especially helpful in locating feeder vessels of high-flow arteriovenous malformations.

The ultimate method of differentiating all diagnostic possibilities is with a histologic study of the tissue. A biopsy should be done whenever there is a possibility that the lesion in question is a **malignant tumor**; however, a biopsy is rarely necessary as there is usually ample epidemiologic, clinical, and radiologic information that can facilitate a reliable diagnosis.

Complications

Although rare, the complications of hemangiomas dictate a need for treatment. These complications include:

1. Ulceration (most common in the perineum and lip/perioral area).
2. Airway obstruction.
3. Visual loss. Obstruction of the visual axis for one week in the first year of life can cause permanent amblyopia.
4. External auditory canal obstruction.
5. Bleeding. Bleeding is usually low flow and therefore can be managed simply with pressure.
6. Heart failure. This complication is managed with medical therapy (usually by a cardiologist) and with attempts to control the growth of the hemangioma. Steroids should be the initial medical therapy, with vincristine and other chemotherapies used for steroid failures. Surgical therapy combined with embolization would be a second tier of therapy if medical treatment was not effective and the problem became life threatening.

Treatment

The decision to intervene and attempt to treat the patient without an active or inevitable complication must be weighed against the fact that most hemangiomas will resolve completely or with minimal long-term sequelae. For hemangiomas with active or inevitable complications, multiple treatment options exist. The most appropriate treatment will depend on the location and the nature of the impending complication as well as the child's specific medical and social situation. For example, if follow-up is not possible, early definitive surgical management may be more strongly considered.

A. Steroids

Steroids are the usual first line of treatment. Typical initial doses are 2–5 mg/kg/d of prednisolone or prednisone. Steroids are best administered in a single dose in the morning. This initial therapy is usually used for 4–12 weeks. This dose is then tapered over the next several months, according to what the patient can tolerate. Rebound growth may necessitate a second course of therapy. Alternate-day dosing or rest periods of several weeks may lessen troublesome side effects such as cushingoid appearance, growth retardation, decreased appetite, and susceptibility to infection. Monitoring of blood glucose and blood pressure are recommended. Adrenal suppression can be a result of therapy. Concomitant use of a proton pump inhibitor is also suggested.

Intralesional steroid injections may be used as an initial therapy, especially for orbital or periorbital lesions, tumors of the nasal tip, and globular tumors of the lips, ears, and cheeks and parotid hemangiomas. A 1:1 ratio of long-acting steroids (eg, triamcinolone 40 mg/mL) and short-acting steroids (eg, betamethasone 6 mg/mL) yields the best results. Three injections of triamcinolone, at doses of 3–5 mg/kg per procedure spaced 4–6 weeks apart, are the suggested course. Injections of long-acting corticosteroids in a suspension in the periorbital tissues can result in blindness. Great caution is needed in this area, especially in the upper lid. A low-pressure injection technique is thought to decrease risk of embolization. When effective, injection therapy usually leads to a dramatic reduction in the size of the lesion within one week. In general, steroid therapy (systemic or intralesional) can be extremely effective in one-third of patients, partially effective in another third, and ineffective for the final third of patients.

B. Propranolol

A new treatment gaining rapid acceptance is treatment of hemangiomas with propranolol. This treatment seems both effective and safe. Typically, infants are treated at a dose of 1 mg/kg/dose. The medication is given twice daily. Prior to initiating therapy the children are screened for cardiac defects with an echocardiogram. The medication is typically prescribed for 1 year. This therapy, although new, is now widely used and under study at many institutions. The mechanism of action is unknown.

C. Interferon

Interferon alfa-2a is a comparatively new agent for the treatment of hemangiomas. Although it is effective in most cases, it is generally considered a second-line drug because of cost, the route of administration, and the potential side effects. The treatment is generally reserved for pulmonary hemangioma, life-threatening hemangioma, and diffuse neonatal hemangioma. Transient side effects include fever, elevated liver enzymes, and neutropenia. Spastic diplegia and other permanent neurologic complications associated with the use of interferon alfa-2a have resulted in the cautious application of this therapy. The typical dose is 3 million units/m^2 injected subcutaneously daily. The therapy is generally administered for 6–12 months.

D. Vincristine

Vincristine is gaining popularity as another efficacious treatment for complicated or refractory hemangiomas. There are relatively few side effects as compared to interferon. The therapy should be coordinated by someone experienced in using the medication. One drawback of the therapy is the need for central venous access for up to 12 weeks.

E. Laser

Laser therapy for hemangiomas is becoming widely practiced to combat mucosal lesions and cutaneous lesions with or without ulceration. In the United States, laser debulking of mucosal lesions is the typical treatment of obstructing lesions such as subglottic hemangiomas. The goal is to reduce the lesion size to allow for an adequate airway. Recurrence is anticipated, and the treatment is repeated until the hemangioma stops proliferating and involutes. Various laser therapies are employed, but all share the drawback of causing a mucosal ulceration in the airway.

Ulceration is a controversial indication for cutaneous laser therapy. The yellow light emitted by pulsed dye lasers is selectively absorbed by hemoglobin and melanin. In an ulcerated hemangioma, the laser light does not need to pass through the skin and the melanin within the skin to reach the hemangioma; therefore, the risks of scarring due to absorption by melanin are considered lessened. Recent advances in the flashlamp pulsed dye laser include longer wavelengths, longer pulse durations, and the very important dynamic cooling of the surface tissues. These advances have allowed for higher energy treatments, deeper penetration, fewer complications, and better overall responses. These advances have led to increased confidence in using flashlamp pulsed dye laser for the treatment of select non-ulcerated cutaneous lesions. The KTP and Nd:YAG lasers have been employed for intralesional therapy by using bare fibers to deliver high energies to the deep components of the lesions. The use of these laser technologies, although gaining in acceptance and recognition of their utility, is not standardized and is limited by the experience of the practitioner.

F. Excision

It is commonplace to consider excision in a completely involuted lesion, when the residuum causes a functional or aesthetic problem. Baggy fibrofatty tissue is recontoured for improved cosmesis.

The early surgical excision of an actively proliferating lesion is appropriate in an area (eg, the glabella, eyelid, airway, the nasal wall) that will certainly lead to complications or impaired function. This may also avoid the need for protracted systemic therapy and spare the child and family the anticipated psychosocial difficulty.

Some surgeons also advocate the surgical intervention of lesions that have stopped proliferating instead of waiting for a protracted involution phase. Physicians who advocate this earlier removal do so with the hope of diminishing psychosocial stress. This technique also takes advantage of the natural tissue expansion of surrounding skin and soft tissue, which occurs in the proliferative phase.

Regardless of the timing, the procedures are typically accomplished using routine techniques. Special preoperative planning consideration should be taken when operating on actively proliferating or recently quiescent lesions to minimize blood loss such as embolization. In addition to standard techniques, circular excision with purse-string closure, with subsequent lenticular removal of scar, has been advocated. This technique may lead to smaller eventual scarring.

G. Treatment of Ulceration

Local wound care consisting of topical and oral antibiotics, topical steroids, barrier creams, and wound dressings are the mainstay of treatment. Treatment to minimize the ongoing proliferation of the hemangioma remains necessary. Management of pain is also very important, not to overlook while focusing on the ulceration. Reports of the use of topical recombinant platelet-derived growth factor (Regranex) are new and promising.

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VASCULAR MALFORMATIONS

CAPILLARY MALFORMATIONS

ESSENTIALS OF DIAGNOSIS

- Present at birth.
- Distribution remains constant, although the color may darken.
- Overlying skin is unaffected in childhood but may change in adulthood with the development of a nodular skin surface and ectatic dermal vessels.
- Capillary malformations must be differentiated from commonplace fading macular stains of infancy (nevus flammeus neonatorum), which are referred to as stork bites, angel kisses, or salmon patches.
- Lesions roughly follow cutaneous sensory nerve distributions.

General Considerations

Capillary malformations are the most common of the vascular malformations and occur in 0.3% of newborns. These lesions are also known as *nevus flammeus* or *port wine stains*. MRI with contrast is the most useful of all radiologic modalities for evaluations of vascular malformations, although usually unnecessary for most lesions.

Pathogenesis

The improper sympathetic neuronal control of the capillaries may lead to chronic dilatation of dermal capillaries and their development into ectatic vessels. Clinical observation provides evidence that these lesions follow cutaneous sensory nerve distributions. While an autosomal dominant mode of inheritance with variable penetrance has been suggested, this finding is not observed in most clinical situations.

Clinical Findings

Although usually not associated with other abnormalities, a capillary malformation may point to other problems. When capillary malformations are associated with other vascular malformations, these combined situations are recognized as syndromes. A facial capillary vascular malformation in the ophthalmic distribution of the trigeminal nerve (CN V) may indicate the patient has **Sturge–Weber syndrome.** This syndrome is a congenital condition consisting of the aforementioned cutaneous vascular malformation associated with a similar malformation of the underlying meninges and cortex. Children with Sturge–Weber syndrome are at increased risk to develop seizures and glaucoma as well as soft-tissue and bony overgrowths in the midface. Children with a capillary malformation located in the V_1 division (the first division of the trigeminal nerve) should have both an MRI scan of the brain and screening ophthalmologic exams.

A capillary malformation that overlies a deep venous or lymphatic malformation (a mixed vascular malformation) of the extremity is referred to as **Klippel–Trenaunay syndrome**. The overlying skin is often involved with ulceration and infection. The underlying bone becomes overgrown, adding to limb hypertrophy and often necessitating surgical intervention.

A capillary malformation that overlies a deep high-flow arteriovenous malformation is referred to as **Parkes–Weber syndrome.**

Lumbo-sacral capillary malformations may indicate that spinal cord abnormalities exist and should also be investigated further.

Differential Diagnosis

The typical capillary malformation must be differentiated from the commonplace fading **macular stains of infancy** (eg, "stork bite"). These lesions, in contrast to a true capillary malformation, will fade by the age of one and are usually seen in the nuchal region, the eyelid, the glabella, or the lips. Location is the best clue to help differentiate.

Complications

The primary complications of capillary malformations are skin changes and bleeding. If untreated, a significant percent of patients will manifest a change in the surface appearance of the skin. The skin can become nodular, and the increasingly dilated and ectatic dermal vessels may bleed spontaneously.

Treatment

The treatment of choice for a capillary malformation is laser photocoagulation. Both cosmetic improvement and the prevention of complications in adulthood are possible with laser therapies. These therapies often require multiple treatments and are more efficacious when started early in life. The flashlamp pulsed dye laser is reported to give a 50–70% response rate. These rates range from complete to partial resolution. In a previously untreated adult patient with both progression of the lesion to a nodular appearance and troublesome bleeding, skin grafting may be necessary.

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VENOUS MALFORMATIONS

ESSENTIALS OF DIAGNOSIS

- Usually present at birth, but not detected.
- As they become apparent, venous malformations are bluish-purple in color, raised, and easily compressible.
- Enlarge when dependent or straining/crying.
- Gradually dilate, giving the appearance of a growing lesion.

Pathogenesis

Some venous malformations occur in families and are inherited in an autosomal dominant fashion. This occurrence has been mapped to chromosome 9q. **Blue rubber bleb nevus syndrome** (cutaneous venous malformations associated with gastrointestinal bleeding) may be genetically similar.

Clinical Findings

Craniofacial venous malformations cause symptoms dependent on location. They are almost always a cosmetic problem, and thrombosis often makes these lesions painful, impairing basic activities (Figure 7–3). MRI scanning is the single best modality to evaluate the three-dimensional complexity of a craniofacial venous malformation. Some patients will also have intracranial involvement; therefore, the initial study should always include an MRI of the brain. Coagulation studies should also be done, as these patients often have low-grade disseminated intravascular coagulopathy; however, this condition typically requires no therapy.

Differential Diagnosis

A venous malformation can be confused with a "deep" hemangioma, although an MRI should easily differentiate between the two. Several syndromes are also included in the differential diagnoses of venous malformations:(1) Blue rubber bleb nevus syndrome. The affected patients have multiple cutaneous venous malformations and sometimes also have problematic gastrointestinal bleeding from intestinal lesions. (2) Maffucci syndrome. This syndrome of multiple venous malformations associated with enchondromas begins in adolescence. The skeletal lesions often degenerate into malignant tumors.

Glomangiomas may also be diagnosed as venous malformations. The solitary type of glomangioma is the most common and is characterized by five classic symptoms: (1) severe pain that is seemingly out of proportion to the lesion; (2) localized tenderness; (3) sensitivity to cold; (4) the ability to localize pain to a pinpoint location (Love sign); and (5) painful symptoms eradicated by a proximal tourniquet (Hildreth sign).

Complications

Rapid growth is usually secondary to hemorrhage and hematoma formation. This can be the result of minimal trauma.

These patients may have a chronic consumptive coagulopathy. An evaluation of the coagulation parameters and a platelet count are generally warranted.

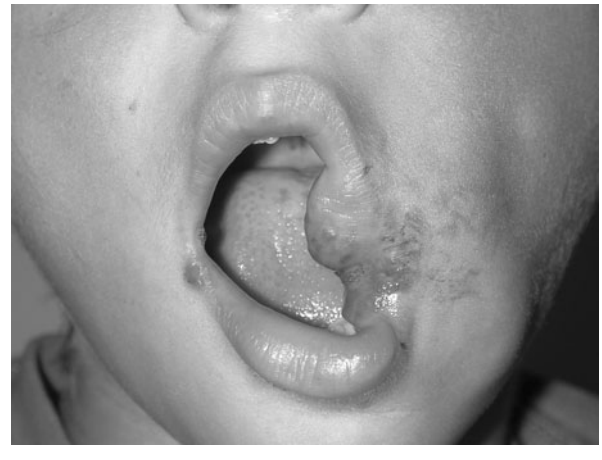
Treatment

A. Compression

If a patient with a venous malformation of the extremities is able to wear a compressive garment, he or she may avoid the long-term morbidity of chronic engorgement. This approach is a primary therapy for extremity lesions, especially simple lesions (eg, benign varicose veins) and lesions of a combined nature (eg, Klippel–Trenaunay syndrome).

B. Sclerotherapy

Sclerotherapy is the mainstay of treatment for craniofacial lesions and for extensive extremity lesions. Sclerosants are effective for these lesions because the sclerosant will stay in the



▲ **Figure 7–3.** A typical venous malformation of the oral cavity.

lesion or can be made to stay in the lesion with compression of the outflow pathway. Alcohol-based sclerosants are the most commonly used type of sclerosing agent. The sclerosant, in any formulation, is intended to do extensive endothelial damage, induce clotting, and induce eventual vascular obliteration. Complications of sclerotherapy can occur, most commonly skin necrosis. Bleomycin can be used instead of alcohol for venous malformations when swelling or necrosis is a concern.

C. Laser Therapy

Laser treatment with the Nd:YAG can be used in selected cases. The goal of laser therapy is also to cause endothelial injury sufficient to lead to coagulation and partial resolution. Percutaneous laser use avoids damaging the skin, so it may be most beneficial at the lip vermilion. The mucosal component of lesions can also be effectively managed with the Nd:YAG laser. This is best done in a non-contact fashion using the laser at 4–6 W. Any bleeding encountered during laser work can usually be managed with pressure.

D. Surgical Measures

Surgical therapy of these lesions is generally reserved for resection of previously sclerosed areas for improved cosmesis or for lesions that respond poorly to sclerosant therapy. Surgical therapy may also be necessary for dental malocclusion or other secondary problems after primary sclerosant or laser management.

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ARTERIOVENOUS MALFORMATIONS

ESSENTIALS OF DIAGNOSIS

- Commonly noted at birth and confused with a hemangioma or a capillary malformation.
- Eventually local warmth and pulsation lead to diagnosis.
- Not easily compressible.
- Overlying skin changes usually precede heart failure.

▲ **Figure 7–4.** A large arteriovenous malformation that has progressed to Schobinger stage IV. Skin changes are obvious, which are present in both stages III and IV.

General Considerations

Arteriovenous malformations, excluding intracranial lesions, are uncommon and are most often found in the head and neck. These malformations are sometimes referred to as "fast-flow" lesions. Trauma or the onset of puberty may precipitate a growth of the malformation.

An arteriovenous malformation is a diffuse lesion with a myriad of microscopic and macroscopic components (Figure 7–4). In contrast, an arteriovenous fistula is a smaller, more localized shunt from a large artery to nearby veins. Despite their different manifestations, arteriovenous fistulas fall within the broad grouping of arteriovenous malformations.

Clinical Findings

Lesions are staged in four categories (Table 7–1). Clinical suspicion is easy to confirm with ultrasound or color Doppler. Either MRI or MRA (magnetic resonance angiography) is the best modality to visualize the extent of the lesion. Arteriography is often reserved for the eventual treatment phase.

Differential Diagnosis

Arteriovenous malformations are commonly noted at birth but are confused with hemangiomas or capillary malformations. Ultrasound can differentiate these lesions.

Table 7–1. Schobinger Clinical Staging System for Arteriovenous Malformations.

Stage	Description	Hallmark
I	Quiescent	Skin discoloration
II	Expansion	Pulsation
III	Destruction	Overlying skin change
IV	Decompensation	Heart failure

Complications

Congestive heart failure may necessitate urgent embolization. Echocardiography should be used to evaluate patients in stage III and at least yearly thereafter to screen for progression to stage IV.

Treatment

Ligating a large feeding vessel is always contraindicated. This procedure shifts the blood flow to collateral vessels and serves only to accelerate the growth of the malformation.

Complete surgical excision is the only way to ensure a permanent, successful treatment. With early diagnosis, surgical excision of a stage I malformation is possible. Early lesions have a greater chance for complete and successful surgical excision. However, because of late diagnosis or the risk of excising large lesions, patients are often followed until symptoms dictate intervention. Super-selective arterial embolization using permanent material can be used palliatively to relieve pain or other symptoms, or as part of a combined treatment plan intended to completely eliminate the lesion. These combined treatments usually consist of either serial embolization followed by surgical resection, which is most commonly used, or embolization followed by sclerotherapy. If the overlying skin is normal, it can be saved; however, this is often not the case. Long-term follow-up is essential as these lesions have a tendency for recurrence even when treated by an experienced physician.

Breugem CC, van der Horst CMAM, Hennekam RCM. Progress toward understanding vascular malformations. *Plast Reconstr Surg* 2001;107:1509 [PMID: 11335828]. (A detailed review of the current understanding of the pathogenesis of these birth defects.)

Kohout MP, Hansen M, Pribaz JJ, Mullkien JB. Arteriovenous malformations of the head and neck: natural history and management. *Plast Reconstr Surg* 1998;102:643 [PMID: 9727427]. (A description of the treatment outcome of 81 patients.)

LYMPHATIC MALFORMATIONS

ESSENTIALS OF DIAGNOSIS

- Incorrectly known as cystic hygroma or lymphangioma.
- Typically thought of as microcystic or macrocystic based on the size of the lymphatic spaces within the malformation.
- Macrocystic lesions are soft, compressible, and transilluminate.
- Microcystic disease is almost always present at birth and is associated with distortion of the cervicofacial soft tissue and eventually the maxillofacial bones.

General Considerations

The commonly used term *lymphangioma* implies cellular proliferation, which is incorrect. The tissue structure of these lesions, like all vascular malformations, demonstrates no proliferative component. In the simplest terms, lymphatic malformations and all vascular malformations are birth defects.

Fifty to sixty percent of lymphatic malformations are recognized at birth; 90% are recognized by the second year. Eighty percent of all lymphatic malformations are located in the head and neck. There is no gender predilection. A lymphatic malformation tends to be slowly progressive, growing with the child. In some instances, it is apparent that the lymphatic malformation rapidly increases in size. In these cases, it is likely that the lesion has either hemorrhaged into itself or has become infected. There are reports of spontaneous regression, although they are far from typical. If regression occurs, long-term follow-up is advised, as the lymphatic malformation may recur. The incidence of lymphatic malformations is unknown.

Pathogenesis

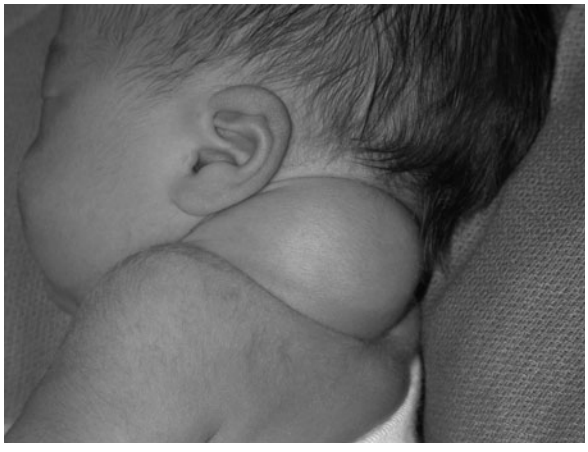
Lymphatic malformations are thought to arise from sequestrations of the developing lymphatic system.

Clinical Findings

An MRI scan with contrast is the typical and best means for evaluating patients with a presumed lymphatic malformation. A lymphatic malformation is hyperintense on a T_2-weighted image and has only a slight increase in intensity on a T_1-weighted image. A lymphatic malformation does not enhance on gadolinium contrast images. Based on the radiographic appearance of the size of the lymphatic spaces located within the lesion, lymphatic malformations are then broadly categorized as either macrocystic or microcystic. Further categorization may then be made based on the location of the lesion (Table 7–2). This type of staging system does offer some important prognostic

Table 7–2. de Serres Classification of Lymphatic Malformations.

Stage	Location
I	Unilateral infrahyoid
II	Unilateral suprahyoid
III	Unilateral suprahyoid and infrahyoid
IV	Bilateral suprahyoid
V	Bilateral suprahyoid and infrahyoid

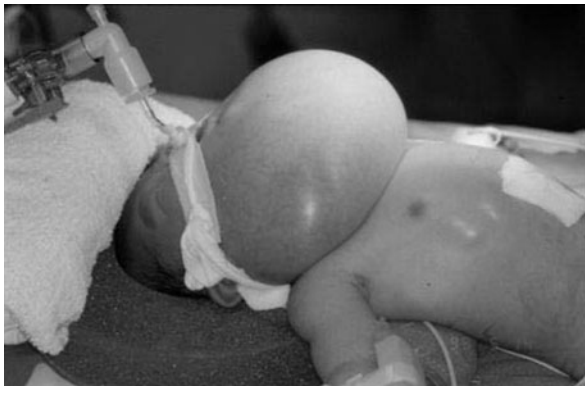


▲ **Figure 7–5.** A macrocystic localized lymphatic malformation in an infant.

information: generally, as the stage increases, the prognosis for the cure decreases. It is also generally true that facial and oropharyngeal involvement are associated with a poor prognosis.

While the lymphatic malformation classification system is helpful prognostically, the staging system does not simplify the clinical complexities of dealing with children who have lymphatic malformations. A more practical classification designates these malformations as either **localized** and macrocystic (Figure 7–5) or **diffuse** and interdigitating (Figure 7–6). The therapeutic goals and appropriate treatments for the two groups are dramatically different.

The increased use of prenatal ultrasound has led to the diagnosis of patients with lymphatic malformations in utero, which has led to some treatment dilemmas at very early stages of life. Not all fetal ultrasound diagnoses of cystic hygroma equate with the postnatal condition of lymphatic malformation. Posterior nuchal swellings are often referred to as cystic hygromas on ultrasonography. This finding is associated with chromosomal abnormalities and increased fetal death rates. These posterior nuchal swellings are not necessarily associated with lymphatic malformation.



▲ **Figure 7–6.** An example of a congenital interdigitating, and diffuse lymphatic malformation.

Anterior and lateral neck swellings identified on fetal ultrasound, which remain persistent on repeat ultrasound, likely represent congenital lymphatic malformations and are sometimes massive (see Figure 7–6). This distinction is well known to the experienced radiologist; however, the terminology can lead to confusion. When children with massive congenital lymphatic malformations are born, they usually undergo an "exit procedure" in which the airway is stabilized by intubation, bronchoscopy, or tracheostomy. These neonates should not undergo massive neonatal dissection unless symptoms dictate the need. These procedures are more likely to result in surgical complications and require, at the least, a dedicated surgical team to perform this procedure as completely as possible.

Differential Diagnosis

When these lesions become infected or hemorrhage into themselves, their rapid enlargement can be misdiagnosed as an infected branchial cyst or acute lymphadenitis. A plunging ranula or a branchial cyst can be confused with a lymphatic malformation. Aspiration and examination of the cyst fluid should differentiate these lesions.

Complications

Diffuse microcystic cervicofacial disease often results in mandibulomaxillary hypertrophy, which is due to the direct invasion of the bone and growth of the lymphatic malformation within the bone. After the child has matured, this hypertrophy can be managed with mandibular osteotomy and, if necessary, Le Fort osteotomies.

A secure airway is essential in patients with diffuse microcystic cervicofacial disease. It is often necessary to perform a tracheostomy to avoid acute respiratory problems.

A lymphatic malformation often swells with the onset of a general viral infection or a remote bacterial infection. This swelling typically resolves with the resolution of the infection. Occasionally, the malformation itself will become infected, which generally requires IV antibiotics.

Treatment

Multiple treatments have been employed for the management of the lesions, which indicates that none have been completely effective. It is helpful to consider treatment of the localized and diffuse groups separately.

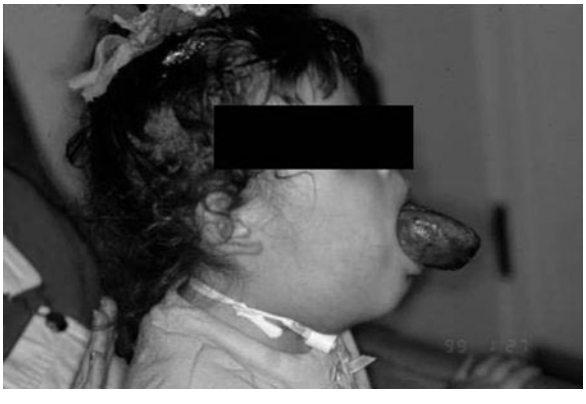
A. Localized Malformations

The treatment of localized malformations relies essentially on sclerosis or surgery, except in some specialized locations. Both surgery and sclerosis are very effective for localized lesions; choosing between these two modalities depends on the surgeon's experience and the specifics of the patient's situation.

1. Sclerosis—Numerous agents have been used in an effort to sclerose these lesions, including boiling water, tetracycline, cyclophosphamide, sodium tetradecyl sulfate, bleomycin, doxycycline, alcohol, and OK-432. OK-432 is a medication developed in Japan with extensive worldwide use. In the United States, the medication is under FDA investigation. The medication, a streptococcus culture treated and killed with penicillin, incites an immune response (delayed hypersensitivity reaction) in the location of the lymphatic malformation. Typically, the lesion swells and subsequently resolves, although it may be necessary to inject the medication several times for some lesions.

2. Laser resurfacing—Other localized lesions may present within the tongue. The tongue may be involved with small blebs that bleed and become infected. An old term used to describe this type of lesion is "lymphangioma circumscriptum." These lesions can be managed with CO_2 laser resurfacing.

3. Tongue reduction surgery—The tongue can also become massively enlarged due to lymphatic malformation (Figure 7–7). Children with this condition cannot be managed with laser and generally require tongue reduction surgery.



▲ **Figure 7–7.** An interdigitating, microcystic, diffuse lymphatic malformation, with involvement of the neck, mandible, floor of mouth, and near-total infiltration of the tongue.

4. CO_2 laser surgery—Glottic involvement is best managed with a CO_2 laser to open lesions and debulk airway obstruction. A tracheostomy tube should always be in place for this type of airway surgery.

B. Diffuse Malformations

The management of diffuse cases is much more complex and may be a lifelong endeavor. For this reason, initial management decisions should not increase the morbidity of the disease by causing cranial nerve injury. The first goals of managing diffuse cervicofacial disease are to allow for an adequate airway and feeding, which will often require a tracheostomy and possibly a gastrostomy. Surgical management is the mainstay of treatment for these lesions. If complete resection is not possible, it may be helpful to manage different anatomic areas as individual problems. The mylohyoid muscle is a typical boundary used to divide these massive lesions into several "zones." It is also advisable to approach the divided components of the total malformation from the "top down," if possible. For instance, the physician should attempt to deal with the tongue before the floor of mouth and then approach the neck; this approach will prevent superior swelling of the untreated zone. Additionally, children with diffuse cervicofacial disease will also frequently require maxillomandibular reconstruction due to overgrowth of the facial bones.

It is also advisable in the care of children with diffuse disease to involve a child psychiatrist. It is likely that these children will have long-term morbidity, and a means for dealing with the psychosocial implications is essential.

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Marler JJ, Fishman SJ, Upton J et al. Prenatal diagnosis of vascular anomalies. *J Pediatr Surg* 2002;37:318 [PMID: 11877641]. (A discussion of prenatal diagnosis and its implications.)

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Padwa BL, Hayward PG, Ferraro NF, Mulliken JB. Cervicofacial lymphatic malformation: clinical course, surgical intervention, and pathogenesis of skeletal hypertrophy. *Plast Reconstr Surg* 1995;95:951 [PMID: 7732142]. (A convincing explanation for skeletal hypertrophy in patients with diffuse lymphatic malformation of the cervicofacial area.)

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8 Maxillofacial Trauma

Andrew H. Murr, MD, FACS

Patients with maxillofacial trauma are seen everyday in emergency rooms throughout the United States. The cause of the trauma can be quite variable, ranging from industrial and motor vehicle accidents to interpersonal trauma involving either fists or weapons. It is common for trauma to be related to substance abuse or to behavior that can be linked to substance abuse. Sometimes trauma is related to sports activities or simply to accidental or work-related occurrences. The principles of management are directed at stabilizing a patient's medical condition and providing safe reconstruction to maximize both functional and aesthetic rehabilitation.

THE ABCS OF TRAUMA

It can be disconcerting when a patient is brought into the emergency room with severe craniofacial trauma. Patients may be covered with blood and have distorted anatomy that may divert attention from the initial principles of Advanced Trauma Life Support (ATLS). In these circumstances, it is critically important to follow the basic tenets of initial trauma stabilization, also known as the ABCs of trauma:

Airway management and assessment

Breathing

Circulation

Tamponade of bleeding and C-spine clearance are also critical factors when the patient initially presents to the emergency room. In the initial management period, even occurrences of severe craniofacial trauma may be examined after cases of abdominal, thoracic, and—at times—limb trauma. A neurosurgical examination and clearance are frequently desirable in severe high-velocity injuries. When ocular injury is suspected, an examination by an ophthalmologist can be indispensable. Patients on the most severe end of the injury spectrum often require airway control via orotracheal intubation or, in certain cases, via cricothyroidotomy or tracheotomy.

Most attempts to repair maxillofacial trauma will be considered after the patient is stabilized. Almost all skeletal trauma repair is guided by the information provided by fine-cut computed tomography (CT) scans. Fine-cut scans take more time and require more medical condition stability than the initial screening provided by head and brain CT scans, which are often obtained to rule out suspected neurological injury during the initial, acute evaluation period. In contrast, soft-tissue injuries are often repaired as soon as it is practically possible. Low-velocity injuries, such as isolated nasal and mandible fractures, do not usually require the same highly consultative and collaborative team approach, especially if no other injuries are found or suspected. With isolated injuries, which tend to be more minor than multisystem injuries, treatment can be better directed; it can proceed on a pace both commensurate with and concentrated upon the direct injury.

ACS Committee on Trauma. *ATLS for Doctors: Student Course Manual [with DVD]*, 8th ed. American College of Surgeons, Chicago, Illinois, 2009. (This is the best resource for individuals interested in the basics of ATLS training and initial trauma management.)

SOFT TISSUE TRAUMA

ESSENTIALS OF DIAGNOSIS

- Obtain hemostasis
- Tetanus prophylaxis
- Irrigate/clean wound
- Meticulous layered closure

TREATMENT

Managing Blood Loss

Although the ABCs of trauma take precedence over most of the issues associated with maxillofacial trauma, sometimes the

soft tissue injuries of the face or scalp can add substantially to blood loss. A temporal injury may lacerate the superficial temporal artery or a scalp laceration may contribute to the loss of many units of blood. Under these circumstances, it is desirable to halt bleeding immediately. The discrete clamping of an arterial vessel in a laceration may be necessary if the physician is unable to gain adequate control of blood loss by applying simple pressure. Scalp injuries usually respond to closure with a few simple mattress sutures, placement of staples to approximate the wound, or a pressure dressing. This blood loss management allows time for the rest of the trauma evaluation to proceed and for the patient to be stabilized.

Prophylactic Treatment Measures

A. Antibiotics

Lacerations of the scalp, face, and neck should be closed as soon as the patient is stable. In cases in which the tissue loss is minimal, which is the most common circumstance, primary closure is utilized. Primary closure is direct edge-to-edge skin approximation using fine sutures with precise suture approximation of deeper tissue layers. Protecting the patient prophylactically with tetanus immunoglobulin and tetanus toxoid should be considered. In contaminated wounds, which are extremely common, prophylactic antibiotic administration should also be considered.

B. Anesthesia

It is important to administer adequate anesthesia for wound closure if the closure is to be made under local sedation. Typically, injectable 1% lidocaine with epinephrine mixed 1:100,000 is adequate to obtain anesthesia for closure. This preparation can be injected with a fine, 27-gauge needle and a control-type syringe. The toxic dose of lidocaine with epinephrine is 7 mg/kg and should be noted. During the procedure, it is often possible to keep the patient comfortable with a small amount of sedation if no contraindication exists. Sometimes topical EMLA cream (lidocaine 2.5% and prilocaine 2.5%) can be used if it is difficult to inject the patient (eg, a child) with a local anesthetic agent.

Wound Irrigation

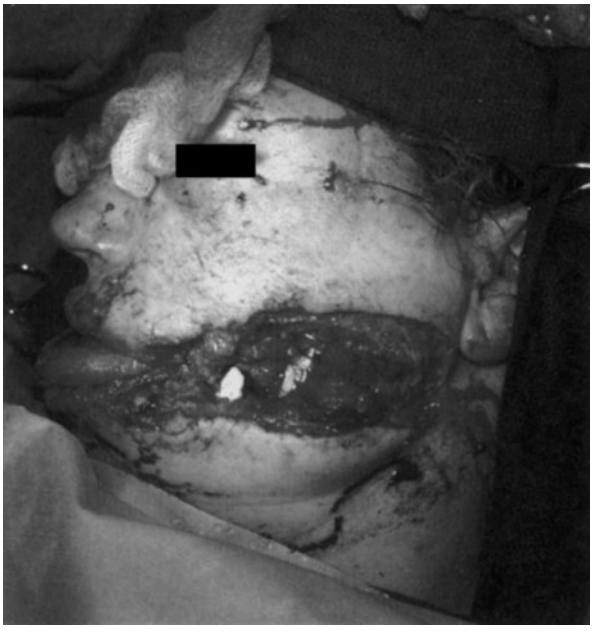
Once anesthesia takes effect, the wound should be irrigated to help prevent future infection. However, irrigation can only be done effectively if the patient is comfortable. Saline can usually be used to irrigate the wound with a 60-mL syringe. If glass, gravel, or other foreign material is suspected to be in the wound, a finger can be used to probe the wound and remove the foreign material. Sometimes the skin is abraded so badly that the area needing to be anesthetized would be too large to safely administer lidocaine to the patient without causing lidocaine toxicity. In these cases, it is best to proceed to the operating room so that general anesthesia can be administered and the wound can be manipulated without the risk of excessive local anesthesia (Figure 8–1). In some wounds contaminated by tar, as sometimes occurs in motorcycle accidents or other road injuries, administering general anesthesia is the best recommended option for wound manipulation that is comfortable for the patient. Once the wound is thoroughly clean, povidone–iodine, commonly known as Betadine, can be used to create a sterile environment for wound closure. Any small bleeding areas can be handled with a disposable electric cautery, bipolar cautery, or by using individual clamps and suture ties.

Wound Closure

Facial wound closure should heal by first-intention (primary) healing whenever possible; lacerations should be closed with direct suturing to approximate skin edges. This closure can be improved with the discrete undermining of skin flaps, where necessary, to produce a tension-free closure. The key elements to obtaining good results with wound closure are (1) having a clean and sterile wound, (2) respecting anatomic boundaries, (3) avoiding tension on the suture line, and (4) having atraumatic surgical technique. The wound should be closed in layers, in the following order: (1) muscle, (2) subcutaneous tissue, (3) subcuticular tissue, and (4) superficial skin. Chromic gut sutures are useful for deep closure; fine nylon or proline stitches are useful for skin closure. Although polyglactin (eg, Vicryl) and polyglycolic acid (eg, Dexon) can also be used for deep stitches, they can sometimes become infected due to sluggish absorption, which can lead to their eventual migration out of the wound. Other dissolvable monofilament sutures may also be used for deep closure. In areas where it is difficult to remove stitches, such as around the eyelid, fast-absorbing 6–0 gut sutures or 6–0 mild chromic sutures can be used. These sutures have the advantage of leaving little trace of their placement and dissolving without requiring removal. These types of stitches may also be useful in children to prevent the need for future stitch removal or when patient follow-up is doubtful. When taking care of patients with heavy beards or dark facial hair, it is best to use a skin suture color other than black to facilitate future removal. Blue proline suture works well in these circumstances.

If wound coverage is difficult because of lost skin, transposition flaps can be used to create closure. However, these flaps are rarely necessary. If they are required, it is often best to accomplish the closure in the operating room setting as instrument sets and nursing assistance become more critical. The risk in using transposition flaps is that the wound is usually contaminated; utilizing these flaps may increase the risk of tissue loss if the wound becomes infected. In these cases, wounds may be allowed to heal by second-intention (secondary) healing through the granulation and contracture process with a subsequent plan, if necessary, for wound revision.

A special circumstance of trauma involves **bite injuries**, which may be of animal, insect, or human origin. Allowing a bite injury to heal by first-intention healing should be



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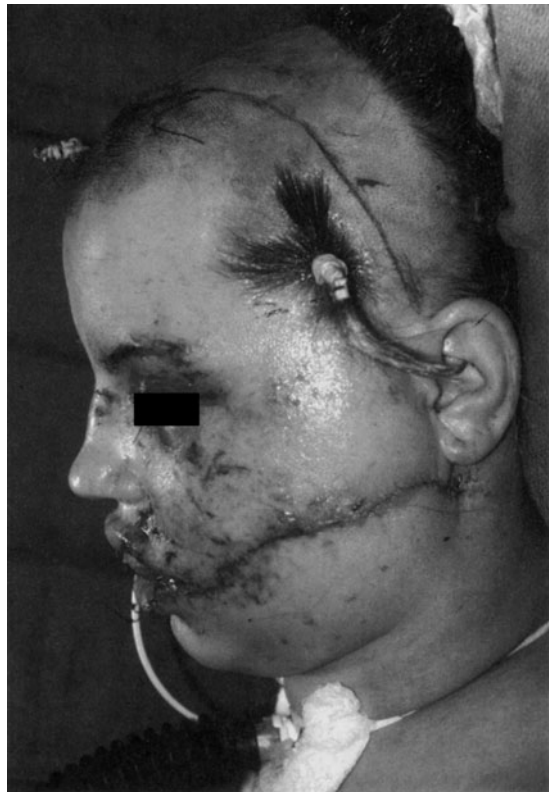

B

▲ **Figure 8–1.** A severe laceration may sometimes require general anesthesia to properly identify cut nerves and provide a stable condition for operative closure. **(A)** Laceration of cheek with cut facial nerve **(B)** Meticulous closure of wound accomplished in an operating room setting

considered carefully because the wound is likely to be contaminated. Although infection may ensue, primary closure is still recommended for these wounds after thorough irrigation and with concomitant antibiotic administration. The antibiotic coverage should be directed at a polymicrobial spectrum, including α-hemolytic streptococci, *Staphylococcus aureus*, and anaerobes such as *Bacteroides*. β-lactamase stable antibiotics such as amoxicillin–clavulanic acid combination drugs are good targeted medications for prophylaxis of these types of injuries. It is likely that the result will be no worse if an attempt at closure is made, even if the wound eventually becomes infected compared with leaving the wound open to heal by second intention.

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Lackmann GM, Draf W, Isselstein G, Tollner U. Surgical treatment of facial dog-bite injuries in children. *J Craniomaxillofacial Surg* 1992;20:81 [PMID: 1569219]. (a good review of wound principles in bite injuries.)

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BURN MANAGEMENT OF THE HEAD AND NECK

During the acute management of patients with facial burns, the fundamental principles of trauma are followed. Special attention must be directed to evaluation of the airway because airway obstruction may develop rapidly after inhalation injury. Delayed onset of obstruction within 24–48 hours may occur from progressive edema. Specific risk factors for airway compromise include a history of burn injury within a confined space, evidence of soot in the oral cavity, production of carbonaceous sputum, and concomitant facial and body burns. Laboratory evidence, including arterial blood

gases and carboxyhemoglobin levels, may further suggest potential airway impairment. If time permits, serial flexible fiberoptic nasolaryngoscopy exams allow for diagnosis of oropharyngeal, true and false vocal fold edema. In management of burn patients, there should be a low threshold for early intubation.

Burns are broadly classified according to depth of penetration. First-degree burns involve the epidermis only (eg, sunburn), and clinical findings include erythema. Second-degree or partial-thickness burns involve the epidermis and a portion of the dermis. These burns are extremely painful and present with blistering and open, weeping surfaces of skin. Third-degree or full-thickness burns represent involvement of all layers of skin, including nerve endings, blood vessels, and skin appendages. As such, they are characterized as insensate, swollen, and white or gray in color. Extent of burn injury is estimated by the "rule of nines," whereby the head and neck region represents approximately 9% of total body surface area.

Inpatient management is universally required for second- or third-degree burns of the face. Early treatment goals involve the prevention of infection via sterile dressings, burn excision, and wound closure if permissible. To attenuate contracture and scar formation, temporary wound cover may be accomplished with cadaver grafts, porcine grafts, and a variety of synthetic skin substitutes. Permanent wound coverage is obtained by split-thickness skin grafts, local flaps, or microvascular free tissue transfer. Microstomia commonly results from perioral facial burns, or thermal burns that occur when small children chew electric cords. Oral splints are available for prevention of microstomia, but the efficacy of these appliances is controversial. Contracture of the eyelid, or ectropion, occurs when the eyelids are everted from the globes following burn injury. Early ophthalmologic consultation is recommended. To prevent corneal damage, early reestablishment of lid position is imperative.

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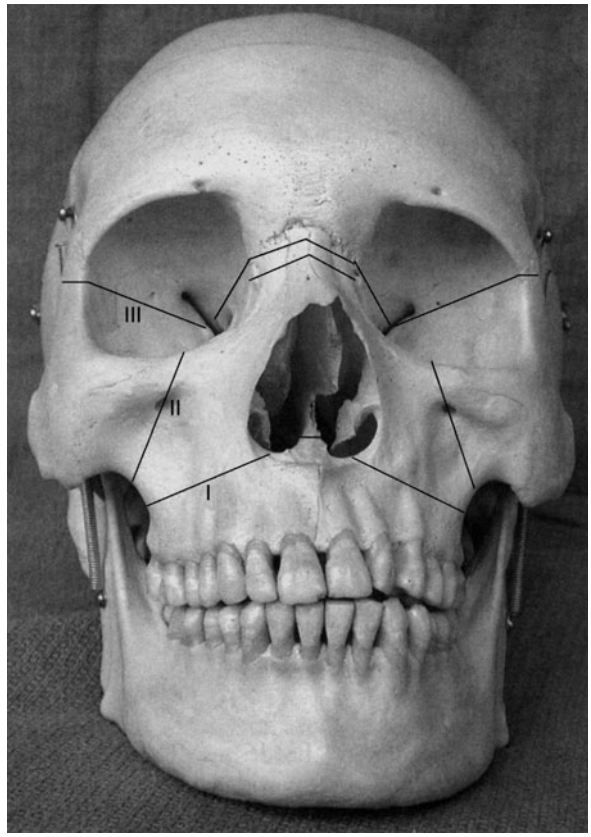
Yowler CJ, Fratianne RB. Current status of burn resuscitation. *Clin Plast Surg* 2000;27:1 [PMID: 10665352].

SKELETAL TRAUMA

The forces of traumatic impact have a fairly predictable effect on the facial skeleton: most force is directed through the buttress system. The buttresses consist of both vertical and horizontal supports. The horizontal buttresses are (1) the zygomatic arches, (2) the supraorbital and infraorbital rims, and (3) the glabella or nasal root (Figure 8–2). The vertical buttresses consist of (1) the frontozygomatic buttresses; (2) the maxillary buttress of the pterygoid plate; (3) the posterolateral maxillary sinus wall, which is known as the zygomaticomaxillary buttress; and (4) the frontoethmoid maxillary buttress (Figure 8–3). The successful repair of midface skeletal fractures requires an understanding of the impact of forces on the skeletal buttresses; it also requires a recognition of the weakness patterns common to this buttress system. In general, the midface creates a vertical maxillary dentition and palate height that needs to be maintained if the repair process is to maximize function.

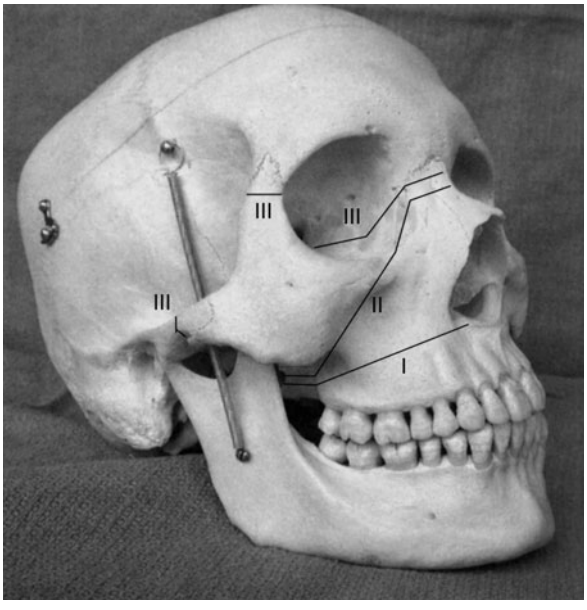


▲ **Figure 8–2.** Anterior view of Le Fort midface fractures.

ORBITAL FRACTURES

ESSENTIALS OF DIAGNOSIS

- Ophthalmological examination is critically important
- Fine cut CT scan is necessary for treatment planning



▲ **Figure 8–3.** Lateral view of Le Fort midface fractures.

Orbital fractures may occur either as a part of massive facial trauma, in conjunction with Le Fort fractures, or as isolated fractures. Orbital floor fractures known as **blowout fractures** are commonly encountered as isolated fractures. The mechanism of injury for these fractures is usually from direct anterior orbital trauma, such as from a fist or from a ball during a sporting activity. The orbit is made up of buttresses connected by very thin bones that include maxilla, sphenoid, lacrimal, frontal, zygomatic, ethmoid, and palatine bones. The orbital floor is also the roof of the maxillary sinus and has a natural weakness where the second division of the trigeminal nerve traverses it; the bone in this area is quite thin. Sudden anterior pressure on the orbital contents can cause a fracture of the orbital floor, which results in periorbital fat sagging into the maxillary sinus. In some cases, the inferior orbital rim may be involved at the level of the infraorbital foramen, which may also result in numbness in the V2 distribution (ie, the second division of the trigeminal nerve).

Not all orbital floor fractures require exploration and repair. Orbital fractures need surgical intervention under the following circumstances: (1) they cause entrapment of the extraocular muscles, resulting in gaze limitation or diplopia; (2) the patient has sagging of the orbital contents, causing enophthalmos and subsequent diplopia; or (3) imaging studies reveal a greatly increased relative orbital volume (greater than 5–10% relative increase when compared with the noninjured side) due to the loss of the orbital floor and sagging of the contents into the maxillary sinus. In this latter scenario, the patient is at risk for late enophthalmos, and repair would be more easily accomplished within a few weeks of the injury rather than months later, when scarring will cause the procedure to be more difficult. It is highly recommended to obtain a baseline ophthalmologic exam of vision acuity and range of motion for all patients with orbital fractures, especially before proceeding with operative repair. A fine-cut axial and coronal CT scan of the orbits is essential for operative planning. The ideal time for the repair is often 7–14 days after the injury; much of the edema from the trauma will have subsided, and the repair technique will be easier to precisely gauge. The operative technique involves either a subciliary or a transconjunctival incision, both of which give access to the orbital periosteum. The orbital contents are then raised out of the fracture line and supported with a titanium plate, cartilage, bone, absorbable plate, or other material. Many permanent orbital implant materials have a long history of use, including Medpore (ie, porous polyethylene), Marlex (ie, polypropylene mesh), silicone, and other materials. They all have the possibility of late extrusion. Titanium has the advantage of being able to be fixed to bone via screws, which decreases the chance of late migration. Titanium is also biocompatible. Combination implants consisting of porous polyethylene wrapped around a titanium framework are available, which have the advantage of being malleable and impervious to soft tissue growing through the titanium lattice. Conchal or nasal cartilage is autologous and is therefore a good material for supporting orbital repairs of this type. After the repair is completed, a forced duction test of extraocular motility should be performed to ensure that any entrapment of the extraocular muscles is relieved.

Dal Canto AJ, Linberg JV. Comparison of orbital fracture repair performed within 14 days versus 15 to 29 days after trauma. *Ophthal Plast Reconstr Surg* 2008 Nov–Dec;24(6):437–443. [PubMed PMID: 19033838]. (The question of timing of the orbital floor repair is controversial—this paper compares the early and late group up to 29 days and finds no significant difference in success.)

Manolidis S, Weeks BH, Kirby M, Scarlett M, Hollier L. Classification and surgical management of orbital fractures: experience with 111 orbital reconstructions. *J Craniofac Surg* 2002;(6):726 [PMID: 12457084]. (An excellent review of methods of orbital fracture repair.)

Manson PN. The orbit after Converse: seeing what is not there. *J Craniofac Surg* 2004 May;15(3):363–367. [PubMed PMID: 15111791]. (Well worth the read, this lecture summarizes the history of orbital surgery from the time of Converse to contemporary practice.)

Ridgway EB, Chen C, Colakoglu S, Gautam S, Lee BT. The incidence of lower eyelid malposition after facial fracture repair: a retrospective study and meta-analysis comparing subtarsal, subciliary, and transconjunctival incisions. *Plast Reconstr Surg* 2009 Nov;124(5):1578–1586 [PubMed PMID: 20009844]. (A single institution experience with 3 different surgical approaches combined with a literature meta-analysis.)

NASOETHMOID COMPLEX FRACTURES

ESSENTIALS OF DIAGNOSIS

- Condition of the medial canthal tendon is critical in the decision making process
- CT scan is vital diagnosis and planning

The nasoethmoid complex involves both a horizontal and a vertical buttress. The horizontal buttress is the nasal root, and the vertical buttress is the frontonasal maxillary pillar. Nasoethmoid complex fractures usually require high velocity and a more powerful force in order to be produced compared with isolated nasal fractures or orbital floor fractures. The key physical findings are often severe orbital swelling and ecchymosis with traumatic telecanthus (widening of the intercanthal distance), which gives the impression of widening of the eyes. Because of the close proximity of the ethmoid bone to the skull base, skull base trauma and cerebrospinal fluid (CSF) leak should be suspected in patients who sustain nasoethmoid complex fractures; neurosurgical consultation is therefore advisable.

Because the anterior ethmoid cells have an impact on frontal sinus drainage, patients with severe nasoethmoid complex fractures may require follow-up to ensure that the frontal sinus drainage is physiologically functional. If it is not, a late frontoethmoid or frontal sinus mucocele may occur, with the potential for eye or brain involvement. The key to repairing nasoethmoid complex fractures is the reestablishment of the midline vertical height of the nasal root. Reestablishing the midline vertical height prevents late deformity and restores the medial canthal tendon to an anatomically functional position. It is important to keep in mind that the normal intercanthal distance is 30–35 mm.

The surgical approach to repair a nasoethmoid complex fracture is often accomplished through a bicoronal forehead flap, which gives an excellent exposure of the nasal root to allow fracture reduction. Alternative techniques include a midfacial degloving incision or a bilateral external ethmoidectomy incision with a connection via the glabella; the latter procedure is known as the "open sky" approach. Small midface plates in various configurations can be used to painstakingly replace the shattered nasal and ethmoid bones into their anatomic positions. Bone grafts may be required if the fracture has a high degree of comminution. Occasionally, the medial canthal tendons must be retrieved and reapproximated with fine-gauge stainless-steel wire, either to titanium plates or to holes drilled in the lacrimal bone. Late diplopia can occur if the medial orbital attachments are not replaced optimally.

Cultrara A, Turk JB, Har-El G. Midfacial degloving approach for repair of naso-orbital-ethmoid and midfacial fractures. *Arch Facial Plast Surg* 2004;6(2):133 [PMID: 15023802]. (An excellent discussion of a useful surgical approach to facial trauma.)

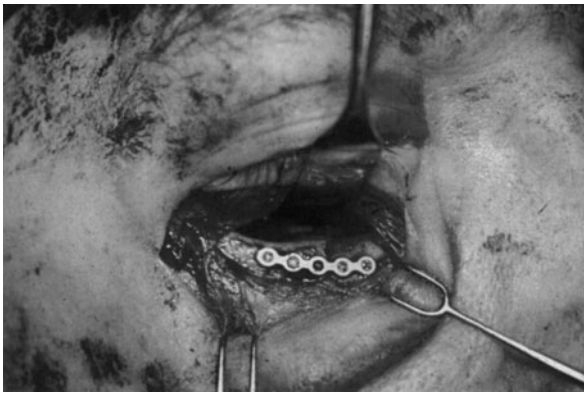
Potter JK, Muzaffar AR, Ellis E et al. Aesthetic management of the nasal component of naso-orbital ethmoid fractures. *Plast Reconstr Surg* 2006;117(1):10e–18e [PMID: 16404240]. (A definitive and well-organized article that emphasizes treatment principles.)

Sargent La, Rogers GF. Nasoethmoid complex fractures: diagnosis and management. *J Craniomaxillofacial Trauma* 1999;5(1):19 [PMID: 11951221]. (A good review of NEC fractures.)

ZYGOMATIC COMPLEX FRACTURES

The zygomatic complex, also known as the trimalar complex, is a facial bone commonly injured in low-velocity trauma. Lateral trauma sometimes produces an isolated zygomatic arch fracture; however, more severe force can fracture the entire zygomatic complex. Although commonly referred to as a "tripod" fracture, this name is a misnomer: a zygomatic complex fracture constitutes four discrete fractures. The components of this fracture are (1) the zygomatic arch, (2) the orbital rim, (3) the frontozygomatic buttress, and (4) the zygomatico-maxillary buttress. Patients often present with infraorbital ecchymosis and occasionally with paresthesia in the V2 distribution. There is a loss of cheek prominence, with asymmetry upon inspection. The asymmetry can be most noticeable when the patient's head is tilted back and viewed from beneath the chin. Ophthalmologic consultation should be encouraged for a patient with a zygomatic complex fracture because the repair involves manipulating the inferior and lateral orbit walls, which may affect vision. Occasionally, tooth roots can also be involved in the fracture; therefore, an inspection of the dentition is recommended as part of the presenting history and physical exam.

The repair of zygomatic fractures is often accomplished on an elective basis. Isolated arch fractures can be elevated via a classic Gillies approach. The Gillies technique involves three steps: (1) creating an incision behind the temporal hairline, (2) identifying the temporalis fascia, and (3) placing an elevator beneath the fascia to approach the arch from its deep aspect. By sliding the elevator in the plane deep to the fascia, injury to the frontal branch of the facial nerve is avoided. The arch can then be levered into a more normal anatomic position. An alternate approach, called Keen's approach, is to place an elevator via a transoral gingival buccal sulcus incision underneath the arch; the elevator then passes through the buccal space with the elevation of the arch taking place. Zygomatic complex fractures can also be approached with the same transgingival buccal sulcus incision, which can give access as high as the orbital rim. One four-hole, midface titanium plate is enough to counteract the muscular forces to reduce and fix the fracture. However, it is usually desirable to expose at least two of the four buttresses in order to allow an accurate reduction of these fractures. A small incision at the lateral brow or superior eyelid crease may be necessary to access the frontozygomatic



▲ **Figure 8–4.** A midface reconstruction plate placed on the orbital rim via a subciliary approach.

buttress and the sphenozygomatic buttress; alternately, a transconjunctival or subciliary or subtarsal incision may be needed to access the infraorbital rim (Figure 8–4). In rare cases, a bicoronal or a unicoronal approach may be used to obtain direct access to the zygomatic arch (1) if the fracture is very severe, (2) in cases of severe orbital-zygomatic fractures, or (3) in cases of bilateral zygomatic complex fractures. The main goals in operating on these fractures are to restore symmetry to the face and to prevent late orbital complications such as enophthalmos.

Manson PN, Clark N, Robertson B et al. Subunit principles in midface fractures: the importance of sagittal buttresses, soft-tissue reductions, and sequencing treatment of segmental fractures. *Plast Reconstr Surg* 1999;103:1287 [PMID: 10088523]. (A definitive and well-organized review article that emphasizes treatment principles.)

Rinehart GC, Marsh JL, Hemmer KM, Bresina S. Internal fixation of malar fractures: an experimental biophysical study. *Plast Reconstr Surg* 1989;84(1):21 [PMID: 2734399]. (A good study of the forces needed to stabilize ZMC fractures.)

MAXILLARY FRACTURES

ESSENTIALS OF DIAGNOSIS

- Midface and palatal mobility can be defined on physical examination
- Occlusion must be corrected
- CT imaging is necessary for planning

Midface maxillary fractures are usually the result of high-velocity injuries (eg, motor vehicle accidents or severe and life-threatening interpersonal trauma). The primary surgical goals in repairing maxillary fractures include restoring normal contour to the facial skeleton and restoring normal dental occlusion.

Maxillary fractures were classified by René Le Fort. He subjected cadavers to various types of trauma and found that certain patterns of injury resulted. Le Fort divided these midface fractures into three discrete types: Le Fort I, Le Fort II, and Le Fort III. (Figures 7–2 and 7–3 display Le Fort fracture characteristics.)

1. Le Fort I Fractures

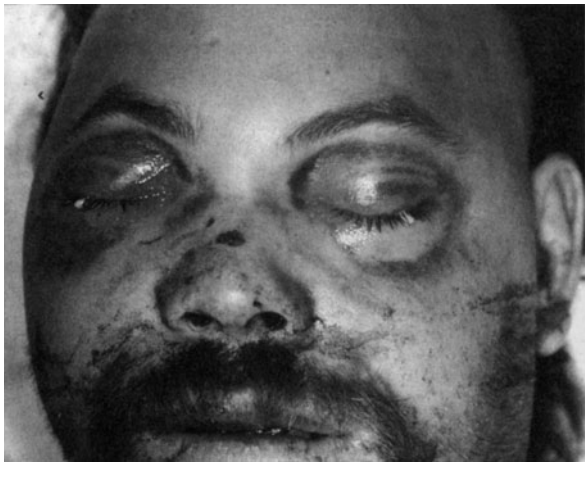
Le Fort I fractures are fractures that separate the palate from the midface and, by definition, involve the pterygoid plates bilaterally. This fracture type results in a mobile palate but a stable upper midface. Patients present with malocclusion and an anterior open-bite deformity. The deformity occurs because the pull of the muscles of mastication forces the palate to slide backward, retruding the maxillary teeth. Airway compromise can occur if the palate retrusion is severe. The operative strategy in repairing Le Fort I fractures is to reduce the fracture by aligning the dentition into as normal a configuration as possible.

Normal physiologic occlusion is referred to as **Class I occlusion**. It takes place when the mesiobuccal cusp of the maxillary first molar interdigitates with the mesiobuccal groove of the mandibular first molar. **Class II occlusion** occurs when the mandible is relatively retrognathic or retruded. **Class III occlusion** occurs when the mandible is relatively prognathic or protruded. The key goal in repairing any fracture involving the dentition is to reduce the fracture to the premorbid occlusion. This goal is best accomplished with a Class I occlusion. The surgical access for the repair of a Le Fort I fracture is often obtained via bilateral maxillary gingival buccal sulcus incisions; these incisions expose the anterior maxillary wall as well as the lateral and anterior maxillary buttresses. Intermaxillary fixation using either skeletal screws or arch bars with wires is used to pull the fractures into ideal occlusion. Occasionally, reduction forceps may be necessary to bring the palate back into functional occlusion. Once the fracture is reduced and stabilized, titanium miniplates, which have low profile but great strength, are screwed directly to the maxilla both to create permanent stability and, ideally, to restore midface height and functional occlusion. The blood supply to the maxilla is quite rich, and complications such as osteomyelitis or sequestrum occur rarely. Even small fragments of bone often survive if well fixed with the miniplate systems. If the fracture is so severe that no solid bone can be used to provide stable fixation, split calvarial bone grafts or grafts from the iliac crest can be plated into position to provide a stable repair. However, if the fracture is minimally displaced, sometimes intermaxillary fixation alone for 4–6 weeks will allow an excellent recovery.

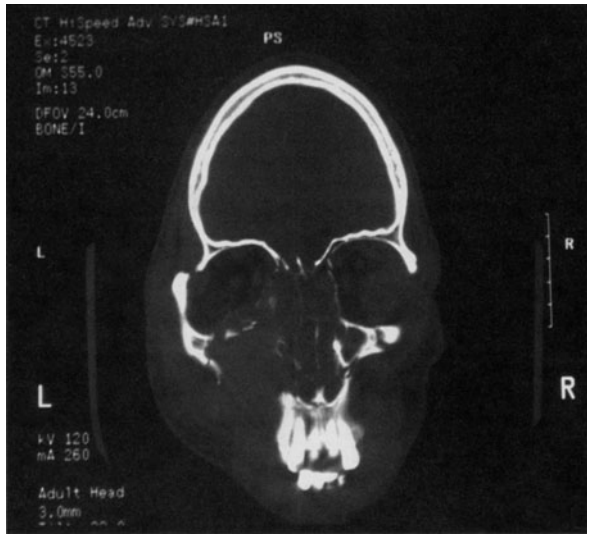
2. Le Fort II Fractures

Le Fort II fractures involve the pterygoid plates, the frontonasal maxillary buttress, and often the skull base via the ethmoid bone. This fracture, therefore, has a pyramidal appearance and results in palatal and upper-midface mobility. Because of the large amount of force required to cause Le Fort II fractures, patients who have this type of fracture often have other injuries as well, including orthopedic and neurosurgical problems (Figure 8–5). The skull base may be involved, and so nasotracheal intubation should be avoided in the acute setting because a nasal tube could potentially be forced through the fracture and into an intracranial cavity. CSF leakage is common in this type of midface fracture. The initial medical stabilization is often accomplished in the intensive care unit. Fine-cut computerized imaging, usually CT scanning (possibly with three-dimensional reconstruction), is desirable as it allows for adequate operative planning once the patient's condition has stabilized (Figure 8–6). Patient stabilization often requires several days of convalescence.

The operative approach to Le Fort II fractures requires alignment of the dentition into Class I occlusion, using arch bars and wires or screws to reduce the fracture. This approach is known as intermaxillary fixation. Following intermaxillary fixation, the maxillary buttresses need to be surgically exposed to allow for miniplate fixation. Many strategies can be used to accomplish the exposure, including bilateral gingival buccal sulcus incisions together with incisions designed to approach nasoethmoid complex fractures. The midface degloving incision, which uses a rhinoplasty-type intranasal exposure, combined with the gingival buccal sulcus incisions, often provides excellent access to allow placing the titanium miniplates in this type of fracture.



▲ **Figure 8–5.** A patient with "raccoon eyes" and a midface fracture. Neurosurgical evaluation is important.

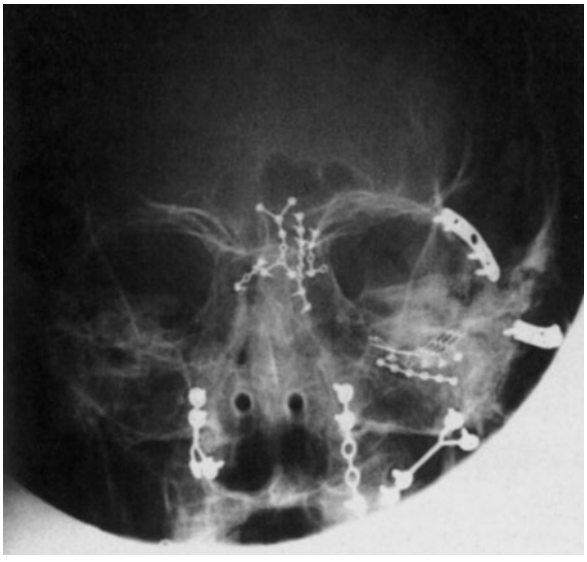


▲ **Figure 8–6.** A CT scan of a midface fracture is essential for operative planning.

3. Le Fort III Fractures

Le Fort III fractures involve the same types of force as Le Fort II fractures; however, Le Fort III fractures result from a greater *degree* of force than Le Fort II fractures. A consultative team approach is best for these severely injured patients. In addition to injuring the pterygoid plate and the frontonasal maxillary buttress (as is found with Le Fort II fractures), Le Fort III fractures involve the frontozygomatic buttress. These fractures therefore result in complete craniofacial dislocations. In addition, associated neurosurgical injuries are often seen in patients with Le Fort III fractures.

The preoperative issues associated with Le Fort III fractures are similar to those seen in Le Fort II cases. After intermaxillary fixation, a bicoronal approach is used to facilitate the repair of the frontozygomatic buttress and zygomatic arch. This approach allows excellent access to the lateral and medial buttress systems in order both to restore the adequate vertical height of the occlusion and to provide stable fixation. A midfacial degloving approach is often combined with the bicoronal approach to allow access to the lower maxilla for plating (Figure 8–7). It is not uncommon to recommend elective tracheotomy for these patients in the postoperative period. This approach is recommended for several reasons: (1) nasotracheal intubation is usually not safe for a patient with this degree of injury because of the risk of frontal skull base injury; (2) the patient must be placed into intermaxillary fixation; (3) owing to related neurosurgical issues, the patient usually has a fairly prolonged need for the attention of an intensive care unit; and (4) the reduction of this type of severe fracture also causes temporary but significant upper airway edema. Again, a team



▲ **Figure 8–7.** A postoperative plain film X-ray shows the locations of the plates that have stabilized the midface fracture.

approach to the treatment of patients with this type of severe injury often increases the prognosis for a favorable recovery.

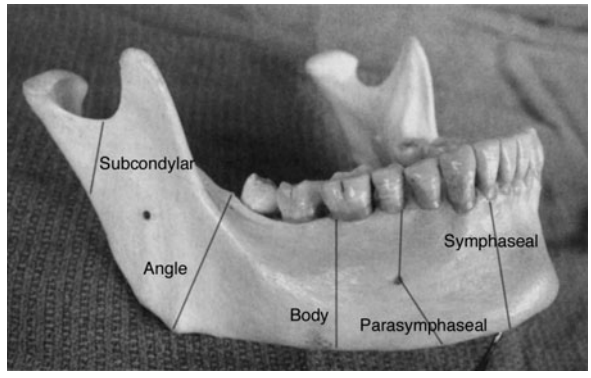
Mithani SK, St-Hilaire H, Brooke BS, Smith IM, Bluebond-Langner R, Rodriguez ED. Predictable patterns of intracranial and cervical spine injury in craniomaxillofacial trauma: analysis of 4786 patients. *Plast Reconstr Surg* 2009 Apr;123(4):1293–1301 [PubMed PMID: 19337097]. (An extensive review of the epidemiology of fractures, which includes midface fractures and associated injuries)

Manson PN, Clark N, Robertson B et al. Subunit principles in midface fractures: the importance of sagittal buttresses, soft-tissue reductions, and sequencing treatment of segmental fractures. *Plast Reconstr Surg.* 1999;103(4):1287 [PMID: 10088523]. (A definitive and well-organized review article that emphasizes treatment principles.)

MANDIBLE FRACTURES

ESSENTIALS OF DIAGNOSIS

- A panoramic radiograph or preferably CT imaging is best for diagnosis
- Intermaxillary fixation is a key principle to re-establish premorbid occlusion
- Many fixation techniques are available to permanently stabilize the fracture; some internal fixation techniques may allow immediate return to function

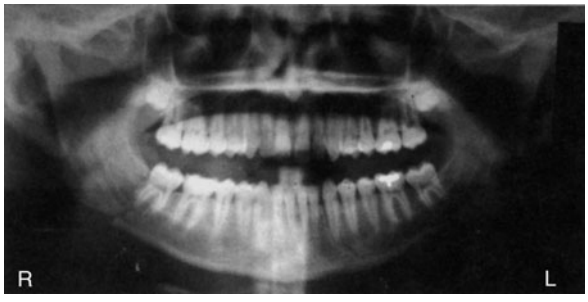


▲ **Figure 8–8.** Subunit regions of the mandible.

Mandible fractures can be part of both high-velocity and low-velocity traumas. Mandible fractures may occur as a result of sports activities, falls, motor vehicle accidents, and interpersonal trauma. In busy inner-city emergency departments, mandible fractures are seen almost daily. Patients often present acutely and may be intoxicated by alcohol or illicit substances. Patients sometimes present the morning after the injury, when they are no longer intoxicated and realize that a problem exists due to pain and malocclusion.

Patients with mandible fractures often have pain with attempts at mastication; this symptom usually results in their seeking medical attention. Other symptoms include malocclusion and numbness of the third division of the trigeminal nerve. The initial examination should note any sensory nerve deficit and associated dental injury, such as cracked or missing teeth. The mobility of a mandibular segment is a key physical diagnostic finding in confirming a mandible fracture. However, this mobility can vary with the location of the fracture. Fractures can occur in the anterior mandible (symphysial and parasymphysial), along the body of the mandible, at the angle of the mandible, or in the ramus or condylar regions (Figure 8–8). Most fractures of the symphysis, the mandible body, and the mandible angle are open fractures that will reveal mobility upon palpation. However, condyle fractures are extremely common; they typically are not open to the oral cavity and may only present as malocclusion with some pain.

Plain X-ray films are extremely helpful in determining both the presence and type of a mandible fracture. To help delineate the extent of the fractures, a mandible series usually consists of several different views: (1) a Towne's view to examine the condyles, (2) a submental-vertex view, (3) a posteroanterior view, and (4) both left and right lateral oblique views. Often, the fracture is bilateral; therefore, the presence of a right-body fracture should alert the physician to search carefully for a fracture on the opposite side. Panorex-view plain film X-rays help to delineate the condyle and angle regions and, if available, are excellent studies (Figure 8–9).



▲ **Figure 8–9.** A Panorex plain film X-ray can be helpful in identifying mandible fractures.

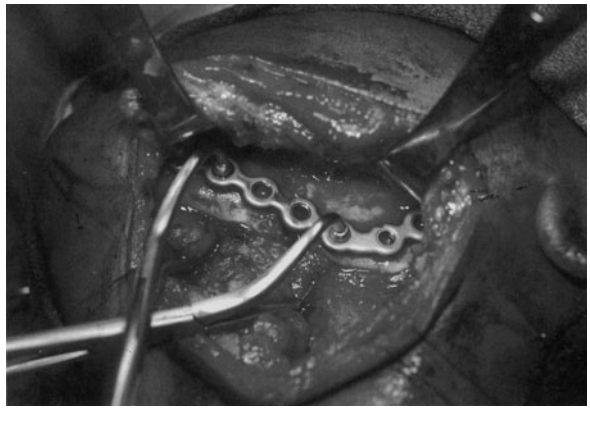
Mandible fractures may be displaced and distracted by the pull of the muscles of mastication. When this occurs, it is termed an **unfavorable fracture**. In contrast, some fractures form in such a way that the muscles of mastication tend to help keep the fracture well aligned; this type of fracture is termed a **favorable fracture**. Fractures in adolescents are often in excellent alignment because the bone is more flexible. These fractures are referred to as **greenstick fractures** and may require less immobilization time in order to heal.

A number of approaches allow for the optimal healing of a mandible fracture; however, the first step in fracture repair is the assessment of dental occlusion. The major principle in treating a mandible fracture is to place the patient into intermaxillary fixation; this positioning approximates the premorbid occlusion. In practice, this often means that the surgeon will try to reduce the fracture to produce a Class I occlusion. Placing a patient into intermaxillary fixation requires an assessment of the existing dentition and an inspection of the way in which the teeth interdigitate. Often, wear facets on the teeth can help guide the restoration of a good functional occlusion. The AO/ASIF (Arbeitsgemeinschaft Für Osteosynthese-fragen, the Association for the Study of Internal Fixation), a study group that crosses a number of specialty lines, developed and continues to refine fixation techniques. They have also established guidelines for closed and open rigid fixation.

Closed splinting approaches rely either on arch bars and intermaxillary fixation or on skeletal fixation with titanium screws. Immobilization for a period of 4–6 weeks is necessary to allow secondary bone healing. For condyle fractures, a lesser period of immobilization is usually preferred to avoid post-fracture joint ankylosis. IMF or intermaxillary fixation is accomplished when patients have their jaws wired into centric occlusion without the ability to open their mouths for an extended period of time. Patients must be on a liquid diet during the time period; many lose weight. If a patient becomes nauseated and vomits while his or her jaws are wired shut, there is a risk of aspiration with subsequent pneumonia; in the worst case, airway compromise is possible. Although this technique is the least surgically invasive approach, the disadvantages are that it (1) requires a great deal of patient cooperation, (2) requires close and intensive patient follow-up, and (3) can lead to functional temporomandibular joint problems owing to a prolonged lack of use. In patients with substance abuse issues, the lack of postoperative cooperation can lead to malunion, nonunion, and osteomyelitis, all with devastating effects. The advantages of extended immobilization are that (1) closed intermaxillary fixation minimizes risk to the mandibular and facial nerves; (2) it allows some flexibility in achieving the exact premorbid occlusion, thus minimizing the chance of iatrogenic malocclusion; and (3) it makes wound dehiscence extremely unlikely.

The advantage of **open rigid fixation** techniques is that fractures are stabilized with titanium plates and screws, essentially allowing functional mastication immediately after surgery. These plating systems can also allow primary bone healing due to the compression of the bone fracture segments, in contrast to secondary bone healing, which occurs through callus formation that occurs with other approximation techniques. Open rigid plating techniques also allow immediate postoperative function, which can help to prevent iatrogenic temporomandibular joint fixation caused by prolonged periods of immobilization (Figure 8–10). Nevertheless, plating techniques applied to the mandible are highly technique sensitive; iatrogenic postoperative malocclusion and injury to the mandibular, mental, or facial nerve and the teeth are known complications of the technique. The need for postoperative patient cooperation, however, is minimized with the adequate application of the AO principles.

Surgical approaches to mandible fractures can rely on either transoral or external incisions. Decisions must be made about whether to use compressive or noncompressive



▲ **Figure 8–10.** A reconstruction plate placed via an external incision on an angle fracture.

reconstruction plates, depending on the type and location of the fracture. Lag-screw and miniplate techniques (Champy techniques) can also play a role in the internal fixation of mandible fractures. The repair of these fractures is technique sensitive, however, and requires selective patient application. In addition, bilateral condylar fractures may be approached with minimally invasive endoscopic techniques.

Postoperatively, patients with mandible fractures are usually kept on oral antibiotic coverage and oral rinses with topical antimicrobial solutions such as chlorhexidine. Plate extrusion is fairly infrequent, but local infection with the loosening of screws and plates may need to be addressed with local debridement and placement of a heavier reconstruction plate system. Wound repair failures are more often due to the choice of an inadequate fixation system or a retained or cracked tooth root than to the rejection of the titanium hardware. If necessary, a transcutaneous external fixation system (known as a Joe Hall Morris appliance) may be useful, although the need to resort to this type of external fixation is rare.

Biller JA, Pletcher SD, Goldberg AN, Murr AH. Complications and the time to repair of mandible fractures. *Laryngoscope* 2005;115(5):769 [PMID: 15867637]. (Analyzes the causes of complications as it relates to the timing of repair of mandible fractures, and it relates the incidence to several types of patient factors.)

Kaplan BA, Hoard MA, Park S et al. Immediate mobilization following fixation of mandible fractures: a prospective, randomized study. *Laryngoscope* 2001;111:1520 [PMID: 11572207]. (An excellent prospective study looking at the issues surrounding alternative plating techniques for fractures.)

Murr AH. Mandibular angle fractures and noncompression plating techniques. *Arch Otolaryngol Head Neck Surg* 2005;131(2):166 [PMID: 15723951] [PubMed indexed for MEDLINE]. (Good summary of philosophies of managing various types of mandible fractures using several types of fixation approaches.)

Seemann R, Schicho K, Wutzl A, Koinig G, Poeschl WP, Krennmair G, Ewers R, Klug C. Complication rates in the operative treatment of mandibular angle fractures: a 10-year retrospective. *J Oral Maxillofac Surg* 2010 Mar;68(3):647-650 [PubMed PMID: 20171484]. (Controversy exists with regard to using one or two monocortical miniplates on mandible angle fractures. This study shows no difference in the complication rates.)

Cutaneous Malignant Neoplasms

9

C. Patrick Hybarger, MD, FACS

Cutaneous malignant neoplasms encompass a large spectrum of tumors that may arise from any of the component cells in skin or its underlying structures. This chapter separates pediatric tumors from those that predominantly affect adults; it further separates nonmelanoma skin cancer from melanoma.

PEDIATRIC NEOPLASMS

Many lesions are present at birth or shortly thereafter. Some have the potential for malignant transformation later in life; other lesions may be mistaken for a malignant growth.

BENIGN NEOPLASMS

DERMOID CYSTS

Dermoid cysts may be seen at birth as smooth, cystic tumors that may have both solid and cystic components. The cysts are usually attached to periosteum, are lined with keratinizing epidermis, and may contain hair and fat in addition to keratinous debris. Clinical examination most often shows tumors located in the lateral periocular or nasal areas. Because of tumor fixation to the underlying periosteum, the tumor may feel immobile when palpated. Treatment is simple excision, which may be delayed until later in childhood.

PILOMATRIXOMA

Pilomatrixoma is usually a benign subcutaneous tumor that originates from the hair matrix and may show calcification. Clinical examination usually shows the tumors as stony-hard, slow-growing, deep subcutaneous masses that develop in early childhood. Rarely, invasive malignant variants with metastases have been reported. Treatment is simple excision.

SEBACEOUS NEVI

Sebaceous nevi are noted at birth as linear, raised, and tan- to yellow-colored patches on the scalp, face, or neck. The nevi may be several centimeters in size or much larger. Regression of the nevi is common until puberty, when growth of the nevi accelerates and lesions become multinodular and darker. Benign syringocystadenoma papilliferum, as well as various types of malignant neoplasms including basal cell carcinoma, squamous cell carcinoma, and adnexal tumors, may arise in adulthood. To provide optimum cosmesis and to minimize the risk of these malignant growths, patients should be treated in preadolescence with simple excision of the nevi.

NEUROFIBROMA

Neurofibroma may appear singly or may be multiple in **von Recklinghausen disease** or NF-1 (ie, neurofibromatosis with von Recklinghausen disease) and present as soft, skin-colored nodules composed of nerve cells, mast cells, and oval- to spindle-shaped nuclei in a wavy collagen matrix. The neurofibromatous nodules are usually unencapsulated and may infiltrate fat. Café au lait spots are associated with multiple neurofibromatous lesions and are usually excised for cosmetic or functional reasons. Neurofibrosarcoma may rarely develop in syndromic patients.

INFANTILE MYOFIBROMATOSIS

In infantile myofibromatosis, single or multiple fibrous, firm nodules composed of fibroblasts and smooth muscle cells are present at birth or in early childhood. The nodules are palpable, firm, and either cutaneous or subcutaneous. Lytic lesions of the cranium may occur in as many as one-third of children, and visceral nodules are associated with the multicentric form. Visceral nodules may be confused with a malignant growth; indeed, the visceral form of infantile

myofibromatosis is frequently fatal. Lesions occurring in the superficial, nonvisceral form usually resolve. Lesions compromising function should be treated with biopsy or excision.

CONGENITAL MELANOCYTIC NEVI

Congenital melanocytic nevi may be seen at birth or several months later as either flat or raised brown lesions, with or without hair, and usually with areas of deeper black or blue pigment. The estimated lifetime risk of developing melanocytic lesions is roughly proportional to the size of the nevus and may be as high as 8%; because of the predictable increased risk, early full-thickness surgical excision for large nevi is advocated where technically feasible.

BENIGN (TYPICAL) ACQUIRED NEVI

Benign (typical) acquired nevi begin early in childhood and are usually smaller than 5 mm. They may be flat or raised, have symmetric, smooth, and well-defined borders, and have uniform pigmentation, which may range from flesh colored to brown. Evidence supports a higher lifetime risk of cutaneous melanoma in patients who have more than 50 benign nevi.

Wyatt AJ, Hansen RC. Pediatric skin tumors. *Pediatr Clin North Am* 2000;47:937 [PMID: 10943267]. (Comprehensive review of common childhood cutaneous malignant neoplasms and lesions that mimic malignant growths.)

MALIGNANT NEOPLASMS

In children, malignant skin tumors may develop sporadically or occur in precursor syndromes with associated abnormalities in other organ systems. The most common precursor syndromes for malignant cutaneous tumors in children are nevoid basal cell syndrome and xeroderma pigmentosum.

ATYPICAL NEVI (DYSPLASTIC NEVUS SYNDROME)

Atypical nevi (dysplastic nevus syndrome) may be familial or occur sporadically. These nevi are usually flat, but they may have a raised center; they may be dark or pigmented in a variegated distribution. The nevi increase in number over years and show histologic features, such as melanocytic atypia and hyperplasia.

Patients with atypical nevi have an increased risk for either the familial or the nonfamilial forms of cutaneous melanoma; this risk is related both to a large number of nevi and to a family history of cutaneous melanoma. Individuals without a family history of melanoma have a 184-fold increased risk for the familial form of melanoma, whereas individuals with a family history of melanoma have a 500-fold increased risk of the disease. The estimated risk for the sporadic form of melanoma is related to the number of dysplastic nevi: a 12-fold increase in risk is estimated for individuals who have more than 10 dysplastic nevi.

NEVOID BASAL CELL CARCINOMA SYNDROME

Among patients with nevoid basal cell carcinoma syndrome, inactivation of the "patched" PTC tumor suppressor gene has been found in both the sporadic and the autosomal-dominant familial forms. Multiple areas of nevoid basal cell carcinoma may develop before the patient reaches 20 years of age. Clinically, in addition to having many basal cell nevi, patients may present with frontal bossing, mandibular cysts, palmar pits, calcified falx cerebri, and one or more skeletal abnormalities. Treatment for small, well-defined areas of basal cell carcinoma is simple excision; treatment is Mohs micrographic excision for recurrent or poorly defined lesions, or lesions located in anatomic areas at high risk for malignant disease.

XERODERMA PIGMENTOSUM SYNDROME

Xeroderma pigmentosum syndrome is inherited as an autosomal-recessive trait in which defects are discovered during the repair of sun-induced DNA damage. Seven genes have been implicated in xeroderma pigmentosum, which manifests in a variety of phenotypes, depending on the specific patterns of mutation. Basal cell carcinoma, squamous cell carcinoma, and cutaneous melanoma may develop in large numbers (preceded by xeroderma pigmentosum) at an early age and in a general anatomic distribution similar to sporadic cases in adults. Clinically, children affected by xeroderma pigmentosum (1) have an onset of extensive freckling early in childhood, (2) are extremely photosensitive, and (3) have an estimated 2000-fold increase in basal cell carcinoma, squamous cell carcinoma, and cutaneous melanoma. These conditions in children occur most commonly on the face, head, and neck; squamous cell carcinoma occurs with notable frequency at the tongue tip. Treatment of xeroderma pigmentosum is total avoidance of the sun, a strategy that is necessary for reducing the number of new tumors.

MALIGNANT CUTANEOUS MELANOMA

Malignant cutaneous melanoma is rare in childhood but is more common among children who have a family history of melanoma, large congenital nevus, large or many dysplastic nevi, xeroderma pigmentosum syndrome, or a history of immunosuppression. In addition, convincing evidence indicates that the incidence of cutaneous melanoma is higher among children who have more than 50 benign melanocytic nevi. The essential aspects of clinical diagnosis are generally the same for children as for adults. Areas of pigment change,

pain, or ulceration in large congenital nevi may indicate malignant change.

The overall treatment parallels adult guidelines and is based on the tumor thickness, the presence or absence of tumor ulceration, and the nodal status. However, the prognosis for cutaneous melanoma in children may be worse than in adults because a disproportionate number of nodular cutaneous melanoma cases in children are associated with a rapid vertical growth phase of the tumor.

In situ melanoma is excised with 7-mm margins or with Mohs micrographic frozen-section margins to minimize the surgical defect size. No further work-up is necessary.

Stage I primary tumors <2 mm without histologic evidence of ulceration can be excised with 1-cm margins. If ulceration is present, 2-cm margins should be used and a chest X-ray should be performed.

Stage II lesions are excised with 2-cm margins where feasible; for high-risk lesions, consideration should be given to computed tomography (CT) scanning of the neck as well as sentinel lymph node biopsy or neck dissection. Recent studies have shown benefits from using high-dose interferon alfa-2b in high-risk patients.

Stage III primary neoplasms can also be excised with 2-cm margins down to the fascia, with CT scanning performed and regional lymphatics treated surgically. The postoperative treatment should include radiation as well as high-dose interferon.

Stage IV melanoma carries an extremely poor prognosis, but an attempt should be made to control local and regional disease where possible, as well as defining the extent and the location of systemic disease in order to tailor individual treatment strategies.

The overall survival in childhood melanoma is related to the stage at presentation and generally parallels that of adults: the 5-year survival rate in Stage I disease is about 95%, with the rate dropping to 65% in Stage II and 45% in Stage III disease. There are essentially no survivors in those patients who present with systemic disease.

SUBCUTANEOUS RHABDOMYOSARCOMA

Subcutaneous rhabdomyosarcoma is a poorly differentiated sarcoma; the diagnosis may require immunohistochemical staining. Clinically, the tumor usually presents singly as a firm, reddish or brown, semifixed, noncompressible subcutaneous nodule that becomes enlarged and may deform local structures. These tumors are more common in females and at a mean age of 2–3 years. Currently, surgical excision is recommended where it is technically feasible. Alternatively, radiation and multidrug chemotherapy are recommended.

Jen M, Murphy M, Grant-Kels JM. Childhood melanoma. *Clin Dermatol* 2009 Nov–Dec;27(6):529–536. [PMID: 19880040]. (General review of risk factors, diagnosis and treatment algorithms for pediatric melanomas.)

ADULT NEOPLASMS

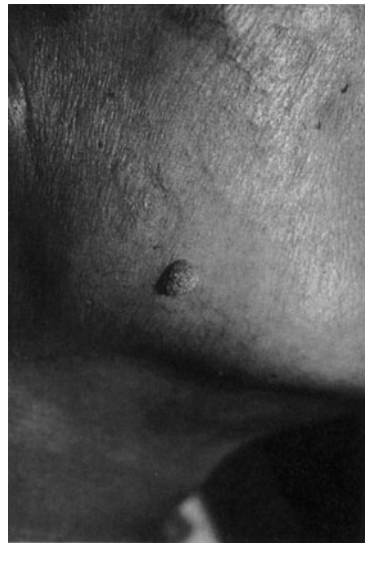
Many benign lesions of childhood (eg, nevi and vascular malformations) persist into adulthood and may undergo change or be difficult to distinguish from tumors more commonly seen in adults.

BENIGN NEOPLASMS

Seborrheic keratoses and chondrodermatitis helicis are the benign tumors most commonly confused with cutaneous malignant tumors. In addition, many varieties of benign skin tumors (eg, dermatofibroma and benign adnexal tumors) may be difficult to distinguish from nonmelanoma skin cancer unless a biopsy is performed.

SEBORRHEIC KERATOSIS

Seborrheic keratosis is a tumor of unknown origin that is unique to adults. Histologically, it may exist in a variety of forms, all of which show hyperkeratosis, papillomatosis, and acanthosis. When the tumor is chronically irritated, whorls of squamous cells may be present with areas of keratin horn pearls and must be distinguished histologically from squamous cell carcinoma. Clinically, the lesions may be flat, raised, smooth, or verrucous and frequently appear to be "pasted" on the skin (Figure 9–1). Their color may vary from tan to black, and lesions containing pigment may mimic cutaneous melanoma. The lesions have no malignant potential. Treatment may be indicated for cosmetic reasons, and the lesions can be frozen with liquid nitrogen or removed by shave biopsy.



▲ **Figure 9–1.** A lesion of seborrheic keratosis. (Photo contributed by John Maddox, MD.)

CHONDRODERMATITIS NODULARIS HELICIS

Chondrodermatitis nodularis helicis typically manifests as an ulcer filled with necrotic dermal debris as well as adjacent granulations with degenerative changes in cartilage. Dystrophic calcification also may be present. The lesions may be seen clinically on the auricular helix as nodules that can be quite painful and may be confused with squamous cell carcinoma. Treatment is intralesional steroid therapy or simple excision.

Hajdarbegovic E, van der Leest RJ, Munte K, Thio HB, Neumann HA. Neoplasms of the facial skin. *Clin Plast Surg* 2009 Jul;36(3):319–334. Review. [PMID: 19505605] [PubMed – indexed for MEDLINE]. (Excellent overall review of spectrum of treatment strategies for various facial neoplasms.)

MALIGNANT NEOPLASMS

Cutaneous malignant lesions in adults are commonly classified as either nonmelanoma skin cancer or cutaneous melanoma. Many lesions have distinct clinical features that provide clues to the diagnosis; considerable overlap exists, however, and biopsy is almost always necessary to plan treatment. To some extent, the biopsy technique is dictated by the tentative clinical diagnosis: **shave biopsy** is an adequate treatment for exophytic nodules thought to be nonmelanoma skin cancer, whereas **punch biopsy** is necessary for flat lesions. Excisional biopsy with a 2-mm margin is preferred for pigmented lesions thought to present a high risk for cutaneous melanoma. Deep punch biopsies into subcutaneous fat in the deepest or darkest portions of the lesion also may be performed in selected lesions. Although no evidence exists showing an adverse effect of biopsy, shave biopsy in cutaneous melanoma is to be discouraged when melanoma is suspected. Moreover, wide, local excision may produce scarring that interferes with lymphatic drainage when sentinel node biopsy is later performed. An adequate amount of tissue must be obtained for processing with special stains in the event that an exact histologic diagnosis is difficult, as is frequently the case with rare or poorly differentiated nonmelanoma skin cancer. Photographs of the lesion or the biopsy defect may be valuable for identifying the exact location of the original lesion when definitive surgery is done at a later date.

NONMELANOMA SKIN CANCER

General Considerations

Nonmelanoma skin cancer may be divided into common and rare categories. Basal cell carcinoma, the most common skin cancer, constitutes about 75% of nonmelanoma skin cancer cases; squamous cell carcinoma accounts for about 20% of cases. The remaining 5% of rare nonmelanoma skin cancer cases includes fibrohistiocytic and adnexal cancers. Basal cell carcinoma, squamous cell carcinoma, and some rare types of nonmelanoma skin cancers occur more frequently in sun-exposed areas and in light-skinned individuals with light eye and hair color; they are associated with unrepaired DNA mutations induced by UV-A and UV-B radiation. The incidence of both basal cell carcinoma and squamous cell carcinoma has steadily increased during the past several decades, and nonmelanoma skin cancer is now a clinically significant health problem and a source of morbidity. Both conditions are more common in patients exposed to ionizing radiation. Basal cell carcinoma and squamous cell carcinoma also occur more frequently in patients with HIV; patients with lymphoproliferative disorders, particularly chronic lymphocytic leukemia; and patients receiving long-term immunosuppressive drug therapy after organ transplantation.

Differential Diagnosis

Rare types of nonmelanoma skin cancers include fibrohistiocytic tumors, adnexal cancers, and rare cutaneous sarcoma. Special histochemical stains are frequently necessary for distinguishing varieties of nonmelanoma skin cancer, especially adnexal tumors.

Treatment

Treatment of nonmelanoma skin cancer is determined by many factors, including the exact histologic subtype, the tumor size, the growth characteristics, and the anatomic location. Treatment is also determined by the previous treatment received, current medical problems, and patient expectations. Treatment options for nonmelanoma skin cancer can be categorized as nonsurgical and surgical.

A. Nonsurgical Measures

Nonsurgical strategies include topical or injection chemotherapy (eg, with 5-fluorouracil [5-FU], a 5% preparation of imiquimod, or interferon), cryotherapy using liquid nitrogen, photodynamic therapy (PDT), and radiation therapy.

1. Topical drug therapy—Topical 5% imiquimod is now widely used by dermatologists as primary treatment for actinic keratoses, superficial basal cell carcinoma, and squamous cell carcinoma in situ (Bowen disease). It may also be used for selected thin nodular basal cell carcinomas, but is not indicated for infiltrating or sclerosing basal cell carcinoma.

2. Cryotherapy—Cryotherapy is usually done by dermatologists or by primary care physicians. The results of this procedure are related to the skill and experience of the treating physician. The technique is especially useful for treating actinic keratoses, small nodular or superficial lesions of basal cell carcinoma, and squamous cell carcinoma in situ. Treatment is relatively inexpensive and fast but can be painful and leave dense, hypopigmented scars that may conceal deep, multifocal, persistent tumors.

3. Photodynamic therapy—PDT with 5 aminolevulinic acid or methyl aminolevulinate activated by unique light source is used to treat actinic keratoses, Bowen disease, and basal cell carcinomas (superficial and nodular types). PDT can be highly effective and cosmesis is typically superior to existing standard therapies.

4. Radiation therapy—Radiation therapy is used primarily in patients older than 60 years or who are not suitable candidates for surgery. Radiation therapy is also used postoperatively for aggressive tumors or where perineural spread is noted. Because this therapy is expensive and requires frequent visits over several weeks, it is often not an option for elderly patients with a limited support system. The control rates for basal cell and squamous cell carcinoma are generally reported to be greater than 90%, and the incidence of post-therapy recurrence increases with increasing tumor size. Recent use of the electron beam and more sophisticated techniques used to model treatment fields has improved cure rates and reduced the number of complications. Long-term cosmetic results may be poor, and the complications of tissue necrosis, chondritis, and osteoradionecrosis may occur. Because of the risk of a radiation-induced malignant growth that may occur later, radiation is generally not recommended as the primary treatment modality for patients younger than 50 years of age.

B. Surgical Measures

Surgical techniques for the treatment of nonmelanoma skin cancer include curettage and desiccation, simple or wide local excision, and Mohs micrographic surgery.

1. Curettage and desiccation—Dermatologists most often perform curettage and desiccation for small, well-defined, previously untreated areas of nodular basal cell carcinoma; this procedure is also used for some squamous cell carcinomas. The advantages of this technique are its low cost and rapidity of treatment. Its 5-year recurrence rate ranges from 10% to 20%. The disadvantages of the technique are poor cosmetic results, with hypertrophic scarring as well as multifocal tumor recurrence in the scars.

2. Simple excision—Simple excision with 5-mm margins is the appropriate treatment for most well-defined, primary nodular basal cell carcinomas; it is also recommended for low-risk squamous cell carcinoma in anatomic locations where adequate excision with primary closure can be achieved with a good cosmetic result. Five-year recurrence rates of about 10% can be expected. Simple excision is not indicated for tumors that recur after radiation or surgical treatment or for high-risk tumors (eg, sclerosing basal cell carcinoma or poorly differentiated squamous cell carcinoma). It is also not indicated for rare nonmelanoma skin cancer (eg, fibrohistiocytic or adnexal cancer).

3. Wide local excision—Wide local excision generally connotes margins of 2–5 cm and is indicated primarily for (1) well-differentiated squamous cell carcinoma; (2) well-defined, large, nodular-ulcerative basal cell carcinoma; and (3) sarcomas, such as angiosarcoma and malignant fibrous histiocytoma.

4. Mohs micrographic surgery—Mohs micrographic surgery is a technique in which precise surgical margins are obtained by using inverted horizontal frozen sections in conjunction with tumor mapping. The bulk of the tumor is either excised or curetted, and the surrounding perimeter is excised around and deep to the tumor defect. The resulting disk of tissue is then separated into individual quadrants and is inked for orientation, producing a tumor map that is color-coded to represent the inked edges. Histotechnicians specially trained in the technique mount the sections, which are inverted and frozen at –30°C to –50°C. Thin frozen sections are obtained, showing the base in continuity with the epidermis. The slides are stained and are examined microscopically, and tumor locations are graphically noted on the map. Additional margins are then created in the same manner, but only in areas positive for a tumor. This process is repeated until all margins are negative for a neoplasm. The process may be enhanced using rapid selective stains. Some centers perform formalin-fixed horizontal sections (1) on final margins that are shown as negative by frozen section, (2) where the tumor histology is subtle, and (3) where tumor recurrence would be catastrophic. These centers convert selected tissue blocks obtained as frozen-section margins to rush paraffin–formalin fixed slides using the same inverted tissue sectioning techniques and tumor mapping to further ensure true negative final margins on difficult cases.

An advantage of Mohs micrographic surgery is its potential to achieve the highest reported control rates for nonmelanoma skin cancer while maximally conserving normal adjacent tissue. The precise surgical margin control used in Mohs micrographic surgery has largely replaced wide local excision for most nonmelanoma skin cancer; the use of an arbitrary margin size with wide local excision does not benefit the outcome for most skin cancers. The overall cure rates using Mohs micrographic surgery are 99% for primary basal cell carcinoma, 96% for recurrent basal cell carcinoma, and 98% for primary squamous cell carcinoma. Mohs micrographic surgery is the treatment of choice for sclerosing or recurrent basal cell carcinoma, large or poorly differentiated squamous cell carcinoma, and most cases of fibrohistiocytic and adnexal cancer. The disadvantages of this technique are its high cost, lack of easy availability, and long procedure time.

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(Literature review and up to date recommendations on use of topical photodynamic therapy for selected NMSC.)
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BASAL CELL CARCINOMA

Basal cell carcinoma is the most common cancer seen in adults. Historically, basal cell carcinoma has been considered most common in persons older than 60 years, but the increased incidence in younger patients has been noted and may be related to a decrease in the atmospheric ozone as well as to the use of tanning salons. Basal cell carcinoma occurs predominantly on hair-bearing skin, and most tumors arise on the face, head, and neck. No precursor lesions are known to exist. In addition to UV radiation, an increased incidence of basal cell carcinoma has been noted in patients exposed to arsenic and insecticides, and at previous vaccination sites and burn scars. Multiple sites of basal cell carcinoma may develop at an early age in patients with basal cell nevus syndrome, xeroderma pigmentosum, Rombo and Bazex syndromes, and sebaceous nevus.

If untreated or recurrent, basal cell carcinoma may produce clinically significant local destruction and cosmetic and functional morbidity. Metastatic behavior, though rare (its occurrence rate is <0.025%), most frequently occurs in patients with cancer that is neglected for many years, who have large or recurrent tumors, who are immunosuppressed, or whose tumors have been previously irradiated. Metastases usually affect bone or lung. Locally advanced, unresectable or metastatic basal cell carcinomas have recently been found to respond to a novel new small molecule (GDC 0449)which inhibits sustained signaling in the sonic hedgehog pathway, essential to the growth of basal cell carcinomas.

Basal cell carcinoma arises from keratinocytes of the epidermis and from adnexal structures and may extend as superficial nests, cords, or filamentous strands surrounded by basement membrane and stroma. These tumors usually grow slowly, spread by direct local extension, and carry the stromal component with them. Some tumors are highly neurotropic and are spread via superficial nerves, a phenomenon that can result in local "skip" areas with false-negative margins. Particularly dangerous anatomic areas are "embryonal fusion planes," such as those found in the nasofacial sulcus, the medial canthus, and pre- and postauricular areas: in these areas, a neoplasm can proliferate deeply before becoming clinically apparent.

Minimizing exposure to the midday sun is the most important and effective measure to reduce the lifetime risk of developing basal cell carcinoma. This practice may include the use of opaque clothing and hats (microfiber nylon fabrics in particular), as well as eyewear rated to block UV-A and UV-B radiation. Although the efficacy of sunscreens in preventing sunburn is documented, recent large studies seem to suggest that sunscreen use is associated with a reduction in new cases of squamous cell carcinoma, but not of basal cell carcinoma. No benefit has been shown with the use of oral beta-carotene or topical or systemic retinoids. Treatment for small, well-defined basal cell carcinoma is simple excision; for lesions that are recurrent, poorly defined, or located in high-risk anatomic areas, treatment is Mohs micrographic excision.

Basal cell carcinoma is most conveniently divided into four basic categories based on the clinical appearance, the tumor behavior, and the histologic differences between subtypes:

1. Superficial basal cell carcinoma
2. Nodular, ulcerative basal cell carcinoma
3. Sclerosing or morpheaform basal cell carcinoma
4. Basosquamous (keratotic or metatypical) basal cell carcinoma

These categories overlap considerably, and some tumors have features of more than one subtype.

1. Superficial Basal Cell Carcinoma

Histologically, in superficial, multicentric basal cell carcinoma, basaloid cells proliferate downward at the dermal epidermal junction. This feature also may be found in clinically normal adjacent skin. Clinically, this condition frequently

presents as scaling, erythematous plaques that may be pruritic, bleed, and appear almost psoriatic or eczematoid. These plaques may be difficult to distinguish from Bowen disease clinically, and borders may be well defined or indistinct.

Previous treatment with cryotherapy, topical agents, curettage and desiccation, and other methods may render this field change multifocal and discontinuous, leading to high rates of recurrence with surgical removal. Superficial basal cell carcinoma is very slow growing and is not aggressive, but it can affect large areas of skin. Because of this characteristic, selected cases can initially be treated with a topical agent such as 5% fluorouracil or 5% imiquimod. Although most of these lesions can be cured with these regimens, many patients do not tolerate the pain and desquamation associated with topical treatment. Careful follow-up and rebiopsy are indicated if a complete clinical response is not obtained. Although effective, cryotherapy may erratically destroy lesions and produce dense scars with a buried tumor. Photodynamic therapy has been shown effective; the largest series were reported in Europe. Curettage and desiccation, radiation, or Mohs micrographic surgery is used when topical regimens fail or in areas where conservative regimens are not tolerated (eg, the eyelids or the lips).

2. Nodular, Ulcerative Basal Cell Carcinoma

Histologically, tumors of nodular, ulcerative basal cell carcinoma show solid masses of malignant basal cells with scant cytoplasm and peripheral palisading of nuclei, proliferating with an associated connective tissue stroma. A variety of histologic subtypes exist within this category, and long-neglected neoplasms may have micronodular filaments or sclerosing features at the periphery of the lesion.

Clinically, the tumors are typically discrete, painless, well-defined nodules that may be ulcerated centrally with a waxy, telangiectatic peripheral border. Small, nodular neoplasms of basal cell carcinoma must be distinguished from acneiform eruptions and common benign skin lesions such as nevi or granulomatous skin lesions. Nodular, ulcerative lesions of basal cell carcinoma carry a low risk unless they persist for long durations or are located in high-risk anatomic areas. If untreated or recurrent, these lesions may become quite large and clinically more aggressive and may pose considerable challenges both for adequate tumor removal and reconstruction.

Treatment for the lesions is dictated by patient age and expectations for cosmesis, associated medical problems, the anatomic location and size of the neoplasm, and whether the lesion is primary or has recurred after previous treatment. Curettage and desiccation may be appropriate for small nodular basal cell carcinoma, but recurrence is common and scars are typically hypopigmented and conspicuous. Simple excision with 5-mm margins is the appropriate treatment for lesions smaller than 1 cm located in low-risk anatomic areas (ie, where surgical closure is possible without using a flap or graft). Mohs micrographic surgery is ideal for optimizing the conservation of normal tissue while achieving the highest tumor control rates. It is the technique of choice for neoplasms that recur after prior treatment or where reconstruction with a flap or skin graft is anticipated. Radiation therapy for these tumors is effective, but recurrence rates with this therapy are higher than for Mohs micrographic surgery. Cosmetic results may be poor over time, and subsequent radiation-induced tumors may occur.

3. Sclerosing Basal Cell Carcinoma

In sclerosing or morpheaform basal cell carcinoma, the histologic examination may show fine, filamentous tumor strands that extend in all directions; these strands account for high tumor recurrence rates. Clinically, the lesions present as white-to-yellow, telangiectatic, indurated plaques with poorly defined margins. Dense stroma associated with the neoplasm gives it a sclerotic appearance, and over time, it may ulcerate. Although many patients have the lesions for long periods, some tumors have a more aggressive growth pattern and widely infiltrate seemingly normal adjacent tissue, resulting in large surgical defects and considerable morbidity.

In general, basal cell carcinoma with sclerosing features should be treated with Mohs micrographic surgery. Radiation may be appropriate for patients who are not suitable candidates for surgery; however, recurrence rates are higher with this mode of treatment, and it may yield cosmetically poor results. To minimize the risk of tumor recurrence, which may be catastrophic in locations such as the medial canthus, Mohs micrographic surgery followed by radiation is the necessary treatment for neoplasms showing perineural spread.

4. Basosquamous Basal Cell Carcinoma

Keratotic (basosquamous or metatypical) basal cell carcinoma represents a true basal cell carcinoma and is characterized by squamous differentiation and keratinization. Clinically, these tumors can be aggressive locally and may occasionally metastasize, particularly if large or recurrent. The tumors may appear similar to nodular basal cell carcinoma and may be confused clinically with squamous cell carcinoma, fibrohistiocytic lesions, or adnexal tumors. Treatment for this form of basal cell carcinoma is Mohs micrographic surgery or wide local excision. Radiation therapy is effective but yields recurrence rates higher than for Mohs micrographic surgery.

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SQUAMOUS CELL CARCINOMA

Lesions of squamous cell carcinoma, the second most common skin cancer, have an epidemiology and an anatomic distribution similar to basal cell carcinoma. Patients with squamous cell carcinoma may present with keratotic nodules, granular plaques, or ulcerating nodules that may or may not be painful. Common predisposing conditions for squamous cell carcinoma of the face, head, and neck are previous radiation burn scars or long-standing sinus tracts, a history of psoralen and UV-A phototherapy, and immunosuppression. The risk of local recurrence, metastasis, or both is increased by multiple factors and by each of the following:

The size and depth of the invasion: tumors with a depth of ≥6 mm or a diameter of ≥2 cm.

The location on the lip (especially near the commissure), ear, and nasal septum.

The degree of differentiation; the risk of local recurrence and metastatic disease is generally inversely proportional to the degree of differentiation.

The rapidity of growth (except for patients with keratoacanthomatous tumors), where a history of rapid growth between the diagnoses and the time of treatment is a poor prognostic sign.

Recurrence after prior treatments; a subsequent recurrence is associated with a high risk of both local recurrence and metastatic disease.

Perineural spread, which carries a particularly poor prognosis and may be suggested by intense pruritus, pain, hypesthesia, or (rarely) paralysis.

Immunosuppression in patients with squamous cell carcinoma, either as a result of chronic disease (eg, chronic lymphocytic leukemia) or drugs (eg, cyclosporine, azathioprine); this immunosuppression is associated with an increasing number of lesions over the time of exposure, and many lesions may develop synchronously with a high cumulative risk of metastases and a very poor prognosis. Most of these patients can be shown to have human papillomavirus.

Squamous cell carcinoma may be preceded by precursor lesions such as actinic keratosis (most commonly) or Bowen disease (ie, squamous cell carcinoma in situ). A histologic examination of actinic keratoses shows superficial neoplasms consisting of defined epidermal proliferation of abnormal keratinocytes. In an estimated 1% per year of affected patients, actinic keratoses may evolve into squamous cell carcinoma. Clinically, the lesions are small, scaly, white, red, or occasionally pigmented keratotic crusts with a friable base. Treatment consists of cryotherapy with liquid nitrogen, curettage and desiccation, topical 5-FU, or simple excision.

1. Squamous Cell Carcinoma in Situ (Bowen Disease)

Bowen disease (ie, intraepidermal squamous cell carcinoma or squamous cell carcinoma in situ) appears histologically as squamous cells with acanthosis and large, hyperchromatic nuclei that proliferate radially along the epidermis. Individual cell keratinization may be present, and the basement membrane is preserved. Bowen disease generally occurs on sun-exposed areas of the face; its occurrence on areas not exposed to sunlight has been linked to arsenic exposure. If left untreated, a small percentage (perhaps 5%) of lesions will develop into invasive squamous cell carcinoma.

Lesions typically present as erythematous superficial plaques with irregular, variably defined borders and may be confused with superficial basal cell carcinoma, psoriasis, or eczema. Induration may indicate invasive squamous cell carcinoma.

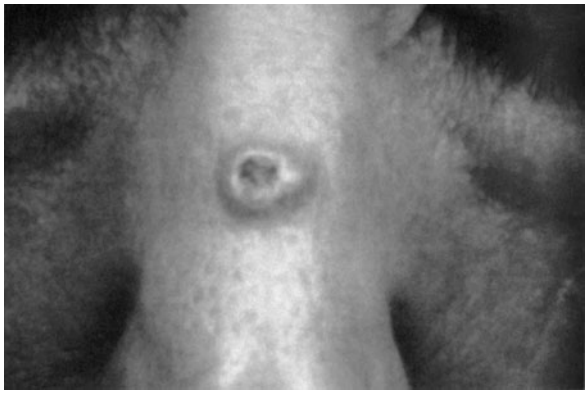
If biopsy results fail to show invasion and if the lesion occurs in a suitable area, topical treatment may be administered initially. A 0.025% preparation of tretinoin gel in conjunction with 5% 5-FU is used for 4–6 weeks. Daily application of imiquimod 5% cream for 16 weeks has recently been shown to be a safe and very effective regimen in treating Bowen disease.

Excellent short-term results also have been reported with photodynamic therapy and laser. Mohs micrographic surgery is recommended for treating lesions located in anatomic areas such as the eyelids, lips, and other areas where topical agents are not suitable, or when conservative treatment fails.

Patel GK, Goodwin R, Chawla M, Laidler P, Price PE, Finlay AY, Motley RJ. Imiquimod 5% cream monotherapy for cutaneous squamous cell carcinoma in situ (Bowen's disease): a randomized, double-blind, placebo-controlled trial. *J Am Acad Dermatol* 2006;54(6):1025 [PMID: 16713457]. (Controlled trial demonstrating that patients with cutaneous squamous cell carcinoma in situ receiving topical and allowed 5% cream as monotherapy experienced a high degree of clinical benefit compared with placebo.)

2. Keratoacanthoma

Squamous cell carcinoma can be usefully classified as well-differentiated or poorly differentiated tumors that vary both in terms of their histologic features and their clinical behavior. In addition to tumors in these categories, however, keratoacanthoma should be mentioned because of its clinical and histologic similarities to squamous cell carcinoma; some pathologists consider it a low-grade squamous cell carcinoma.



▲ **Figure 9–2.** A keratoacanthoma lesion shows the central crater filled with a keratin plug. (Photo contributed by Jeffrey Schneider, MD.)

A biopsy of keratoacanthomatous neoplasms shows histologic features that may be indistinguishable from those of squamous cell carcinoma, except for the absence of epithelial membrane antigen. To exclude a diagnosis of invasive squamous cell carcinoma, the biopsy specimen must include the tumor junction and adjacent normal tissue. A cross section of the tumor shows a central keratinous core, an epidermal lip, and glassy keratinocytes with numerous mitoses in the proliferative phase and a few mitoses in the resolution phase.

Keratoacanthoma is generally considered a benign lesion but is characterized by explosive growth in the proliferative phase, which lasts 2–4 weeks and is associated with a central crater filled with a keratin plug (Figure 9–2). The tumors may grow to a large size and then mature over weeks to months; they usually resolve if left untreated. Special tests to distinguish keratoacanthoma from invasive squamous cell carcinoma include cytokeratin staining and epithelial membrane antigen. Tumors that are believed to be clinically obvious keratoacanthoma or that are confirmed by biopsy frequently respond to intralesional administration of either 5-FU or methotrexate. Larger lesions or those not responding to intralesional agents should be excised, and radiation therapy can be used in patients who are not suitable candidates for surgery.

3. Well-Differentiated Squamous Cell Carcinoma

In well-differentiated squamous cell carcinoma, microscopic examination shows large, malignant squamous cells that proliferate downward from the epidermis as nests or cords. Intercellular bridges are seen and keratin pearls are seen frequently; peritumoral inflammation also may be present. These tumors stain positive for cytokeratins. Inactivation of the tumor suppressor gene *TP 53* appears to be involved in both actinic keratoses and squamous cell carcinoma. Primary lesions with well-defined borders are best treated by simple excision and primary closure. Recurrent tumors or those occurring in immunosuppressed patients should be removed using frozen-section margin control, preferably with Mohs micrographic surgery. Radiation therapy also is effective.

4. Poorly Differentiated Squamous Cell Carcinoma

In squamous cell carcinoma, the extent of cellular differentiation is directly proportional to amount of keratin and intercellular bridges: The less the differentiation, the fewer keratin and intercellular bridges are present. In anaplastic tumors, no keratin or intercellular bridges are present, and individual cells are markedly atypical with increased mitoses. Immunohistochemical stains or electron microscopy may be necessary to distinguish poorly differentiated squamous cell carcinoma from melanoma, atypical fibroxanthoma, or other poorly differentiated neoplasms. Dedifferentiated squamous cell carcinoma can appear as granular plaques, rapidly growing nodules, or areas of ulceration. Distant metastases occur but are usually preceded by nodal disease; occasionally, tumors originating in the lung present as skin metastases. Patients should be examined carefully for regional adenopathy and have an X-ray of the chest. Other tests, including imaging studies to detect occult nodes, may be indicated, especially in immunocompromised patients.

In poorly differentiated squamous cell carcinoma, the treatment of primary tumors is surgical; ideally, frozen-section margin control should be used (as in Mohs micrographic surgery) or at least 1-cm margins. Defects should be closed without a flap, if possible. Tumors that recur after surgery or after radiation should be excised with Mohs micrographic surgery. Postoperative radiation therapy to the tumor bed and regional lymph nodes is indicated for tumors larger than 2 cm, for perineural invasion, or for tumors occurring in immunocompromised patients. Neck dissection is indicated for adenopathy detected clinically or by imaging; sentinel node biopsy has been shown feasible but remains investigational.

RARE NONMELANOMA SKIN CANCER

The most frequently encountered of the many varieties of rare nonmelanoma skin cancer include three types of fibrohistiocytic tumors: (1) atypical fibroxanthoma, (2) dermatofibrosarcoma protuberans, and (3) malignant fibrous histiocytoma. Rare nonmelanoma skin cancer also includes adnexal cancers.

1. Atypical Fibroxanthoma

Atypical fibroxanthoma is a relatively common tumor thought to represent a superficial form of a low-grade malignant lesion. Histologic examination of the tumor shows

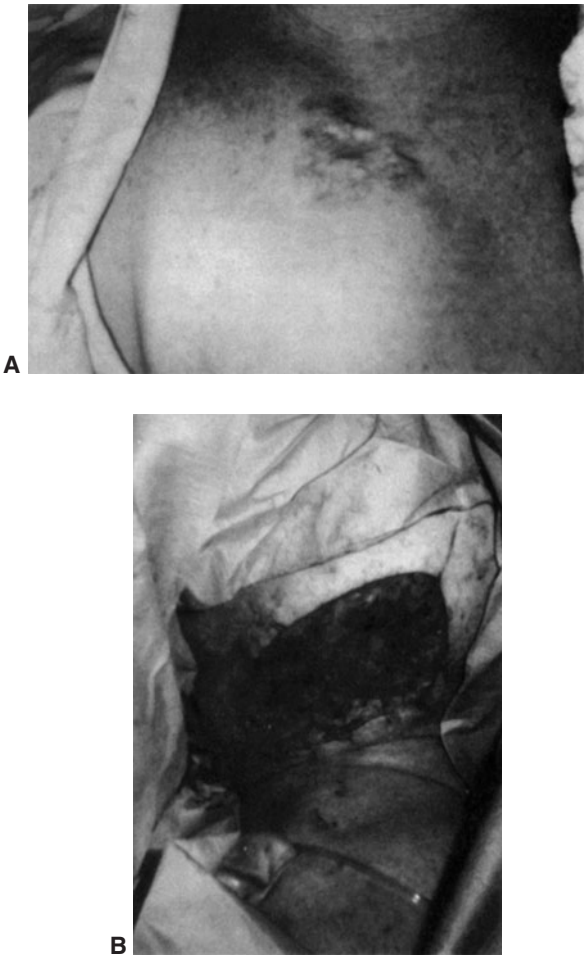
densely cellular spindle cell neoplasms in the dermoepidermal junction; pleomorphic, histiocytic cells; giant cells with bizarre nuclei; and fibroblastic spindle cells. By definition, these tumors do not extend into the underlying muscle or fascia. From a histologic perspective, the differential diagnoses include spindle cell carcinoma, malignant fibrous histiocytoma, and melanoma. Special stains are frequently needed to confirm the diagnosis.

Atypical fibroxanthoma generally appears as flat plaques with pigment ranging from yellow to reddish brown in areas of sun-damaged skin; the tumor may grow rapidly. Tumors classified as atypical fibroxanthoma can recur locally if excision is inadequate and rarely metastasize. Lesions proven to invade muscle or fascia should be considered malignant fibrous histiocytoma. Treatment for atypical fibroxanthoma is excision, ideally using Mohs micrographic surgery to minimize local recurrence.

2. Dermatofibrosarcoma Protuberans

Dermatofibrosarcoma protuberans is a slow-growing, fibrous tumor that originates in the dermis, is locally invasive, and occasionally metastasizes. Histologic examination shows packed spindle cells with diffuse infiltration into the dermis and subcutaneous fat as well as (rarely) into deeper structures. Expression of CD34 antigen is positive, and expression of s100 is negative. In younger patients, dermatofibrosarcoma protuberans usually presents as a raised plaque that may appear similar to a keloid in some patients (Figure 9–3). An initial staging evaluation, including a chest X-ray and possibly a CT scan, is indicated because these tumors occasionally metastasize.

Although wide local excision has long been advocated as a treatment for dermatofibrosarcoma protuberans, local recurrence of the disease still occurs, even when 3-cm margins are used. Increasing evidence in the medical literature shows that excision using Mohs micrographic surgery in conjunction with rush paraffin sections provides the highest local control rates; in this technique, the wound is closed only after both frozen and paraffin sections show no tumor. Prophylactic nodal dissection is not indicated for the treatment of dermatofibrosarcoma protuberans because the tumors do not spread to the local nodes. Radiation therapy should be added postoperatively where local recurrence would be catastrophic, but this therapy generally is not used as the primary treatment modality. Patients should be observed at frequent intervals for early detection of local tumor recurrence. Neoadjuvant imatinib therapy has recently been shown to be successful in improving outcomes when used for locally advanced or recurrent dermatofibrosarcoma protuberans.



▲ **Figure 9–3. (A)** A preoperative lesion of dermatofibrosarcoma protuberans and **(B)** a postoperative defect.

3. Malignant Fibrous Histiocytoma

Malignant fibrous histiocytoma is predominately a tumor of adults and rarely occurs on the head and neck. The term defines a spectrum of cellular tumors that may resemble atypical fibroxanthoma or dermatofibrosarcoma protuberans (when well differentiated or superficial) or may appear as a poorly differentiated, deeply invasive fibrosarcoma. The neoplasm is considered to be of fibroblastic origin and seems to be more common in previously irradiated areas. Several general subtypes exist, including storiform pleomorphic, myxoid, giant cell, inflammatory, and angiomatoid forms; a single tumor may contain separate areas with features of each subtype.

Clinically, the tumors may appear as elevated plaques or nodules, and surgical borders may be poorly defined because of the diffuse infiltrative nature of the tumor. Rapidly growing tumors may present with hemorrhage and necrosis. The prognosis for lesions of the head and neck is generally related to the depth of the invasion, the tumor grade, and the tumor size at diagnosis. Tumors invading muscle or fascia have

high rates of both local recurrence and metastases, whereas superficial tumors confined to the subcutis have a more favorable prognosis. The differential diagnosis includes other fibrohistiocytic tumors and sarcomas, Hodgkin disease, and pleomorphic carcinoma. Distinguishing between these conditions and malignant fibrous histiocytoma may require immunohistochemical staining.

Patients should undergo initial staging, including CT scans of the chest, head, and neck, as well as an evaluation by an oncologist. Wide excision with 3- to 5-cm margins including fascia is generally recommended. Mohs micrographic surgery with both frozen and rush paraffin sections may be of value for head and neck tumors to achieve comparable (or higher) local control rates and possibly smaller defect size; comparisons of long-term outcomes are lacking because of the rarity of the neoplasm. Nodal metastases are unusual, so neck dissection is not indicated. Postoperative radiation may further reduce the likelihood of local recurrence.

4. Adnexal Tumors

Adnexal tumors—cutaneous malignant growths arising from adnexal structures—are the rarest types of skin cancer, and several types are highly malignant. Only the more common tumors in this group, that is, proliferating trichilemmal cysts, microcystic adnexal carcinoma, Merkel cell carcinoma, and sebaceous carcinoma, are reviewed here.

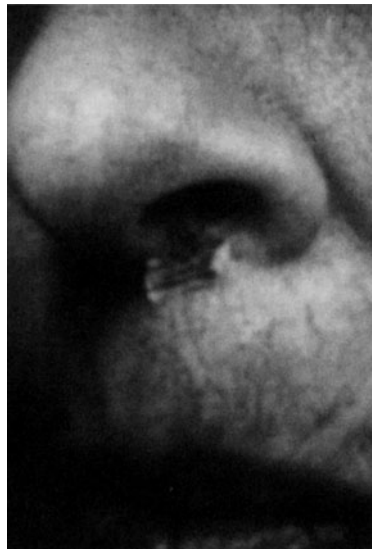
Classification

A. Proliferating Trichilemmal Cysts

Proliferating trichilemmal cysts or tumors are usually composed of proliferating lobules of squamous epithelium with central keratinous debris and are sharply separated from normal surrounding tissue. Malignant variants occur and are usually characterized by sudden rapid growth as well as by an invasion or an erosion of the underlying structures. Regional as well as distant metastases with transformation to invasive squamous cell carcinoma have been reported; indeed, some pathologists consider all proliferating trichilemmal cysts to be low-grade squamous cell carcinoma. The tumors usually occur singly on the scalp in older women as subcutaneous nodules or cysts and are most often confused with a wen or an inclusion cyst. Malignant transformation may be preceded by rapid growth, necrosis, and ulceration. Treatment is simple excision; malignant variants are treated like squamous cell carcinoma.

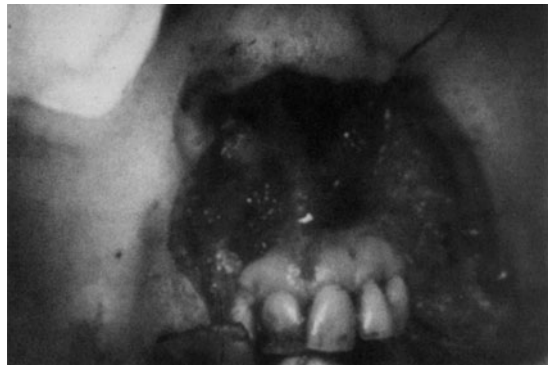
B. Microcystic Adnexal Carcinoma

Microcystic adnexal carcinoma (also termed sclerosing sweat duct carcinoma) has microscopic features consisting of basaloid keratinocytes, horn cysts, and abortive hair follicles in desmoplastic stroma. Perineural invasion occurs frequently; these tumors grow aggressively with extensive infiltration beyond the apparent clinical margins, and rates of local recurrence are high. Nodal spread does not occur, and distant metastases have not been reported. Clinically, microcystic adnexal carcinoma usually presents as an indurated papule on the midfacial region (Figure 9–4) and may be confused with trichoepithelioma or basal cell carcinoma. A deep biopsy may be necessary to make the diagnosis.



▲ **Figure 9–4.** A taped lesion of microcystic adnexal carcinoma.

Treatment is surgical excision, and Mohs micrographic surgery apparently provides optimal local control because of the ability to pursue the unpredictable tumor filaments at the margins (Figure 9–5). The role of radiation therapy for microcystic adnexal carcinoma remains unclear.



▲ **Figure 9–5.** Intraoperative appearance of Mohs defect.

C. Merkel Cell Carcinoma

Merkel cell carcinoma is a rare, highly aggressive skin cancer that probably has a neuroendocrine origin. Histologic examination shows small- to medium-size cells with scant cytoplasm originating in the basal layer. These cells proliferate as cords and contain neuroendocrine granules. Special stains or electron microscopy may be necessary to distinguish Merkel cell carcinoma from small cell lymphoma or metastatic oat cell cancer. Large tumors consisting of small cells with numerous mitoses (10 per high-power field) have the poorest prognosis. Ultraviolet radiation has been implicated as causing Merkel cell carcinoma, which occurs most frequently in patients who received psoralen UV-A treatment. *Merkel cell carcinoma has recently been associated with human polyomavirus (MCPyV) infection.*

Clinically, Merkel cell carcinoma usually presents as a bland, painless nodule on the head and neck of older patients; it is usually pink to almost purple but can appear cystic. Nodal metastases may be found in up to 15% of patients at the initial presentation and subsequently develop in over 50% of cases. Distant metastases occur frequently in patients with nodal disease and can develop rapidly; the overall mortality remains about 50% and most affected patients die within 3 years after the initial diagnosis. Therefore, the initial diagnostic examination should include not only blood tests and CT scans of the chest and neck, but also should include a positron emission tomography (PET) scan, which may cause some tumors to be reclassified into a higher stage because of the early detection of metastatic disease. When staging is reclassified, treatment strategies must be altered accordingly.

Treatment of Merkel cell carcinoma should be planned in conjunction with an oncologist and generally consists of an initial surgical excision followed by radiation to the primary site and nodes. Although excisional margins of 2 cm are generally recommended, the relation between surgical margins and successful outcome is difficult to evaluate. Available studies suggest that, like excision of melanoma, excision of Merkel cell carcinoma using larger surgical margins does not necessarily increase local disease control or the treatment outcome. Mohs micrographic surgery may therefore be a reasonable choice to minimize defect size (especially on the face); studies have shown local recurrence rates comparable with those obtained by using wide local excision. Although Merkel cell tumors are highly radiosensitive, surgery followed by radiation probably achieves locoregional control more successfully than radiation or surgery alone. However, this comparative result has not been reflected in overall survival rates.

Other treatment modalities include sentinel node technology, which has been shown to be feasible and may correctly identify the nodal basin at risk for metastases. Although sentinel node biopsy in necks without clinical signs of disease may aid in staging disease and may limit the frequency of unnecessary neck dissection, the relation between sentinel node biopsy and a successful outcome ultimately is unclear. Finally, chemotherapy is effective for palliating metastatic disease, but the role of adjuvant chemotherapy remains to be defined.

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D. Sebaceous Carcinoma

Sebaceous carcinoma, the fourth most common skin cancer, is more common in patients with Muir–Torre syndrome and in anatomic areas that have been previously irradiated. Histologic examination of tumor nodules shows variably sized lobules of sebaceous cells that contain lipid globules. Sebaceous carcinoma must be distinguished from basal cell carcinoma with sebaceous differentiation. Patients with sebaceous carcinoma present with tumors as nodules on the head and neck; most tumors occur on the eyelids. Symptoms of ocular irritation are common and may be confused with blepharitis or chalazion. Mortality rates increase with tumor size. About 50% of affected patients with tumors larger than 1 cm die; distant metastases occur in viscera and bone, and orbital invasion may be more common in tumors with pagetoid features. Local recurrence and nodal metastases are common. The initial diagnostic examination should include an ophthalmologic examination; magnetic resonance imaging (MRI) of the orbits and neck should be used to rule out occult metastatic disease in tumors larger than about 6 mm.

Treatment for sebaceous carcinoma is surgical excision; Mohs micrographic surgery using frozen sections followed by rush paraffin sections may optimize local control and tissue conservation. The role of radiation therapy as a primary treatment for sebaceous carcinoma is less clear, but improved technology may make this treatment an option when excision is contraindicated or refused.

Alam M, Ratner D. Cutaneous squamous cell carcinoma. *N Engl J Med* 2001;344:975 [PMID: 11274625]. (A review of the incidence, etiology, and treatment of cutaneous squamous cell carcinoma.)

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Ballo MT, Zagars GK, Pollack A. The role of radiation therapy in the management of dermatofibrosarcoma protuberans. *Int J Radiat*

Oncol Biol Phys 1998;40:823 [PMID: 9531366]. (Combined resection and postoperative radiation therapy should be considered for high-risk tumors.)

Chiller K, Passaro D, Schueller M, Singer M, McCalmont T, Grekin RC. Microcystic adnexal carcinoma: forty-eight cases, their treatment, and their outcome. *Arch Dermatol* 2000;136:1355 [PMID: 11074698]. (Average surgical defect size four times the clinical estimate; Mohs micrographic surgery rated superior due to the unpredictability of surgical margins.)

Clark JR, Veness MJ, Gilbert R, O'Brien CJ, Gullane PJ. Merkel cell carcinoma of the head and neck: is adjuvant radiotherapy necessary? *Head Neck* 2007 Mar;29(3):249–257 [PMID: 17163472]. (Retrospective analysis of 110 patients from 3 tertiary care centers in Canada supports combined surgery and radiotherapy to improve both locoregional control and disease free survival.)

Han A, Chen EH, Niedt G, Sherman W, Ratner D. Neoadjuvant imatinib therapy for dermatofibrosarcoma protuberans. *Arch Dermatol* 2009 Jul;145(7):792–796. [PMID: 19620561] [PubMed—indexed for MEDLINE]. Related articles. (Novel approach using neoadjuvant imatinib therapy for locally advanced or recurrent DFSP reduced tumor size at Mohs micrographic surgical excision with excellent long term tumor control.)

Jambusaria-Pahlajani A, Miller CJ, Quon H, Smith N, Klein RQ, Schmults CD. Surgical monotherapy versus surgery plus adjuvant radiotherapy in high-risk cutaneous squamous cell carcinoma: a systematic review of outcomes. *Dermatol Surg* 2009 Apr;35(4):574–585, Review [PMID: 19415791] [PubMed—indexed for MEDLINE].

(Reviews reported outcomes of surgery alone vs. surgery and radiation, and concludes current data are insufficient to identify high risk features in which radiation may be beneficial . The extent of perineural invasion appears to be important prognostic variable.)

Leibovitch I, Huilgol SC, Selva D, Lun K, Richards S, Paver R. Microcystic adnexal carcinoma: treatment with Mohs micrographic surgery. *J Am Acad Dermatol* 2005 Feb;52(2):295–300, Review [PMID: 15692477] [PubMed—indexed for MEDLINE]. (Review of all patients in Australia with MAC treated with MMS between 1993 and 2002 confirms low recurrence rate at 5 years.)

Meguerditchian AN, Wang J, Lema B, Kraybill WG, Zeitouni NC, Kane JM 3rd. Wide excision or Mohs micrographic surgery for the treatment of primary dermatofibrosarcoma protuberans. *Am J Clin Oncol* 2010 June; 33(3):300–303 [PMID: 19858696] [PubMed—as supplied by publisher]. (Multi institutional review comparing outcomes of WLE vs Mohs micrographic margins showed better long term tumor control for Mohs but longer operating times.)

Nyquist GG, Mumm C, Grau R, Crowson AN, Shurman DL, Benedetto P, Allen P, Lovelace K, Smith DW, Frieden I, Hybarger CP, Richard G. Malignant proliferating pilar tumors arising in KID syndrome: a report of two patients. *Am J Med Genet A* 2007 Apr 1;143(7):734–741 [PMID: 17330861]. (Genetic analysis of proliferating pilar tumors in two unrelated patients supports malignant transformation from proliferating pilar cysts.)

Spencer JM, Nossa R, Tse DT, Sequeira M. Sebaceous carcinoma of the eyelid treated with Mohs micrographic surgery. *J Am Acad Dermatol* 2001;44:1004 [PMID: 11369914]. (Mohs micrographic surgery results are superior to historic series of standard excision.)

Tom WD, Hybarger CP, Rasgon BM. Dermatofibrosarcoma protuberans of the head and neck: treatment with Mohs surgery using inverted horizontal paraffin sections. *Laryngoscope* 2003;113:1289 [PMID: 12897547]. (Improved outcome using addition of rush paraffin conversion of all negative frozensections before final reconstruction.)

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CUTANEOUS MELANOMA

General Considerations

Malignant melanoma of the skin is the third most common cutaneous malignant lesion; about 25% of these lesions occur on the head and neck. The incidence of cutaneous melanoma continues to increase exponentially and is currently increasing at a rate of about 5% annually. The overall mortality rate per 100,000 persons continues to increase, but survival rates among patients with lower-staged tumors have increased, and the overall cure rates for melanoma exceed 90%. Both an increased incidence and a decreased mortality may be related to an increased awareness of cutaneous melanoma and its early detection and treatment. Although most cases of the disease are sporadic, some show familial patterns and may be associated with dysplastic nevus syndrome, which carries a 100-fold increased lifetime risk for the development of cutaneous melanoma.

Other precursor lesions associated with an increased risk of cutaneous melanoma include large congenital nevi and the presence of more than 50 benign acquired nevi. A strong correlation with prior intermittent intense sun exposure exists, and active programs for prevention as well as early detection may ultimately help decrease the incidence. The role of sunscreens in preventing melanoma remains unclear. Melanoma of the head and neck can be separated into three general categories: (1) melanoma in situ (ie, lentigo maligna melanoma), (2) superficial spreading melanoma, and (3) nodular melanoma. Primary tumors are also classified using the American Joint Committee on Cancer (AJCC) nomenclature.

A. Melanoma in Situ

Melanoma in situ is characterized by the proliferation of atypical neoplastic melanocytes at the dermoepidermal junction along adnexal structures. A characteristically prolonged radial growth pattern is present and may last decades; approximately 0.10–0.25% of such lesions annually become invasive melanoma. These lesions occur on the cheek, nose,

or temple in elderly patients. Early lesions may be clinically indistinguishable from solar lentigo. Topical imiquimod has been shown to successfully eradicate a significant percentage of in situ lesions and may find increasing utility in older patients who are poor surgical candidates.

B. Superficial Spreading Melanoma

Superficial spreading melanoma, the most common form, may evolve during a period of several years from a preexisting lesion, such as a nevus, in middle-aged individuals. The lesion is characterized histologically by a predominantly radial growth phase with eventual proliferation of malignant cells into the dermis, as well as upward growth that may present as nodularity and ulceration, which denotes the onset of the vertical growth phase.

C. Nodular Melanoma

Nodular melanoma occurs most commonly in children and represents approximately 15% of adulthood melanomas. It is characterized by early invasion and a vertical growth phase. The neoplasms can be black or variegated in color and are occasionally amelanotic. These tumors show no radial growth phase and are, by definition, invasive at the time of presentation.

Lesions suspected to be nodular melanomas should be either biopsied with a deep 3-mm punch or excised with a 2-mm margin. Shave biopsy should not be performed because the precise measurement of the tumor depth will not be possible and valuable staging information will not be accurate. A careful search for ulceration, induration of surrounding tissue, satellite or in-transit lesions, and regional adenopathy should be part of the initial examination. Nodular melanomas can become quite large and present significant surgical challenges, both in terms of achieving local control surgically and in reconstructing the defects after removal.

Diagnosis

The early clinical diagnosis of cutaneous melanoma requires a high index of suspicion based on family history, risk factors, and physical examination, which should include an examination for satellite lesions, the presence of ulceration, and regional nodes. To distinguish benign, pigmented lesions from high-risk lesions, the "**A-B-C-D-E**" approach to physical diagnosis is useful. This approach consists of observing five criteria:

Asymmetric lesions

Borders are irregular

Color may vary with multiple shades from brown to red-black

Diameter >6 mm

Evolving lesions that have shown growth or change

Staging Criteria

The review of prior staging and survival data (Table 9–1 and Figure 9–6) suggests that, in addition to tumor thickness, the presence of melanoma ulceration, intransit metastases or satellite lesions, and number of nodes (identified as positive by clinical or pathologic examination) has strong independent prognostic predictive value. The 2001 AJCC staging system incorporated several changes relevant to head and neck surgery. These changes relate to melanoma thickness and ulceration (but not to the level of invasion) that is to be used in all but T1 categories. This strategy essentially changes the classification of tumors based on their thickness in millimeters in Stages II–IV to integers, with the substage based on the presence or the absence of ulceration. The current system for classifying primary tumors and nodes is shown in Table 9–2.

The number of metastatic lymph nodes and the delineation of clinically occult or microscopic nodes is used in the "N" category of the classification system. Macrometastases are defined as clinically, radiologically, or pathologically detectable nodes or as gross nodal extracapsular extensions. Micrometastases are detected with sentinel lymph node biopsy or elective node dissection.

As a result of these changes, the overall staging has changed (Table 9–3). As a result of the new staging criteria, some patients qualify for upgraded treatment strategies. The more recent 7th edition of AJCC guidelines to be published in early 2010 will also incorporate mitotic rate (defined as greater than one mitosis per square millimeter as an additional prognostic factor).

All patients with Stage I, II, and III disease are staged upward (or *upstaged*) when the primary melanoma is ulcerated.

Satellite metastases around a primary melanoma site and in-transit metastases are merged into a single staging entity grouped into Stage III disease.

A new convention defines clinical and pathologic staging to incorporate the staging information gained from intraoperative lymph node mapping and sentinel node biopsy.

Sites of distant metastases and the presence of an elevated serum lactic dehydrogenase (LDH) level are incorporated into the "M" category.

The role of the initial evaluation after the initial diagnosis is related to the presumed stage of disease. It has been questioned in lesions measuring <1.0 mm because this examination may yield a high rate of false-positive results and lead to unnecessary further studies. Patients who have melanoma **in situ** or **Stage I** disease without ulceration or symptoms need no further examination. Patients who have **Stage I** or **II** melanoma with ulceration or **Stage III** lesions may benefit from the addition of CT scanning of the neck, sentinel lymph node biopsy, or both procedures. The following tests are indicated for **T4 lesions:** (1) CT imaging to include the chest, the abdomen, and the pelvis; (2) an MRI of the brain; and (3) testing of the serum LDH level before sentinel lymph node biopsy. When confirmed by repeated tests, a finding

Table 9–1. Survival Rates for Patients with Melanoma, Grouped by TNM and Staging Categories and According to Year of Diagnosis.

Pathologic Stage	TNM	Thickness (mm)	Ulceration	No. + Nodes	Nodal Size	Distant Metastasis	No. of Patients	Survival ± SE			
								1-Year	2-Year	5-Year	10-Year
IA	T1a	1	No	0	–	–	4,510	99.7 ± 0.1	99.0 ± 0.2	95.3 ± 0.4	87.9 ± 1.0
IB	T1b	1	Yes or level IV, V	0	–	–	1,380	99.8 ± 0.1	98.7 ± 0.3	90.9 ± 1.0	83.1 ± 1.5
	T2a	1.01–2.0	No	0	–	–	3,285	99.5 ± 0.1	97.3 ± 0.3	89.0 ± 0.7	79.2 ± 1.1
IIA	T2b	1.01–2.0	Yes	0	–	–	958	98.2 ± 0.5	92.9 ± 0.9	77.4 ± 1.7	64.4 ± 2.2
	T3a	2.01–4.0	No	0	–	–	1,717	98.7 ± 0.3	94.3 ± 0.6	78.7 ± 1.2	63.8 ± 1.7
IIB	T3b	2.01–4.0	Yes	0	–	–	1,523	95.1 ± 0.6	84.8 ± 1.0	63.0 ± 1.5	50.8 ± 1.7
	T4a	>4.0	No	0	–	–	563	94.8 ± 1.0	88.6 ± 1.5	67.4 ± 2.4	53.9 ± 3.3
IIC	T4b	>4.0	Yes	0	–	–	978	89.9 ± 1.0	70.7 ± 1.6	45.1 ± 1.9	32.3 ± 2.1
IIIA	N1a	Any	No	1	Micro	–	252	95.9 ± 1.3	88.0 ± 2.3	69.5 ± 3.7	63.0 ± 4.4
	N2a	Any	No	2–3	Micro	–	130	93.0 ± 2.4	82.7 ± 3.8	63.3 ± 5.6	56.9 ± 6.8
IIIB	N1a	Any	Yes	1	Micro	–	217	93.3 ± 1.8	75.0 ± 3.2	52.8 ± 4.1	37.8 ± 4.8
	N2a	Any	Yes	2–3	Micro	–	111	92.0 ± 2.7	81.0 ± 4.1	49.6 ± 5.7	35.9 ± 7.2
	N1b	Any	No	1	Macro	–	122	88.5 ± 2.9	78.5 ± 3.7	59.0 ± 4.8	47.7 ± 5.8
	N2b	Any	No	2–3	Macro	–	93	76.8 ± 4.4	65.6 ± 5.0	46.3 ± 5.5	39.2 ± 5.8
IIIC	N1b	Any	Yes	1	Macro	–	98	77.9 ± 4.3	54.2 ± 5.2	29.0 ± 5.1	24.4 ± 5.3
	N2b	Any	Yes	2–3	Macro	–	109	74.3 ± 4.3	44.1 ± 4.9	24.0 ± 4.4	15.0 ± 3.9
	N3	Any	Any	4	Micro/macro	–	396	71.0 ± 2.4	49.8 ± 2.7	26.7 ± 2.5	18.4 ± 2.5
IV	M1a	Any	Any	Any	Any	Skin, SQ	179	59.3 ± 3.7	36.7 ± 3.6	18.8 ± 3.0	15.7 ± 2.9
	M1b	Any	Any	Any	Any	Lung	186	57.0 ± 3.7	23.1 ± 3.2	6.7 ± 2.0	2.5 ± 1.5
	M1c	Any	Any	Any	Any	Other visceral	793	40.6 ± 1.8	23.6 ± 1.5	9.5 ± 1.1	6.0 ± 0.9
Total							17,600				

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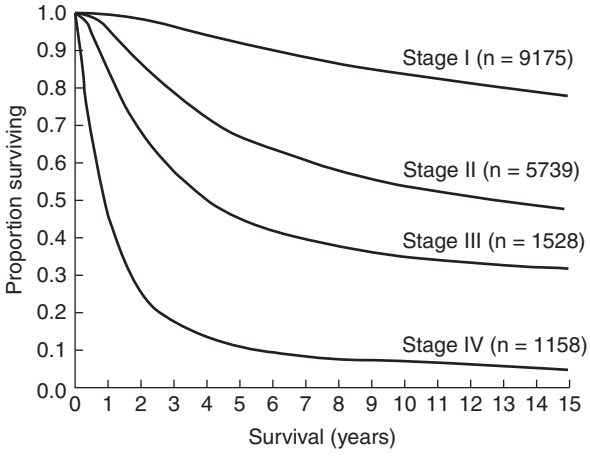

▲ **Figure 9–6.** A graph of the 15-year survival curves comparing localized melanoma (Stages I and II), regional metastases (Stage III), and distant metastases (Stage IV). (Reproduced, with permission, from Balch CM, Buzaid AC, Soong SJ et al: Final version of the American Joint Committee on Cancer staging system for cutaneous melanoma. *J Clin Oncol* 2001;19:3635.)

of an elevated LDH level may have an independent predictive value for a poor prognosis. The addition of PET scanning may add additional prognostic information and cause staging of intermediate-risk lesions to be revised upward, thus changing the treatment strategies in high-risk patients. (Current studies are limited to investigational centers.)

Treatment

A. Surgical Measures

Treatment of melanoma of the head and neck is based on the initial staging and generally consists of surgical excision of the primary lesion; surgical margins are determined on the basis of the T stage. The role of the surgical margin size is particularly important for the head and neck, where conservation of normal structures and function is a high priority, particularly if the effect of larger margins is not manifested in the outcome. It is important to note that if wide local excision is planned, ideally, it should be done in conjunction with sentinel lymph node biopsy; however, it should not be performed before that procedure because of the potential for the altered lymphatic distribution of injected agents. (The role and technique of sentinel, elective, and therapeutic neck dissections are discussed in Chapter 28, Neck Neoplasms & Neck Dissection.)

The generally accepted surgical margins are based on the primary tumor stage. **Melanoma in situ** can be excised using a Wood's light with a 5-mm margin of clinically normal skin into subcutaneous fat. Mohs micrographic surgery may be beneficial for excising melanoma in situ in certain locations where tissue conservation is of great concern (eg, the eyelid or nose).

Table 9–2. Classification System for Describing Primary Tumors and Nodes.

Current Primary Tumor Classification		
T0	No primary tumor located	
T1s	Melanoma in situ	
T1a	1.0 mm or less	Without ulceration and Clark's level II/III
T1b		With ulceration or Clark's level IV/V
T2a	1.01–2.0 mm	Without ulceration
T2b		With ulceration
T3a	2.01–4.0 mm	Without ulceration
T3b		With ulceration
T4a	4.0 mm or more	Without ulceration
T4b		With ulceration
Nodal Classification		
N1a		1 node with micrometastasis
N1b		1 node with macrometastasis
N2a		2–3 nodes with micrometastasis
N2b		2–3 nodes with macrometastasis
N2c		Intransit/satellites without metastatic nodes
N3		4 or more nodes, matted nodes, or satellites with nodes

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Stage I melanomas as deep as 2 mm without ulceration can be excised with a 1-cm margin; Stage I melanoma with ulceration should have 2-cm margins, and consideration should be given to the use of sentinel lymph node biopsy.

Stage II and **Stage III** lesions should have 2-cm margins and should include subcutaneous fat down to the fascia, if possible. Sentinel lymph node biopsy or elective node dissection, as well as postoperative radiation therapy, other adjuvant treatment, or a combination of these therapies, should be considered.

B. Nonsurgical Measures

1. Radiation therapy—Radiation therapy can be used to treat lentigo maligna or in situ disease when surgery is not

Table 9–3. Stage Groupings for Cutaneous Melanoma.

	Clinical Staging	Pathologic Staging
0	T1s N0 M0	T1s N0 M0
IA	T-1A N0 M0	T-1A N0 M0
IB	T-1B N0 M0	T-1B N0 M0
	T-2A N0 M0	T-2A N0 M0
IIA	T-2B N0 M0	T-2B N0 M0
	T-3A N0 M0	T-3A N0 M0
IIB	T-3B N0 M0	T-3B N0 M0
	T-4A N0 M0	T-4A N0 M0
IIC	T-4B N0 M0	T-4B N0 M0
IIIA		T1-4A N1A M0
		T1-4A N2A M0
IIIB		T1-4B N1A M0
		T1-4B N2A M0
		T1-4A N1B M0
		T1-4A N2B M0
		T1-4A/B N2C M0
IIIC		T1-4B N1B M0
		T1-4B N2B M0
		Any T N3 M0
IV	Any T Any N Any M1	Any T Any N Any M1

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feasible. Radiation therapy also has been shown effective in decreasing locoregional recurrence postoperatively in patients with extracapsular spread or bulky nodal disease. Some centers currently recommend radiation therapy for Stage II disease if the nodes are not treated surgically; alternately, these centers recommend postoperative radiation therapy for use in node-positive or recurrent disease.

2. Adjuvant therapies—Interferon-alpha can be offered to patients with melanomas greater than 1.5-mm thick and Stage II to III lesions as treatment may extend the relapse-free survival, but as of yet there is no clear long-term survival benefit.

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Morton DL, Thompson JF, Cochran AJ, Mozzillo N, Elashoff R, Essner R, Nieweg OE, Roses DF, Hoekstra HJ, Karakousis CP, Reintgen DS, Coventry BJ, Glass EC, Wang HJ; MSLT Group. Sentinel-node biopsy or nodal observation in melanoma. *N Engl J Med* 2006 Sep 28;355(13):1307–1317 [PMID: 17005948] [PubMed—indexed for MEDLINE]. (Review of 1269 pts with intermediate thickness melanomas comparing WLE and observation to WLE and sentinel node biopsy (SLNB) and immediate lymphadenectomy for proven micrometastases. Five-year melanoma specific survival rates were similar in both groups.)

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Olfactory Dysfunction

10

Anil K. Lalwani, MD

OLFACTORY LOSS

ESSENTIALS OF DIAGNOSIS

- History of olfactory loss, often manifesting as loss of the sense of taste.
- Sensory evaluation with quantitative tests indicating olfactory loss.

General Considerations

The sense of smell determines the flavor and palatability of food and drink. Along with the trigeminal system, it serves as a monitor of inhaled chemicals, including dangerous substances such as natural gas and smoke, and odors common to everyday life. The loss of smell or a decreased ability to smell affects approximately 1% of people under age 60 and more than half of the population beyond this age.

Abnormalities of olfaction include the following: (1) **anosmia** (absence of the sense of smell); (2) **hyposmia** (diminished olfactory sensitivity); (3) **dysosmia** (distorted sense of smell); (4) **phantosmia** (perception of an odorant when none is present); and (5) **agnosia** (inability to classify, contrast, or identify odor sensations verbally, even though the ability to distinguish between odorants may be normal).

Disorders of the sense of smell are caused by conditions that interfere with the access of the odorant to the olfactory neuroepithelium (transport loss), injure the receptor region (sensory loss), or damage the central olfactory pathways (neural loss). Table 10–1 summarizes the most common causes of olfactory dysfunction.

Classification

A. Transport Olfactory Loss

Transport olfactory loss can result from the following conditions: a swollen nasal mucous membrane in acute viral upper respiratory infections; bacterial rhinitis and sinusitis; allergic rhinitis; and structural changes in the nasal cavity (eg, deviations of the nasal septum, polyps, and neoplasms). It is also likely that abnormalities of mucus secretion, in which the olfactory cilia are immersed, could result in a loss of olfactory sensitivity.

B. Sensory Olfactory Loss

Sensory olfactory loss results from damage to the olfactory neuroepithelium by any of the following causes: viral infections, neoplasms, the inhalation of toxic chemicals, drugs that affect cell turnover, and radiation therapy to the head.

C. Neural Olfactory Loss

Neural olfactory loss can occur in a number of ways: head trauma, with or without fracture of the base of the anterior cranial fossa or cribriform plate area; Parkinson disease; Alzheimer disease; Korsakoff psychosis; vitamin B_{12} deficiency; neoplasms of the anterior cranial fossa; neurosurgical procedures; administration of neurotoxic agents (eg, ethanol, amphetamines, topical cocaine, aminoglycosides, tetracycline, cigarette smoke); and in some congenital disorders such as Kallmann syndrome. Other endocrine disorders can affect smell perception, including Cushing syndrome, hypothyroidism, and diabetes mellitus.

Pathogenesis

Molecular aspects of olfaction are now becoming understood. In mammals, there are probably 300–1000 olfactory receptor genes belonging to 20 different families located

Table 10–1. Causes of Olfactory Dysfunction.

Transport Olfactory Losses
Allergic rhinitis
Bacterial rhinitis and sinusitis
Congenital abnormality (encephalocele)
Nasal neoplasms
Nasal polyps
Nasal septal deviation
Nasal surgery
Viral infections
Sensory Olfactory Losses
Drugs
Neoplasms
Radiation therapy
Toxic chemical exposure
Viral infections
Neural Olfactory Losses
AIDS
Alcoholism
Alzheimer disease
Chemical toxins
Cigarette smoke
Diabetes mellitus
Depression
Drugs
Huntington's chorea
Hypothyroidism
Kallmann syndrome
Korsakoff psychosis
Malnutrition
Neoplasm
Neurosurgery
Parkinson disease
Trauma
Vitamin B_{12} deficiency
Zinc deficiency

on various chromosomes in clusters. The receptor genes are present at more than 25 different human chromosomal locations. Olfactory receptor proteins are G protein-coupled receptors characterized by the presence of seven alpha-helical transmembrane domains. Each olfactory neuron expresses only one or, at most, a few receptor genes, providing the molecular basis of odor distinction. The olfactory system is thus characterized by three important features: (1) the large family of receptor genes exhibits remarkable diversity allowing response to a variety of smells, (2) the receptor proteins exhibit exquisite specificity allowing for odor discrimination, and (3) odor associations are well kept in memory long after the incident that formed the association is forgotten.

Etiology

Many patients experience olfactory dysfunction due to one or more of the following causes: obstructive nasal and sinus disease, post-upper respiratory infection, cranial trauma, and congenital causes. Aging, exposure to toxins, and idiopathic causes also account for the loss of smell.

A. Nasal Obstruction and Upper Respiratory Infection

Air flows through the medial and anterior to the lower part of the middle turbinate to reach the olfactory cleft. Nasal obstruction at this area or above it caused by severe mucosal swelling, tumors, nasal polyps, or bony deformities can result in hyposmia or anosmia. In addition, patients often report a loss of sense of smell during an upper respiratory infection; generally, this loss is due to airway obstruction secondary to mucosal swelling. Olfactory ability should improve or return altogether with relief of the obstruction.

B. Cranial Trauma

Approximately 5–10% of adult patients with head trauma report olfactory loss to be in the anosmic range. The degree of olfactory loss is generally associated with two things: the severity of the trauma and the site of cranial trauma. Total anosmia is more likely to occur with occipital traumas; however, frontal blows most frequently cause olfactory loss.

C. Congenital Anosmia

Perhaps the most well-known type of congenital anosmia is **Kallmann syndrome**, an X-linked disorder. Caused by mutation in the KAL gene, Kallmann syndrome is characterized by hypogonadotropic hypogonadism, which results when olfactory receptor neurons and neurons synthesizing gonadotropin-releasing hormone fail to migrate from the olfactory placode.

D. Aging

Aging and dementia-related diseases can result in olfactory loss. Olfactory sensitivity tends to drop sharply in the sixth and seventh decades of life. Anatomically, cellular elements associated with olfaction decrease with age, as does olfactory bulb volume (found at the base of the frontal cortex). Alzheimer disease and Parkinson disease may be associated with olfactory dysfunction. In these patients, the most likely mechanism is damage to the olfactory bulb or central olfactory cortex, which results in the loss of olfactory detection and recognition ability.

E. Toxins and Other Factors

Olfactory loss from toxins may occur over a period of days or years. Formalin exposure is an example of a toxicity that accumulates over a period of years. Most agents that cause olfactory loss are either gases or aerosols that enter the nose with the respiratory air stream.

Patients with depression and schizophrenia may have olfactory losses as part of their illnesses. Although depressed patients do have some altered gustatory ability, the ability to identify odorants is usually normal; when it is not, the olfactory complaints most likely stem from a problem in the central nervous system. It may be that the same chemicals that cause symptoms of depression affect the neural connections between the limbic system and the hypothalamus.

Clinical Findings

A. Signs and Symptoms

Knowing the onset and development of an olfactory disorder may be of paramount importance in making an etiologic diagnosis. Unilateral anosmia is rarely a complaint; it can be recognized only by separately testing smell in each nasal cavity. Bilateral anosmia, on the other hand, does bring patients to medical attention. Anosmic patients usually complain of loss of the sense of taste, even though their taste thresholds may be within normal limits. In actuality, they are complaining of a loss of flavor detection, which is mainly an olfactory function.

B. Physical Findings

The physical examination should include a complete examination of the ears, upper respiratory tract, head, and neck. Pathology of each area of the head and neck can result in olfactory dysfunction. The presence of serous otitis media suggests the presence of a nasopharyngeal mass or inflammation. A careful nasal examination for nasal mass, clot, polyps, and nasal membrane inflammation is critical. When available, anterior rhinoscopy should be supplemented with endoscopic examination of the nasal cavity and nasopharynx. The presence of telecanthus on the ocular exam may suggest a sinus mass or inflammation. Nasopharyngeal masses protruding into the oral cavity or purulent drainage within the oropharynx may be seen during the oral examination. The neck should be palpated for masses or thyroid enlargement. A neurologic examination emphasizing the cranial nerves and cerebellar and sensorimotor function is essential. The patient's general mood should be assessed and signs of depression should be noted.

C. Laboratory Findings

Techniques have been developed to biopsy the olfactory neuroepithelium. However, because of the widespread degeneration of the olfactory neuroepithelium and intercalation of respiratory epithelium in the olfactory area of adults with no apparent olfactory dysfunction, biopsy material must be interpreted cautiously.

D. Imaging

A computed tomography (CT) scan or magnetic resonance imaging (MRI) of the head is required to rule out neoplasms of the anterior cranial fossa, unsuspected fractures of the anterior cranial fossa, paranasal sinusitis, and neoplasms of the nasal cavity and paranasal sinuses. Bone abnormalities are best seen with CT, whereas MRI is useful in evaluating olfactory bulbs, ventricles, and other soft tissues of the brain. Coronal CT is optimal for assessing the cribriform plate, anterior cranial fossa, and sinus anatomy and disease.

E. Sensory Evaluation

The sensory evaluation of olfactory function is necessary to (1) corroborate the patient's complaint, (2) evaluate the efficacy of treatment, and (3) determine the degree of permanent impairment.

1. Step 1: Determining qualitative sensations—The first step in the sensory evaluation is to determine the degree to which qualitative sensations are present. Several methods are available for olfaction evaluation.

A. The odor stix test—The Odor stix test uses a commercially available magic marker-like pen that produces odor. It is held approximately 3–6 inches from the patient's nose to check for gross perception of the odorant.

B. The twelve-inch alcohol test—Another test that assesses gross perception of an odorant, the twelve-inch alcohol test, uses a freshly opened isopropyl alcohol packet held approximately 12 inches from the patient's nose.

B. Scratch-and-sniff card—A scratch-and-sniff card that contains three odors to test gross olfaction is commercially available.

D. The university of pennsylvania smell identification test (UPSIT)—A far superior test to other assessments is the University of Pennsylvania Smell Identification Test (UPSIT); it is highly recommended for the evaluation of a patient with smell disorder. This test utilizes 40 forced-choice items that feature microencapsulated scratch-and-sniff odors. For example, one of the items reads, "This odor smells most like (a) chocolate, (b) banana, (c) onion, or (d) fruit punch." The patient is instructed to answer one of the alternatives. The test is highly reliable (short-term test-retest reliability $r = 0.95$) and is sensitive to age and gender differences. It is an accurate quantitative determination of the relative degree of olfactory deficit. Individuals with a total loss of olfactory function score in the range of 7–19 out of 40. The average score for total anosmics is slightly higher than that expected on the basis of chance alone because of the inclusion of some odorants that act by trigeminal stimulation.

2. Step 2: Determining the detection threshold—After the physician determines the degree to which qualitative sensations are present, the second step in the sensory evaluation is to establish a detection threshold for the odorant phenyl-ethyl alcohol. This threshold is established using a graduated stimulus. Sensitivity for each side of the nose is determined with a detection threshold for phenyl-ethyl methyl ethyl

carbinol. Nasal resistance can also be measured with anterior rhinomanometry for each side of the nose.

Differential Diagnosis

At the present time, there are no psychophysical methods to differentiate sensory from neural olfactory loss. Fortunately, the history of olfactory loss provides important clues to the cause. The leading causes of olfactory disorders are head trauma and viral infections. Head trauma is a more common cause of anosmia in children and young adults, and viral infections are more common causes of anosmia in older adults.

A. Viral Infection

Viral infections destroy the olfactory neuroepithelium; it is replaced by the respiratory epithelium. Parainfluenza virus type 3 appears to be especially detrimental to human olfaction. Human immunodeficiency virus (HIV) infection is associated with a subjective distortion of taste and smell that may become more severe as the disease progresses. Moreover, the loss of taste and smell may play an important role in the development and progression of HIV-associated wasting.

B. Cranial Trauma

Cranial trauma is followed by a unilateral or bilateral impairment of smell in up to 15% of cases; anosmia is more common than hyposmia. Olfactory dysfunction is more common when associated with loss of consciousness, more severe head injuries (grades II–V), and skull fracture. Frontal injuries and fractures disrupt the cribriform plate and olfactory axons that perforate it. Sometimes an associated cerebrospinal fluid rhinorrhea results from a tearing of the dura overlying the cribriform plate and paranasal sinuses. Anosmia also may follow blows to the occiput. Once traumatic anosmia develops, it is usually permanent; only an estimated 10% of patients ever improve or recover. The perversion of the sense of smell may occur as a phase in the recovery process. Zinc sulfate therapy may enhance improvement in olfaction following trauma.

C. Congenital Anosmia

Congenital anosmias are rare but important. Kallmann syndrome is a neuronal migration defect for which the X-linked gene (KAL) has been cloned. It is characterized by congenital anosmia and hypogonadotropic hypogonadism. Anosmia also can occur in persons with albinism. The receptor cells are present but are hypoplastic, lack cilia, and do not project above the surrounding supporting cells.

D. Meningioma, Adenoma, and Aneurysm

Meningioma of the inferior frontal region is the most common neoplastic cause of anosmia; rarely, anosmia can occur with glioma of the frontal lobe. Occasionally, pituitary adenomas, craniopharyngiomas, suprasellar meningiomas, and aneurysms of the anterior part of the circle of Willis extend forward and damage olfactory structures. These tumors and hamartomas also may induce seizures with olfactory hallucinations, indicating involvement of the uncus of the temporal lobe.

Dysosmia, a subjective distortion of olfactory perception, may occur with intranasal disease that partially impairs smell or may represent a phase in the recovery from a neurogenic anosmia. Most dysosmic disorders consist of disagreeable or foul odors, and they may be accompanied by distortions of taste. Dysosmia is associated with depression.

Treatment

A. Transport Olfactory Loss

Therapy for patients with transport olfactory losses due to allergic rhinitis, bacterial rhinitis and sinusitis, polyps, neoplasms, and structural abnormalities of the nasal cavities can be undertaken rationally and with a high likelihood of improvement. The following treatments are frequently effective in restoring the sense of smell: (1) allergy management; (2) antibiotic therapy; (3) topical and systemic glucocorticoid therapy; and (4) operations for nasal polyps, deviation of the nasal septum, and chronic hyperplastic sinusitis.

B. Sensorineural Olfactory Loss

There is no treatment with demonstrated efficacy for sensorineural olfactory losses. Fortunately, spontaneous recovery often occurs. Some clinicians advocate zinc and vitamin therapy. Profound zinc deficiency undoubtedly can result in loss and distortion of the sense of smell, but it is not a clinical problem except in very limited geographic areas. Vitamin therapy has been predominantly in the form of vitamin A. The epithelial degeneration associated with vitamin A deficiency can cause anosmia, but vitamin A deficiency is not a common clinical problem in Western societies. Exposure to cigarette smoke and other airborne toxic chemicals can cause metaplasia of the olfactory epithelium. Spontaneous recovery can occur if the insult is discontinued; therefore, patient counseling is helpful in these cases.

C. Aging-Related Olfactory Loss (Presbyosmia)

As previously mentioned, more than half of people older than age 60 suffer from olfactory dysfunction. No effective treatment exists for presbyosmia, but it is important to discuss the problem with elderly patients. It can be reassuring to patients when a physician recognizes and discusses that smell disorders are common. In addition, direct benefits can be gained by identifying the problem early; the incidence of natural gas–related accidents is disproportionately high in the elderly, perhaps in part because of the gradual loss of smell. Mercaptan, the pungent odor in natural gas, is

an olfactory and not a trigeminal stimulant. Many older patients with olfactory dysfunction experience a decrease in flavor sensation and find it necessary to hyperflavor food. The most common method is by increasing the amount of salt in their diet. Careful counseling can help these patients develop healthy strategies to deal with their decreased sense of smell.

Prognosis

The outcome of olfactory dysfunction is largely dependent on its cause. Olfactory dysfunction due to an obstruction caused by polyps, neoplasms, mucosal swelling, or septal deviation is reversible. When the obstruction is released, olfactory ability should return. Most patients who lose their sense of smell during an upper respiratory infection completely recover olfactory ability; however, a small number of patients never recover after the other symptoms of the upper respiratory infection resolve. For unclear reasons, these patients are mostly women in their fourth, fifth, and sixth decades of life. The prognosis for recovery is generally poor. Olfactory identification ability and thresholds progressively decline with age. Head trauma to the frontal region most frequently causes olfactory loss, although total anosmia is five times more likely with an occipital blow. Recovery of olfactory function following traumatic cranial injury is only 10%, and the quality of the olfactory ability after recovery is usually poor. Exposure to toxins such as cigarette smoke can cause metaplasia of the olfactory epithelium. Recovery can occur with removal of the offending agent.

Doty RL. The olfactory system and its disorders. *Semin Neurol* 2009;29(1):74–81 [PMID: 19214935]. (An overview of the anatomy, physiology, testing and disorders of the olfactory system.)

Lane AP, Turner J, May L, Reed R. A genetic model of chronic rhinosinusitis-associated olfactory inflammation reveals reversible functional impairment and dramatic neuroepithelial reorganization. *J Neurosci* 2010;30(6):2324–1329 [PMID: 20147558]. (In this mouse model of rhinosinusitis, the investigators showed that direct effect of inflammation on the olfactory epithelium structure and function are important mechanisms of olfactory dysfunction.)

Zou Z, Buck LB. Combinatorial effects of odorant mixes in olfactory cortex. *Science* 2006;311(5766):1477 [PMID: 16527983]. (Cortical neurons that respond to combination of two odorants do not respond to a single odorant, thus explaining why odorant mixtures lead to novel precepts in humans.)

We would like to acknowledge Derek D. Mafong for his contribution to this chapter in the previous editions of CDT.

11 Congenital Nasal Anomalies

Maria V. Suurna, MD

NASAL EMBRYOLOGY

Nasal development occurs during weeks 4 through 10 of gestation. Migrating neural crest cells populate the frontonasal prominence, one of five facial prominences, and form the nasal or olfactory placodes. These placodes appear as convex thickenings on the surface ectoderm of the frontonasal prominence. A central depression deepens in the placodes to form the primitive nasal pit. Mesenchymal proliferation during the 5th week around the nasal placodes allows the horseshoe-shaped medial and lateral nasal prominences to develop and fuse to form the nostrils. The nasal pits grow toward the oral cavity and develop into the early nasal fossae. The nasobuccal membrane separates the nasal cavities from the oral cavity. This membrane subsequently disappears, allowing for communication of the nasal cavities with the oral cavity, forming the primitive posterior nasal choanae. The nasomedial process gives rise to part of the nasal septum and the medial crus of the lower lateral alar cartilage. The nasolateral process develops into the external wall of the nose, nasal bones, upper lateral cartilage, alae, and lateral crus of the lower lateral cartilage. The apex and dorsum of the nose develop from the frontonasal process (Figure 11–1).

The proposed classification of congenital nasal deformities separates them into four categories. Type I deformities represent hypoplasia and atrophy, Type II are hyperplasia and duplications, Type III are clefts, and Type IV deformities consist of neoplasms and vascular anomalies.

Neskey D, Eloy JA, Casiano RR. Nasal, septal, and turbinate anatomy and embryology. *Otolaryngol Clin North Am* 2009 Apr;42(2):193–205 [PMID: 19328886]. (The article describes development and anatomy of nasal structures.)

Szeremeta W, Parikh TD, Widelitz JS. Congenital nasal malformations. *Otolaryngol Clin North Am* 2007 Feb;40(1):97–112 [PMID: 17346563]. (The article discusses embryology and development of congenital nasal abnormalities.)

Losee JE, Kirschner RE, Whitaker LA et al. Congenital nasal anomalies: a classification scheme. *Plast Reconstr Surg* 2004 Feb;113(2):676–689 [PMID: 14758236]. (The article proposes a classification of congenital nasal deformities.)

ARRHINIA

Arrhinia is a rare congenital absence of the nose. The findings include absence of nasal bones, cribriform plate, and nasal septum. In cases of total arrhinia, the olfactory system is also absent. Arrhinia can be associated with other craniofacial anomalies and midline defects.

The likely embryologic abnormality resulting in arrhinia is thought to be a failure of the nasal placodes to invaginate during the 5th week of fetal development. Most cases reported are sporadic, although cases of genetic aberration have been described.

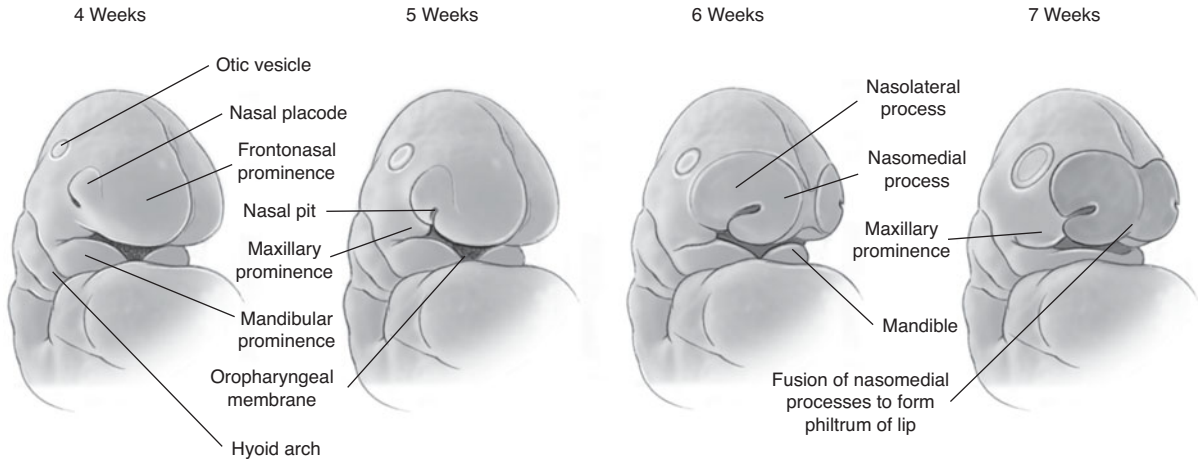
A computed tomography (CT) or magnetic resonance imaging (MRI) scan is performed to plan for surgery and often reveals associated abnormalities. Radiological examination demonstrates small or absent nasal bones and bony masses obstructing the nasal cavity.

All cases require airway management in the neonatal period. Reconstructive surgery is usually postponed until 4–6 years of age. Surgery is often performed in multiple stages, using techniques such as forehead flaps, rib grafts, and tissue expansion.

Tessier P, Ciminello FS, Wolfe SA. The Arrhinias. *Scand J Plast Reconstr Surg Hand Surg* 2009;43(4):177–196 [PMID: 19401938]. (Anatomy, clinical signs, ant treatment of 51 cases of arrhinias are discussed in the article.)

HEMINOSE

Unilateral nostril agenesis is a rare malformation frequently associated with other facial anomalies, including proboscis lateralis, abnormalities of the lacrimal system, and malformations of facial bones. Etiology of heminose is unclear, and in the reported cases, this malformation has occurred



▲ **Figure 11–1.** Diagram of embryologic development of the nose.

sporadically. The lack of a nasal placode is thought to lead to heminasal abnormality. Radiographic examination may reveal unilateral absence of the cribriform plate. Surgical reconstruction is usually performed around 4–6 years of age and involves a complex multistaged procedure.

da Silva Freitas R, Alonso N, de Freitas Azzolini T et al. The surgical repair of half-nose. *J Plast Reconstr Aesthet Surg* 2010 Jan;63(1):15–21 [PMID: 19046661]. (The article presents experience of individualized techniques for half-nose reconstruction and literature review.)

NASAL PYRIFORM APERTURE STENOSIS

ESSENTIALS OF DIAGNOSIS

- Presents with respiratory difficulty due to nasal obstruction at birth or shortly thereafter.
- Examination reveals bony obstruction at the nasal vestibule.
- CT scan is usually performed to confirm the diagnosis.

Congenital nasal pyriform aperture stenosis is a rare cause of airway obstruction in newborns and was first described in 1989. A bony overgrowth of the medial maxilla leads to narrowing of the nasal inlet. Because neonates are obligate nasal breathers, presenting signs and symptoms include respiratory distress, cyclical cyanosis or apnea that is relieved with crying, feeding difficulties, and, in severe cases, life-threatening total airway obstruction. Depending on severity of stenosis, symptoms can occur at birth or shortly thereafter. Examination of the nose reveals a bony obstruction in the vestibule and an inability to pass a catheter or endoscope into the nose. Pyriform aperture stenosis can be found either in isolation or together with other malformations, including submucous cleft palate, absence of the anterior pituitary gland, hypoplastic maxillary sinuses, hypotelorism, and a flat nasal. Up to 60% of nasal pyriform aperture stenosis is associated with a single central maxillary incisor. These patients should be further evaluated for holoprosencephaly.

A CT scan through the midface is usually performed to confirm the diagnosis and delineate the anomaly. On CT imaging, nasal pyriform aperture stenosis is diagnosed when the transverse diameter of each aperture is less than 3 mm or combined aperture width is less than 8 mm. In addition, brain MRI or CT allows evaluation of associated pituitary or midbrain abnormalities.

Management of congenital nasal pyriform aperture stenosis depends on the severity of the symptoms. The primary goal is to establish a safe airway. In mild cases, nasal obstruction can be managed conservatively with topical nasal decongestants, corticosteroids, suctioning, or humidification. Symptoms may resolve as the child continues to grow. In severe cases, a McGovern nipple or oral airway can be used. If the infant fails to respond to medical treatment, loses weight, has cyclical cyanosis, or develops pulmonary hypertension from the obstruction, surgical repair is recommended. Transnasal and sublabial approaches to pyriform aperture stenosis repair have been described, sublabial being a preferred method.

Brown OE, Myer CM III, Manning SC. Congenital nasal pyriform aperture stenosis. *Laryngoscope* 1989;99(1):86–91 [PMID: 2909825]. (This is the first article describing congenital nasal pyriform aperture stenosis.)

Tate JR, Sykes J. Congenital nasal pyriform aperture stenosis. *Otolaryngol Clin North Am* 2009 Jun;42(3):521–525 [PMID: 19486746]. (The article reviews the embryology, diagnosis and management of congenital nasal pyriform aperture stenosis.)

CHOANAL ATRESIA

ESSENTIALS OF DIAGNOSIS

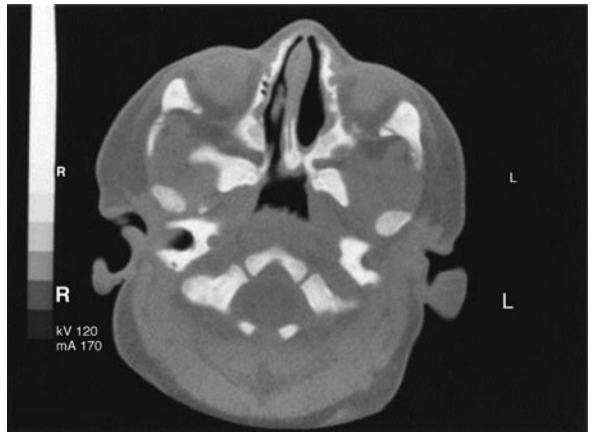
- Bilateral cases present at birth with respiratory distress.
- Unilateral cases may present later in life with unilateral nasal obstruction or nasal discharge.
- CT scan confirms the diagnosis.

Choanal atresia is a congenital obstruction of the posterior nasal apertures. This abnormality occurs in one out of every 5000–7000 live births and affects females twice as often as males. It can occur unilaterally or bilaterally with unilateral atresia being more common. Choanal atresia has been described as bony, membranous, or mixed membranous-bony, with the mixed membranous–bony atresias being most common and occurring in 70% of cases. Possible etiology of choanal atresia includes persistence of the buccopharyngeal membrane from the foregut, failure of perforation of the nasobuccal membrane, abnormal persistence or location of mesoderm forming adhesions in the nasochoanal region, and misdirection of neural crest cell migration.

Choanal atresia is associated with other anomalies in half of the cases. The most commonly described association is with CHARGE (Coloboma of the eye, Heart malformations, Choanal Atresia, Retarded growth or development, Genital or urinary abnormalities, Ear malformations or deafness). Increased rates of choanal atresia have been associated with abnormalities in vitamin A metabolism and with prenatal use of thionamides (eg, methimizole or carbimizole).

Neonates are obligate nasal breathers during the first 3–5 months of life; therefore, choanal atresia leading to nasal obstruction may present as respiratory distress and require emergent intervention. Infants with bilateral choanal atresia present with a cyclical cyanosis that improves with crying and worsens with feeding. Unilateral choanal atresia occurs more frequently in the right choana and may present later in life with unilateral nasal obstruction and persistent nasal discharge. The initial diagnosis usually occurs upon an examiner's inability to pass a small catheter or flexible endoscope through the choana.

The diagnosis is confirmed with a CT scan of the paranasal sinuses and skull base. Radiographic imaging allows for examination of the entire nasal cavity, helps to characterize the nature and severity of the anatomic deformity, and also differentiates other causes of nasal obstruction. On CT imaging, choanal atresia is diagnosed if the posterior choanal orifice measures less than 0.34 cm unilaterally or if the posterior vomer measures greater than 0.55 cm (Figure 11–2).



▲ **Figure 11–2.** CT scan demonstrating left choanal atreasia.

The initial treatment, particularly of bilateral choanal atresia, is to establish a safe airway. Oral airway, McGovern nipple, or intubation can be used as temporary measures. When the patient is stable for general anesthesia, definitive surgical correction of the atresia can be performed.

Several surgical repair techniques have been described. The transnasal approach involves passing dilators under direct vision with either a 120° endoscope or mirror to make an opening in the atretic plate. This technique is fast and involves less blood loss. The transpalatal approach is more often reserved for older patients with unilateral atresia. Although there are better visualization and higher success rates, palate growth can be disrupted, which frequently leads to palate and cross-bite deformities. Endoscopic technique is more difficult to perform in a neonate's nose. An endoscope is used to visualize the atretic plate. The plate is perforated either under direct vision through the nose or using dilators. The opening is then enlarged by removing the posterior part of the septum with back-biting through-cutters, microdebrider, or guarded drill.

To prevent restenosis, stents are placed into the opened choanae and left in place for 2–6 weeks. Application of mytomycin C has been used to reduce postoperative restenosis. However, because of the long-term concerns with the application of a potentially oncogenic medication, routine use is not recommended.

Success rates for surgical repair of choanal atresia range from 55% to 85%. Failure results when the choanae become obliterated by granulation or scar tissue. Recurrences can occur between 2 months and 6 years and often require

further surgical correction or dilations. Recently, repeated balloon dilation has been used successfully to treat recurrent choanal atresia.

Ramsden JD, Campisi P, Forte V. Choanal atresia and choanal stenosis. *Otolaryngol Clin North Am* 2009 Apr;42(2):339–352 [PMID: 19328897]. (Review of surgical approaches to management of choanal atresia and choanal stenosis.)

POLYRRHINIA

Polyrrhinia or true nasal duplication is presence of two external noses. One embryologic theory to describe this malformation involves the development of two pairs of nasal placodes, which then undergo the usual development. Frequently, bilateral choanal atresia is also present. Midline craniofacial clefts may result in anomalies presenting as nasal duplications or bifid nose. The atresia is corrected first, followed by excision of the medial portions of each external nose for cosmetic improvement.

SUPERNUMERARY NOSTRILS

A supernumerary nostril is an extra opening lateral, medial, or superior to the normal nostril. The supernumerary nostril can be unilateral or bilateral; it can open into a common cavity shared with the normal nostril or have its own blind-ending cavity. Supernumerary nostrils have been associated with choanal atresia and pyriform aperture abnormalities. Embryologically, this structure may result from a localized abnormality of the lateral nasal process in which a fissure appears accidentally during mesenchymal proliferation. A supernumerary nostril may be excised as a wedge, closing the normal nasal tissue primarily.

Williams A, Pizzuto M, Brodsky L, Perry R. Supernumerary nostril: a rare congenital deformity. *Int J Pediatr Otorhinolaryngol* 1998 Jul 10;44(2):161–167 [PMID: 9725533]. (The article discusses cases of nasal duplication anomalies and provides literature review.)

PROBOSCIS LATERALIS

Proboscis lateralis is described as a rectangular, tubular, rudimentary nasal appendage that is 1–3 cm long and 1 cm wide. The lesion is located along the embryonic fusion line between the anterior maxillary process and the frontonasal process, and it is most often connected to the medial canthus; however, attachment location can be variable. A central tract is lined with stratified columnar epithelium and usually ends blindly.

It is often associated with abnormalities of the ipsilateral eye. The ipsilateral heminose and face are often anomalous. Imaging to identify bony nasal and paranasal sinus anatomy and possible intracranial adnormalities is recommended prior to surgical repair. Surgical technique to reconstruct the proboscis is based on the anatomical characteristics of the proboscis and should be undertaken when the patient can safely undergo surgery.

Acarturk S, Kivanc K, Atilla E, Sekucoglu T. Proboscis lateralis: evaluation of the anomaly and a review of two cases. *Plast Reconstr Surg* 2006;117:140e–146e [PMID: 16772901]. (The article presents two cases of surgical management of proboscis lateralis and reviews the etiology, diagnosis, and management of the malformation.)

CLEFTS

Clefts usually result in hard and soft tissue deficiencies and are often associated with other craniofacial anomalies. Tessier proposed a classification of facial, craniofacial, and laterofacial clefts. Facial clefts involving the nose are Tessier 0, 1, 2, and 3. Tessier 0 cleft is the most common craniofacial cleft. It passes through the central midface and can present as a widening, duplication, or agenesis/hypoplasia of the midline structures.

Ortiz Monasterio F, Fuente del Campo A, Dimopulos A. Nasal clefts. *Ann Plast Surg* 1987 May;18(5):377–397 [PMID: 3592518]. (The article discusses clinical features and treatment of nasal clefts.)

Tessier P. Anatomical classification facial, cranio-facial and latero-facial clefts. *J Maxillofac Surg* 1976 Jun;4(2):69–92 [PMID: 820824]. (The article proposes classification of facial, cranio-facial and latero-facial clefts and discusses associated malformations.)

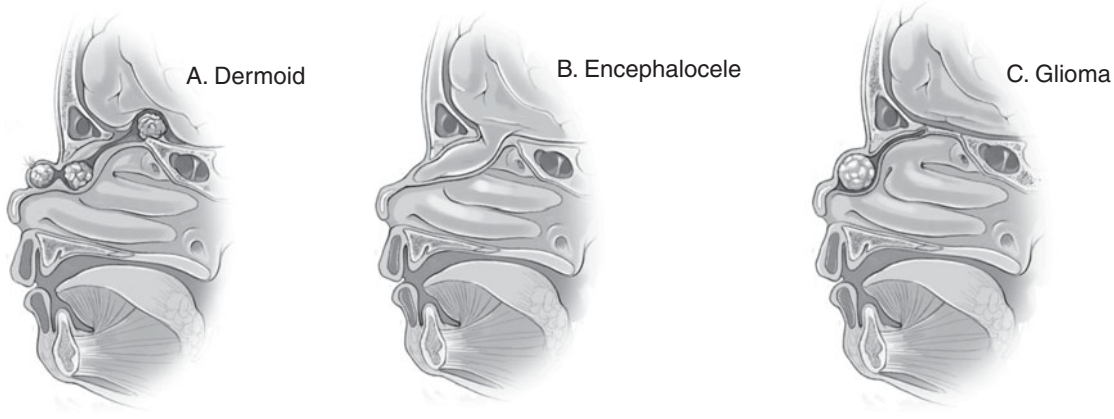
NASAL DERMOID

ESSENTIALS OF DIAGNOSIS

- Usually present as a slow-growing nasal mass or midline cutaneous defect, often with hair protruding from the site.
- Dermoids do not compress or transilluminate.
- MRI is useful for diagnosing intracranial extension.

Nasal dermoid cysts are found in the midline of the nose as masses, sinus tracts, or as a combination of the two. They are derived from ectoderm and mesoderm, are lined by keratinized stratified squamous epithelium, and can contain hair follicles, sweat glands, and sebaceous glands. It is postulated that dermoid develops as a result of failure of dura to separate from nasal skin during development. Dermoid tract or sinus can form anywhere along the nose from the glabella down to the nasal tip or columella, with the most common site being the lower third of the nasal bridge. Up to 45% of nasal dermoid cysts have an intracranial connection (Figure 11–3A).

Nasal dermoids are usually diagnosed within the first 3 years of life. Patients may present with an intermittent discharge of sebaceous material from a cutaneous defect or

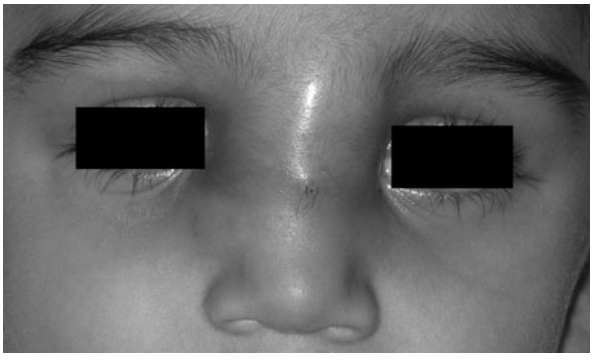


▲ **Figure 11–3. (A)** Nasal dermoid. Dermoid tract can present anywhere along the nasal dorsum and extend intracranially. **(B)** Nasal encephalocele. Intacranial contents are protruding through foramen cecum toward the nasal dorsum. **(C)** Nasal glioma presents as a mass over the nasal dorsum without direct intracranial extension.

inflammation. Hair protruding from the site is pathognomonic (Figure 11–4). Nasal dermoids are firm, slow-growing, noncompressible masses that do not transilluminate. They do not enlarge with crying or Valsalva maneuvers and demonstrate a negative Furstenberg test by not expanding with the compression of ipsilateral jugular veins.

CT scan imaging is useful for visualizing bony defects of the skull base. Findings of bifid anterior crista galli and enlarged foramen cecum suggest intracranial involvement of the dermoid. With CT imaging, false-positive and false-negative results regarding intracranial involvement are not uncommon. In general, MRI is more sensitive and specific than CT. It is, therefore, preferred for visualizing soft tissues and diagnosing intracranial extension. Nasal dermoid cysts appear isointense on T1-weighted images and hyperintense on T2-weighted images.

Untreated nasal dermoid cysts can lead to local inflammation or abscess formation. With the presence of an intracranial connection, they may result in cerebrospinal fluid (CSF) leakage, meningitis, cavernous sinus thrombosis, or periorbital cellulitis. Gradual expansion of nasal dermoid cysts can deform nasal bones or cartilages.



▲ **Figure 11–4.** Infected nasal dermoid with a tuft of hair protruding through the cutaneous defect.

Nasal dermoid cysts and sinuses, in general, should be surgically removed to avoid complications. Any surgical intervention of nasal dermoid cysts should be preceded by full evaluation, including MRI to evaluate for intracranial extension. If intracranial extension is present, a neurosurgical evaluation is required and craniotomy is generally performed as part of the procedure. The nasal portion of the dermoid can be removed using any one of various incisions, including midline vertical, transverse, lateral rhinotomy, or mid-brow. The external rhinoplasty approach allows good surgical exposure and superior cosmetic result. Cartilaginous grafts are sometimes needed for dorsal augmentation when normal nasal structures have been altered by the mass. More recently, intranasal endoscopic approaches have been used to resect nasal dermoid cysts, including their removal from the dura.

Recurrence rates for nasal dermoid cysts are as high as 50–100% when dermal elements are incompletely removed; however, when these elements are completely removed, the prognosis is better, although facial scarring, saddle nose deformity, or other nasal structure abnormalities can persist.

Bloom D, Carvalho DS, Dory C, Brewster DF, Wickersham JK, Kearns DB. Imaging and surgical approach of nasal dermoids. *Int J Pediatr Otorhinolaryngol* 2002;62(2):111 [PMID: 11788143]. (MRI was determined to be the most accurate and cost-effective approach for imaging nasal dermoids, while the external rhinoplasty approach is recommended as the preferred surgical technique.)

Zapata S, Kearns DB. Nasal dermoids. *Curr Opin Otolaryngol Head Neck Surg* 2006 Dec;14(6):406–411 [PMID: 17099348]. (Imaging is essential for diagnosis of dermoids and for surgical planning.)

NASAL ENCEPHALOCELE

ESSENTIALS OF DIAGNOSIS

- Usually present at birth as a midline nasal mass, nasal obstruction, or CSF leak.
- Encephaloceles are compressible, trasilluminate and enlarge with crying.
- MRI is preferred for evaluation.

Nasal encephaloceles occur as a result of herniation of intracranial tissues through skull base defect (Figure 11–3B). The herniated tissue can contain meninges (meningocele), meninges and brain (meningoencephalocele), or meninges, brain, and part of the ventricular system (meningoencephalocystocel). They are always associated with the midline skull defect, and pathogenesis is thought to result from failure in separation of surface ectoderm from neuroectoderm around the time of neural tube closure.

The most common location for encephalocele is occipital (75%), followed by frontal (25%). Frontal encephaloceles are divided into sincipital (60%) and basal (40%). Sincipital encephaloceles appear as external nasal masses and, based on their location, are classified as nasofrontal, nasoethmoidal, and nasoorbital.

Nasal encephaloceles generally present at birth as bluish, soft, pulsatile, and compressible masses near glabella. Patients may have hypertelorism or dislocation of the nasal bones or septum (Figure 11–5). Occasionally, these lesions present with CSF rhinorrhea or meningitis. Encephaloceles transilluminate, enlarge with crying and Valsalva maneuvers, and have a positive Furstenberg test, observation of mass expansion with compression of the jugular veins.

Imaging is important in assessment of suspected encephalocele and associated intracranial anomalies. MRI is the preferred imaging modality. It delineates a continuity of CSF space and can clearly differentiate nasal encephaloceles from nasal gliomas. On MRI scans, encephaloceles usually appear hyperintense on T2-weighted images and of variable intensity on T1-weighted images. CT imaging is most useful for visualizing bony defects of the skull base.

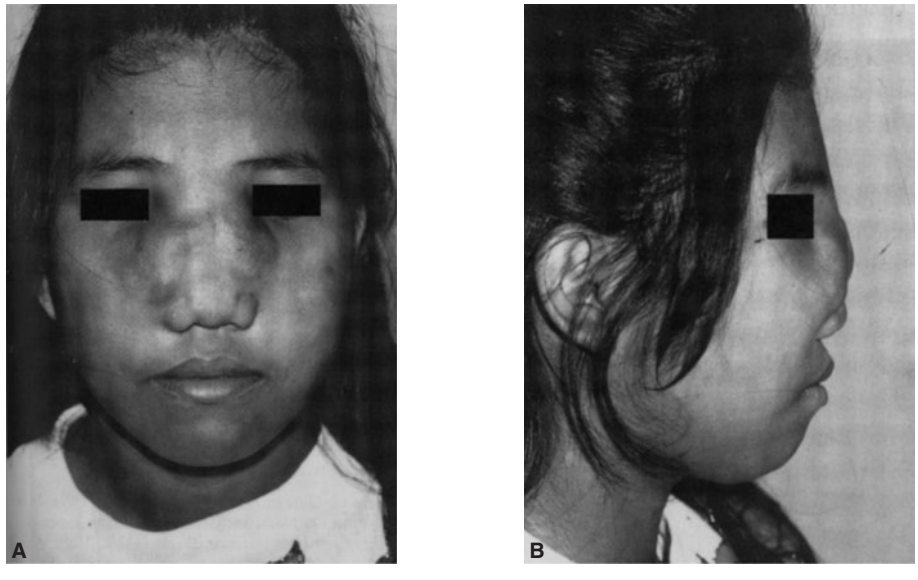
Untreated, nasal encephaloceles carry the risk of CSF leak as well as associated infections that include meningitis and intracranial abscesses. In addition, nasal encephaloceles may increase in size over time, leading to progressive facial deformity.

Treatment of encephaloceles is surgical resection and requires a multidisciplinary approach. Surgical procedure involves closure of the dural and skull base defects through craniotomy, followed by removal of the extracranial component and reconstruction of external bony defects.

NASAL GLIOMA

ESSENTIALS OF DIAGNOSIS

- Usually present at birth.
- Gliomas are non-compressible and do not trasilluminate.
- MRI is preferred for evaluation.



▲ **Figure 11–5.** (**A** and **B**) Nasal encephalocele.

Nasal gliomas are similar to encephalocele, but with obliterated intracranial connection (Figure 11–3C). Nasal gliomas are thought to have a similar embryologic origin as nasal encephalocele. About 15–20% of nasal gliomas have a fibrous stalk connection to the intracranial space.

Nasal gliomas are usually diagnosed at birth or in early childhood. They rarely have associated bony or intracranial abnormalities and carry a low risk for meningitis and CSF leak. Sixty percent of nasal gliomas are extranasal, 30% are intranasal, and 10% are both. Extranasal gliomas are most commonly found along the nasal dorsum and are usually firm, noncompressible masses with a negative Furstenberg test and do not transilluminate. These masses are often purple or gray and can have surface telangiectasias, which explains a frequent misdiagnosis as nasal hemangiomas. Intranasal gliomas can present as pale mass in the nasal cavity causing nasal congestion and obstruction.

MRI is a preferred method for evaluation of nasal dorsal masses and helps to distinguish nasal gliomas from hemangiomas and encephaloceles. Nasal gliomas appear hypo- or isointense on T1-weighted images and hyperintense on T2-weighted images.

Management of nasal glioma consists of surgical excision. Depending on its size, external gliomas can be excised through an external rhinoplasty approach, midline nasal incision, or bicoronal approach. Intranasal gliomas can be excised with endoscopic techniques.

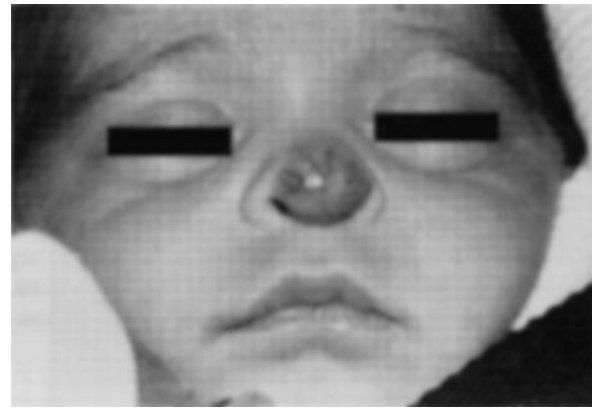
Hedlund G. Congenital frontonasal masses: developmental anatomy, malformations, and MR imaging. *Pediatr Radiol* 2006 Jul;36(7):647–662 [PMID: 16532348]. (The article discusses developmental anatomy and imaging for characterization of midline pediatric frontonasal masses.)

Rahbar R, Resto VA, Robson CD, Perez-Atayde AR, Goumnerova LC, McGill TJ, Healy GB. Nasal glioma and encephalocele: diagnosis and management. *Laryngoscope* 2003 Dec;113(12): 2069–2077. (The article reviews the etiology, evaluation and surgical management of nasal glioma and encephalocele.)

HEMANGIOMAS

ESSENTIALS OF DIAGNOSIS

- Usually not present at birth, appear within the first few months of life.
- MRI is most appropriate for evaluation.



▲ **Figure 11–6.** Nasal tip hemangioma.

Hemangioma is the most common benign tumor in children. These lesions are normally not present at birth and appear within the first few months of life. They undergo a proliferative phase at 3–9 months of age, followed by quiescence and a variable involution phase after 1 year of age.

Hemangiomas can affect any part of the head or neck, including the nose (Figure 11–6). Facial hemangiomas greater than 4 cm can have associated central nervous system malformations. MRI is the most appropriate imaging modality for evaluation.

Most of the hemangiomas regress spontaneously. In comparison to other sites, nasal hemangiomas may have a lower rate of involution. If hemangiomas do not obstruct vision, impair the airway, or distort facial features, they can be observed. Lesions that do not regress and that lead to airway obstruction, facial distortion, bleeding, or thrombocytopenia require more aggressive intervention.

Corticosteroids have been a first line of treatment. Interferon-alpha, vincristine, and surgical excision are other modalities that have been used in treatment of hemangiomas. Recently, reports have been published showing significant improvement of hemangiomas, including nasal hemangioma, with propranolol.

Leaute-Labreze C, Dumas de la Roque E, Thambo JB et al. Propranolol for severe hemangiomas of infancy. *N Engl J Med* 2008;358:2649–2651 [PMID: 18550886]. (The article reports 11 cases of improvement of infantile capillary hemangiomas with propranolol treatment.)

We would like to acknowledge Christina J. Laane, MD for her contribution to this chapter in the previous editions of CDT.

Nasal Trauma

12

Jeffrey H. Spiegel, MD, FACS
& William Numa, MD

ESSENTIALS OF DIAGNOSIS

- History of recent trauma to midface; should assess mechanism of injury, presence of epistaxis or rhinorrhea, history of previous injury, and new onset of nasal airway obstruction or deformity.
- On examination, note any mucosal laceration, septal disruption, or septal hematoma.
- Depending on severity of insult, must rule out concurrent injury to eyes, lacrimal system, paranasal sinuses, teeth, and oral cavity.

General Considerations

Nasal fracture as a result of trauma to the midface is considered the most common of head and neck fractures. Frequently the result of physical altercation, nasal trauma is most often not life-threatening; however, significant functional and aesthetic impairment may result if these injuries are not accurately diagnosed and addressed in a timely fashion.

The incidence of nasal fracture is high in both adults and children. Of maxillofacial injuries, fractures of the nasal bones account for up to 39–45% of cases reported in adults, and up to 45% of injuries in children. In adults, the highest rates of incidence are found among men, with a 2:1 predominance over cases reported in women. In men, nasal fracture is most often associated with intentional trauma and is clearly more common in the 15- to 25-year age group. In women, nasal trauma is usually the result of personal accidental injury; most commonly the result of falls and is often seen in patients over the age of 60.

In children, a clear gender predilection for injury is less likely, although cases are more often reported in boys. Also, more cases of nasal trauma in children are the result of accidental injury related to sports and play rather than physical confrontation. It is important to note, however, that anywhere from 30% to 50% of all pediatric victims of abuse present with maxillofacial injury, a concern not to be overlooked, particularly when evaluating the possibility of fracture concealed by the presence of facial edema.

Pathogenesis

Given the central and prominent position of the nasal bones and the significant lack of skeletal support for their position, the nose is particularly vulnerable to fracture as a result of maxillofacial injury. Reports indicate that the amount of force required to create a fracture of the nasal structure is small, possibly as little as 25 pounds of pressure. Superiorly, the structure of the nasal bones thickens with support from the underlying nasal spine of the frontal bone, an area more resistant to injury than the distal, thinning segment of the nose, which is unsupported and much more often the location of a fracture.

Trauma to the nasal cartilage, either from a directed frontal or inferior assault or from an indirect lateral injury, often results in displacement, dislocation, or avulsion rather than true fracture. The physical elasticity and flexible attachments of the nasal cartilage allow for the significant absorption and dissipation of energy, thus preventing considerable injury from a greater amount of force than the bony structure would tolerate. The nasal septum, however, is less apt to avoid injury given its rigid osteochondral junctions, which include the perpendicular plate of the ethmoid bone and the vomer anteriorly and its relatively weak association with the maxillary crest. As such, a higher incidence of true fracture can be found with the cartilaginous septum as a result of trauma to the midface, usually with a vertical orientation caudally and a horizontal orientation posteriorly.

In children, the nasal bones retain their elasticity with stability resulting from development and immature pneumatization. These factors, combined with a child's proportionally smaller nasal bones and proportionally larger cartilaginous

structures, produce a greater tendency for cartilaginous injury to occur. However, in most cases of nasal trauma, the nasal cartilage fractures without significant displacement and, given the inherent flexibility of a child's nose, often returns to its anatomic position.

Classification

The classification of nasal injuries can be separated into two groups: those created by lateral or oblique impact and those created by frontal impact.

A. Lateral Injuries

Lateral injury, the more common variety given the absence of structural support on either side of the nasal pyramid, can be divided into three planes, with the extent of involvement dependent on the force of impact. Injury in the first plane results only in fracture of the ipsilateral nasal bone, by far the most common occurrence, which usually results in a visible depression of the bony surface two thirds of the way down its slope. With greater force, injury in the second plane would also involve the contralateral nasal bone and septum. In the third plane, enough force would be provided to fracture the frontal process of the maxilla and the lacrimal bone, possibly resulting in fragmentation, a total dislocation of the nasal architecture, or even injury to the lacrimal apparatus.

With lateral injuries, fractures of the nasal septum usually extend posteriorly into the perpendicular plate of the ethmoid bone, but without extension to the cribriform plate.

B. Frontal Injuries

Frontal injuries generally require a greater amount of force and are divided into three planes as well. The first plane is limited to the nasal tip and does not extend beyond an anatomic line separating the lower part of the nasal bones from the nasal spine. With most of the impact absorbed by the nasal cartilage, injury usually involves avulsion of the upper lateral cartilages. Posterior dislocation of the septal and alar cartilages is also possible, but less likely. Injury in the second plane includes the nasal spine as well as the nasal dorsum and the nasal septum. Injuries in this plane produce a flattening and splaying of the nasal bones with deviation of the septum, overriding segmentation, mucosal tearing, and fracture of the nasal spine. Injury in plane 3 requires a substantial force of impact and may involve fractures of the orbit or extend to structures within the cranial vault. The nasal bones are often comminuted and associated with fractures of the frontal process of the maxilla, lacrimal, and ethmoid bones, and occasionally the cribriform plate. Fracture and dislocation of the nasal septum are severe, with collapse of the dorsal plane and telescoping of the septal fragments.

The nasal septum may be involved in approximately 20% of all traumatic fractures of the nose. A substantially greater impact, however, whether frontal, lateral or oblique, consistently produces a C-type fracture of the septum just posterior to the nasal spine and extending posteriorly and superiorly into the perpendicular plate. It then changes direction anteriorly, ending just before and below the cribriform plate, along the posterosuperior aspect of the nasal bones. This finding can be demonstrated on physical exam by noting displacement of the caudal septum to one side and deviation of the posterior septum to the other.

Anatomy

A. Nasal Pyramid

The structure of the nasal pyramid projects anteriorly from the midface, attached to the facial skeleton at its base superiorly. From the apex or nasal tip, the columella projects inferoposteriorly toward the center of the superior lip, adjacent on either side to the nares. Encompassing the border of the nares are the alae of the nose superiorly and laterally, and the floor of the nose inferiorly. At the posterior aspect of the base of the nose is the piriform aperture, bordered superiorly and laterally by the frontal processes of the maxilla and the nasal bones. The inferior portion of the cartilaginous nose, otherwise considered the base of the nose, includes the lobule, which consists of the lower lateral cartilages, the tip, the alae, and the columella. In the midline, the posterior aspect of the medial crura of the lower lateral cartilages articulates with the caudal membranous septum. Anteriorly, the medial crura are enclosed within the columella. The lateral crura of the lower lateral cartilages project superiorly to overlap the inferior aspect of the upper lateral cartilages in the midline. Laterally, these crura loosely attach to the piriform aperture. The superior portion of the cartilaginous nose includes the two upper lateral cartilages and the quadrilateral cartilage of the septum, all of which are invested by a common perichondrial sheath. Laterally, the superior aspects of the upper lateral cartilages are also loosely attached to the piriform aperture.

B. Nasal Vault

Superior to the nasal base is the bony vault of the nose, which is bound by the frontal processes of the maxilla, the nasal bones, and the alveolar process. Through the midline of this vault runs the anterior nasal spine inferiorly and the perpendicular plate of the ethmoid bone superiorly. At the superior aspect of where the nasal bones meet the frontal bone is the nasion, which is the midline portion of the nasofrontal suture. At the inferior aspect of where the nasal bones meet the nasal cartilages is the rhinion, which is also in the midline. The septum of the nose includes the quadrilateral cartilage and the anterior nasal spine anteroinferiorly, and the perpendicular plate of the ethmoid bone, the sphenoid crest, the vomer, and the maxillary crest posterosuperiorly. At the roof of the nose within the nasal cavity is the cribriform

plate, and at the posterior aspect of this roof is the choana, through which the nasal cavities and the nasopharynx communicate. At the floor of the nasal cavity are the palatine process of the maxilla and the horizontal process of the palatine bone, with the medial pterygoid plates located laterally on either side.

C. Nasal Turbinates

The nasal turbinates are found on the medial aspects of the nasal cavities. The inferior turbinate lies superior to the inferior meatus and is the largest of the three. Inferior to the turbinate within the inferior meatus is the opening of the ipsilateral nasolacrimal duct. The middle meatus lies between the inferior and middle turbinates and accepts drainage from the frontal sinus, the maxillary sinus, and the anterior ethmoid air cells. The superior turbinate lies above the superior meatus, which drains the posterior ethmoid air cells. Posterosuperior to this structure lays a sphenoethmoid recess on either side of the anterior aspect of the sphenoid sinus.

D. External Blood Supply

The external blood supply of the nose includes indirect contributions from both the external and the internal carotid arteries. From the external carotid artery, branches of the facial artery supply the inferior aspects of the nose and include the superior labial and lateral nasal arteries. These branches join with the dorsal nasal artery, a terminal point for the ophthalmic artery from the internal carotid artery. The internal blood supply of the nasal pyramid and superior portion of the nasal cavity also include an indirect contribution from the internal carotid artery by way of the anterior and posterior ethmoid branches of the ophthalmic artery. The maxillary artery off of the external carotid artery provides most of the blood supply to the nasal cavity by way of the sphenopalatine artery. At the posterior aspect of the middle turbinate, the sphenopalatine artery splits into the posterolateral nasal and septal arteries, the septal branches of which communicate anteriorly with the anterior ethmoid arteries—an important anastomosis between the external and internal arterial systems.

E. Venous Drainage

Venous drainage of the nose follows the accompanying arterial supply, with facial veins emptying into the external and internal jugular veins. In the nasal cavity, venous drainage from the ethmoid bones enters the orbit, thereby communicating via the ophthalmic veins with the cavernous sinus and dural venous system. Posteriorly, venous drainage from the nasal cavity follows the sphenopalatine veins into the pterygopalatine fossa and plexus, also communicating with the dural venous system. This posterosuperior venous drainage of the nose is thus a potential vehicle for extracranial infections to spread intracranially.

F. Nerve Supply

The nerve supply of the nose includes general somatic efferent innervation from buccal branches of the facial nerve. General somatic afferent innervation is supplied by the first two branches of the trigeminal nerve. From the ophthalmic branch arise the anterior and posterior ethmoid nerves and the infratrochlear nerve. From the maxillary branch arise the posterolateral and posteroinferior nasal nerves, the nasopalatine nerve, and the infraorbital nerve, which joins with the infratrochlear nerve and external nasal branch of the anterior ethmoid nerve to innervate the skin. Sympathetic innervation to the nasal mucosa is derived from postganglionic fibers of the maxillary nerve via the nerve of the pterygoid canal, which originates via the deep petrosal nerve from the superior cervical sympathetic ganglion. Parasympathetic innervation in the nose includes zygomaticotemporal distribution to the lacrimal gland, also via the maxillary nerve and the nerve of the pterygoid canal. Special sensory innervation via the olfactory nerve pierces the cribriform plate at the roof of the nasal cavity from the inferior aspect of the olfactory bulbs to innervate the superior aspect of the nasal septum and the superior turbinate. A terminal nerve also pierces the cribriform plate to innervate the cartilaginous septum anteriorly from a terminal ganglion located medially to the olfactory bulbs.

Clinical Findings

A. History

The mechanism of injury in nasal fracture usually involves some variety of blunt traumas to the midface. However, information regarding the direction, force, and exact location of the impact is valuable in determining the probable extent of injury. Given the nature of severe edema associated with midface trauma, an evaluation of the extent of injury can be hindered if a significant delay exists between the time of injury and the time of examination. Early treatment is important because most nasalseptal fractures can be managed by closed reduction within a few hours. Thus, if the timing of the injury has allowed for a hindrance to proper inspection, repair must be delayed from 3 to 11 days, depending on the time required for the inflammation to subside. If enough time has passed for the initial insult to heal, the management required to repair the fracture could be extensive.

B. Symptoms and Signs

Additional history regarding the findings associated with nasal trauma can also be paramount in determining the extent of the injury. In most cases, a history of epistaxis is noted, the severity of which depends on the extent of mucosal laceration sustained at the time of injury. Rhinorrhea may also be noted and, depending on the accuracy of the patient's

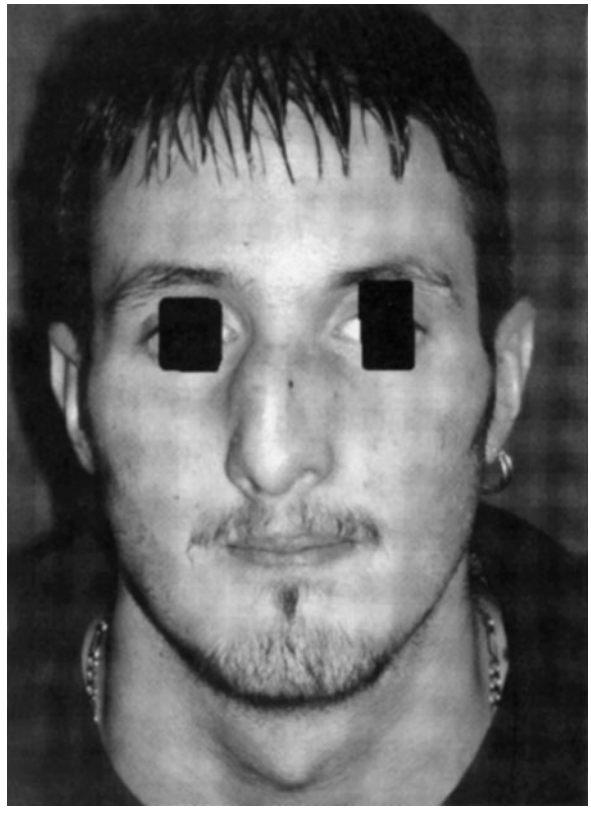
description of his or her nasal discharge, may be indicative of trauma intracranially (eg, cerebrospinal fluid [CSF] rhinorrhea). Deformity of the nose and airway obstruction can be severe, but a history of insult, including fracture, obstruction, or reconstructive surgery, may interfere with determining the degree of the deformity sustained acutely. If the mechanism of injury is severe, a regional review of systems may be required, including a history of oculomotor or visual dysfunction, anosmia independent of mucosal injury, and dental or facial sensory deficits often associated with maxillary involvement.

C. Physical Examination

With the patient seated and comfortable, the nose should be viewed externally from all angles, with any unusual variations in contour, size, anatomic angles, lacerations of the skin, and hematomas noted. The presence and severity of epistaxis and, if applicable, CSF rhinorrhea should also be noted. A proper internal examination of the nose requires mucosal decongestion with either 0.25% phenylephrine or oxymetazoline hydrochloride administered as a spray or with careful placement of cotton pledgets. If desired, 4.0% cocaine may be used, which has the advantage of providing anesthesia in addition to local vasoconstriction. Following this preparation, palpation of the nasal skeleton and cartilages may reveal abnormal variations in position and stability, as well as the presence of crepitus or point tenderness. Using a nasal speculum, each nasal cavity should be assessed either via direct visualization or, if necessary, with the aid of endoscopy. The nasal septum should be examined for the presence of deformity, dislocation, swelling, laceration, and hematoma (Figure 12–1).

During examination, an unusually wide or flat nasal base or nasal tip, along with abnormal nasal tip deflections, suggests prior injury or deformity. Injury extending to the orbit may include loss of the glabellar angle and the presence of telecanthus. CSF rhinorrhea indicates extension to the cribriform plate, frontal sinuses, or nasoethmoid complex. Medial maxillary involvement includes maxillary wall depression and a C-shaped nasal-septal deformity, with or without concurrent depression of the frontal process of the maxilla or inferior orbit. The stability of this process may be assessed further with bimanual examination using a Kelly clamp internally and a finger externally.

Unusual mobility of the nasal cartilages is consistent with avulsion, a finding often associated with mucosal laceration. Acute injury to the nasal septum is better differentiated from prior injury by the presence of motion tenderness with bimanual palpation. Pain localized to the anterior nasal spine, with or without dislocation, is also indicative of acute injury and should be assessed by sublabial palpation. A septal hematoma, if present, usually involves only the cartilaginous septum. It is associated with widening of the septum and persistent discoloration and should be pursued further with direct aspiration or mucosal incision.



▲ **Figure 12–1.** A young man 7 days after getting hit in the nose during an altercation. Note the obvious deformity and deviation.

D. Imaging Studies

Although still controversial, in most cases, the use of imaging studies in the diagnosis of nasal trauma is unnecessary. With radiographs, studies have demonstrated poor sensitivity and specificity in diagnosing nasal fractures; therefore, even in patients whose abnormalities were not demonstrated, management was unaffected. In addition, differentiating prior fracture from acute injury in the case of minimal displacement is unlikely. Thus, since the assessment and intervention of acute nasal injury are determined by clinical presentation, obtaining radiographs is not recommended except when legal documentation is necessary, as in the case of suspected abuse, or when the presence of additional fractures to the midface is suspected, as in more extensive injury. With severe trauma that includes involvement of the orbit, the ethmoid bones, or the cribriform plate, coronal sections with computed tomography (CT) should be obtained.

Differential Diagnosis

Although simple nasal fractures remain the most common of all facial fractures, they must be distinguished from the more serious maxillofacial and nasoethmoid fractures. As mentioned previously, nasoethmoid fractures include extension into and through the nasoethmoid complex, often resulting in dural tears and CSF rhinorrhea. Fractures of the zygoma usually involve a V-shaped deformity with three separate breaks, two occurring along each end and one in the middle of the arch. On physical exam, trismus of the temporalis muscle may be elicited, depending on the degree of bony impingement. A tripod or zygomaticomaxillary fracture may be found with force that has been directed at the cheek; it usually involves one or more of the articulations among the zygoma, the frontal bone, and the maxilla, with extension through the orbital floor. On physical exam, paresthesia may be found along the distribution of the ipsilateral infraorbital nerve. With force directed at the inferior maxilla, alveolar fractures may be found along the superior aspect of the dental margin, often associated with loosened dentition and gingival ecchymosis or hemorrhage.

In ruling out additional fractures of the midface that are seen with nasal trauma, the **Le Fort classification** denotes three classic patterns of injury associated with blunt midfacial injury. **Type I** injury involves separation of the maxillary process from the maxilla itself, with extension to the maxillary sinuses. This typically results from force directed horizontally across the midface below the level of the orbit. **Type II** injury occurs in association with fracture of the nasal bones extending through the lacrimal bone toward and through the zygomaticomaxillary junction. In addition, the fracture extends posteriorly just below the zygoma and along the superior border of the pterygoid plates. Infraorbital paresthesia and bilateral subcutaneous hematomas are often found on examination. **Type III** injury is also associated with nasal fracture, but courses posteriorly through the ethmoid bones and laterally through the orbits below the optic foramen and through the pterygomaxillary suture into the sphenopalatine fossa. This results in craniofacial dysjunction and the appearance of a long, flat, facial deformity.

In children, additional fractures of the face associated with significant nasal trauma are not uncommon. Given the lack of significant nasal projection and inherent cartilaginous flexibility of the pediatric nasal skeleton, trauma to the midface is more evenly distributed to the maxilla. This provides for a significant risk of maxillofacial and midface fracture as well as extensive facial edema, which often obscures the diagnosis. Such injuries have been associated with disturbances in the normal growth and development of the facial structure—as with premature ossification of the septovomerine suture, which is found with injuries of the nasoethmoid complex—and thus require a conservative approach to diagnosis and management.

Complications

A. Cosmetic Deformity

External physical deformities that result from nasal trauma include the creation of a dorsal hump, lateral deviation of the dorsum and tip, a widened nasal base, and depression and splaying of the nasal tip. Complex (and obstructing) septal deformities may also result, including the appearance of bony spurs, complex alterations in nasal symmetry, and angular deflections of the septum itself. Internally, synechiae may develop where mucosal lacerations are found, particularly between the septum and adjacent turbinates. Most deformities require reconstructive septorhinoplasty to restore function and cosmetic appearance. In cases of pediatric deformity, a delay of revision is often required to allow for normal facial growth and development. With obstructive scar tissue and synechiae, simple division and separation with pledgets coated with antibiotic ointment are usually effective in allowing for reepithelialization.

B. Epistaxis and CSF Leak

The initial edema and epistaxis of nasal trauma usually resolve without intervention; however, persistent epistaxis may require tamponade with nasal packing or, rarely, identification and coagulation or ligation of the bleeding vessel. With CSF leak, the injury is significantly more severe and may require consultation with a neurosurgeon. Therapy usually includes close observation and may involve bone grafting or placing a drain in the lumbar spine.

C. Septal Hematoma and Saddle Nose Deformity

Septal hematoma results from bleeding, often bilateral, within the subperichondrial plane of the septum. If left unattended, fibrosis of the septal cartilage may occur, followed by necrosis and perforation within 3–4 days. The loss of structural support leads to septal collapse, which results in a characteristic saddle nose deformity of the nasal dorsum and retraction of the columella. A hematoma is often suspected given excessive septal edema and severe localized tenderness on examination. Treatment is urgent and includes a horizontal incision made at the septal base to provide for mucoperichondrial drainage. Reaccumulation is prevented with the application of plastic splints or intranasal packing. Antibiotic prophylaxis is also required. Saddle nose deformity may require an extensive reconstruction to restore the structure and shape of the nose. We prefer split calvarial bone grafting for reconstruction of this deformity, although rib cartilage and other materials have been used with success.

D. Airway Obstruction

Fibrosis of the nasal septum, as occurs with septal hematoma, may become organized, creating cartilaginous

thickening and resulting in partial airway obstruction. Obstruction may also occur at the nasal vestibule from a traumatic loss of epithelium or the malunion of a nasal fracture. The treatment of nasal septal reorganization may be accomplished with submucosal resection, although some cases require partial turbinectomy. Soft tissue injury and contracture that occur at the nasal vestibule may require excision of the resultant scar and reconstruction with composite or autologous grafts. Malunion is treated with simple osteotomy.

Treatment

A. Timing of Repair

Within 1–3 hours of the time of injury before significant edema has developed, simple closed fixation of nasal fracture is possible given a cooperative patient and uncomplicated clinical findings. However, patients rarely present this early and often require reevaluation within 3–7 days to allow for extensive facial edema to subside. In adults, closed reduction can be performed within 5–11 days after injury before the fractured nasal skeleton becomes adherent and difficult to manipulate, with fixation occurring in 2–3 weeks. In children, healing is more rapid, with adherence and fixation occurring in roughly half that time. Thus, given a significant therapeutic delay, the necessity for osteotomy and bony reconstruction becomes more likely, which is a particular concern for the pediatric population. Regardless of patient age, however, severe nasal trauma that results in more significant injury, such as septal hematoma, open fractures, or associated fractures of the midface and cranium, requires immediate surgical attention.

B. Anesthesia

In choosing a method of anesthesia to use when repairing nasal fracture, both the severity of the injury and the patient's preference should be considered. General anesthesia is necessary for significant trauma that requires operative intervention. With simple nasal trauma, local anesthesia, with or without sedation, is generally preferred. Local anesthesia is safer and considered as effective in providing for adequate fracture reduction when compared to general anesthesia. However, with nasal trauma in children, general anesthesia provides more control than is usually provided by an uncooperative minor. In either case, the physician should decide which method would provide the optimal comfort necessary to allow for the application of force necessary to reduce the nasal fracture. It has been our experience that in a properly prepared patient and with an experienced surgeon, local anesthesia using only topical cotton-soaked nasal packs is adequate for comfortable closed reduction and stabilization of most nasal fractures in all age groups. It is necessary to remember that the anesthetic-soaked cotton must be placed superiorly between the nasal bones and the septum rather than along the inferior septum or along the inferior turbinates, as is commonly done for other intranasal interventions.

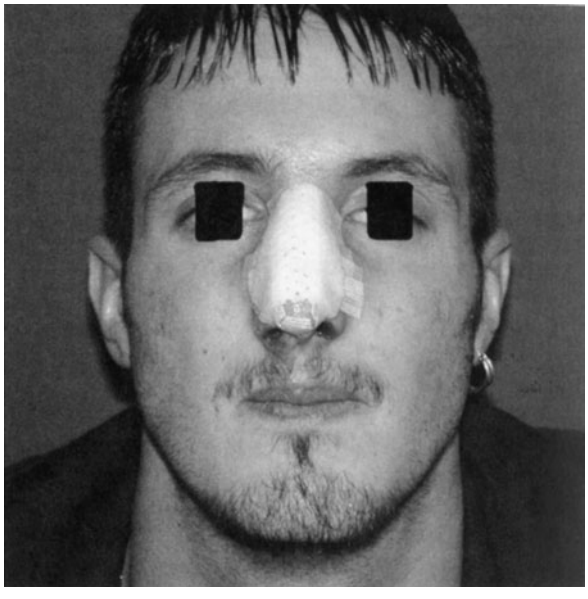
C. Closed Reduction

Closed reduction is safe and easy to perform. Reasonable cosmetic and functional results are attainable with closed reduction, obviating the need, when applicable, to subject the patient to unnecessary risk, procedure, and cost. Treatment should be geared toward the best long-term results possible, given the least invasive technique available. However, the failure rate of closed-reduction procedures may require a secondary open reduction or delayed reconstruction, an inevitability that many proponents of primary open reduction strive to avoid.

Ideally, the presentation of injury suitable for closed reduction includes injury in the first plane as either a fracture of the nasal tip or depressed fracture of the nasal bone on one side. To proceed, local anesthesia should be provided along the distributions of the infraorbital and supratrochlear nerves and at the base of the anterior nasal septum. If needed, nerve blocks are achieved using 1–2% lidocaine with epinephrine. Once the nose has been anesthetized, a Boies elevator, the back of a metal knife handle, or even the closed tips of a straight Mayo scissors can be inserted under the depressed nasal fragments to within approximately 1 cm of the nasofrontal angle. Elevation is accomplished by exerting force in the direction opposite to the direction of the fracture. Pressure is then applied externally with a free hand on any segment that is displaced laterally. If manipulation of the fracture proves difficult owing to impaction or locking of the fragments, Walsham forceps may be used to directly manipulate the nasal bones and facilitate reduction. Occasionally, free-hand manipulation of more mobile fragments may be necessary to achieve adequate repositioning. It is common to need to rotate the depressed fragment first medially, then superiorly and laterally, to dislodge it. In many cases, a satisfying "click" is felt as the bone repositions into the proper location.

Adequate closed reduction in the nasal pyramid often allows for the spontaneous reduction in a displaced or fractured septum. If this is not the case, Asch forceps may be used to gently elevate the nasal dorsum and allow for replacement of the septum into its anatomic position. In the case of a difficult reduction, a perichondrial elevator may be required to expose an overriding segment of cartilage for resection.

Structural support after a successful reduction can be provided using cotton pledgets soaked in an appropriate intranasal antibiotic. It is preferable, however, not to leave in any nonabsorbable material; therefore, we recommend small pieces of surgical oxycellulose (eg, Surgicell), if necessary. Silastic splints may also be desirable to stabilize the septum. Externally, Steristrips or other protective tape should cover the nasal dorsum before applying a malleable thermoplas-



▲ **Figure 12–2.** Same patient as in Figure 12–1 after closed reduction in nasal fracture in the office with local anesthesia. Note that a thermoplastic splint holds nasal bones in a "straight" reduced position.

tic or plaster splint that has been conformed to the shape of the nasal reduction (Figure 12–2). After approximately 3–5 days, the internal packing can be removed, followed by removal of the external splint by day 7–10 if stability has been accomplished.

D. Open Reduction

The reduction of nasal fractures using open techniques is usually reserved for cases in which either a prior closed reduction has failed or malunion has occurred. Other cases where primary open reduction would be appropriate include third-plane fractures, fractures involving the orbit or maxilla, and Le Fort fractures of the midface. Depending on the indication for open reduction, most cases can be adequately reduced with a standard endonasal rhinoplasty. This approach provides for a more appealing cosmetic result while allowing for direct fragment manipulation. Operative exposure, however, is limited. For cases involving the orbit or injury to the frontal sinuses, an external approach from incisions made distal to the nose may be required. Other more complex fractures may require degloving techniques, a coronal approach, or even a lateral rhinotomy.

In most cases, nasal trauma that requires open reduction involves interlocking segments with dislocation of the quadrangular cartilage or a C-shaped septal deformity. After the appropriate administration of anesthesia, open reduction begins with hemitransfixion of the nasal septum on the affected side and septoplasty. Lateral intercartilaginous incisions are then made, allowing for both elevation of the nasal dorsum off of the upper lateral cartilages and elevation of the nasal periosteum. Lateral fracture lines may be accessed via incisions made at the piriform aperture. Affected cartilaginous segments are then exposed and reduced.

With nasoseptal injury, a Cottle elevator is used to strip cartilage from buckled or telescoping portions of the septum, allowing for the spontaneous return of the septum to the midline. Structural support may be lost with excessive resection, and aggressive periosteal elevation may result in necrosis or subsequent malunion. For C-shaped deformities, separation of the upper lateral cartilages from the dorsal septum is necessary. Once reduction is accomplished, additional support for the septum may be provided with stay sutures placed through the periosteum at the anterior nasal spine and the inferior aspect of the septal cartilage.

If encountered, displacement of the maxilla may require the complete removal of the maxillary crest. Any unstable fragments, as seen with comminuted fractures, can be secured using fine wire or miniplate fixation and a minidrill. Using a "figure 8" configuration, wires should not be palpable below the skin. Intranasal packing is rarely necessary, although prophylactic oral antibiotics are administered for at least 5 days. With septal injury, splints may also be applied.

E. Pediatric Considerations

The treatment of nasal trauma in children must be based on the potential for developmental dysfunction as a result of therapy and the consequences of delayed intervention. In cases of minimal injury, the child's nose may spontaneously return to an anatomic position with only an external splint to protect the nasal dorsum during the healing process. The integrity of the nasal septum, however, is vital to nasal skeletal and anterior maxillary growth and therefore requires specific attention.

Operative intervention is required for nasal septal displacement that results in significant cosmetic or functional impairment. As with the adult population, closed reduction is preferred, although general rather than local anesthesia is usually necessary with children. Simple reductions can often be performed with digital manipulation; otherwise, the standard procedure for closed reduction should be used. Fracture dislocations that do not reduce with closed techniques are approached very carefully, making sure no measures are undertaken that might compromise normal growth and development. Aggressive resection is avoided altogether, and any septorhinoplasty deemed necessary to restore appearance or function is delayed until the teenage years. With reasonable conservative correction of the deformity and restoration of a patent airway, adequate

surgical management will not result in a disruption of nasal growth centers or the creation of significant structural abnormalities.

Prognosis

In general, uncomplicated fractures heal within 2–3 weeks with good cosmetic and functional results. Refractory cosmetic complications, however, are possible with both open and closed techniques and usually involve septal deviation. Reductions that result in malunion or deformity may require further reduction or reconstruction, depending on the severity of injury and the difficulty the reduction in the primary injury presents. Septorhinoplasty remains the standard of care for unsatisfactory results and is often necessary in cases of failed reduction attempts.

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We would like to acknowledge Benjamin R. Sigmond, MD for his contribution to this chapter in the previous editions of CDT.

Nasal Manifestations of Systemic Disease

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13

GRANULOMATOUS & AUTOIMMUNE DISEASES

General Considerations

Granulomatous and autoimmune diseases are characterized by a systemic chronic inflammatory process and a predilection for particular organ systems. Occasionally, patients may present with florid nasal symptoms such as severe crusting, inflammation, and saddle-nose deformity, which raise suspicion early in the evaluation. However, sinonasal manifestations are often nonspecific, including nasal obstruction, rhinorrhea, and recurrent sinusitis. The practitioner must therefore include these diseases in the differential diagnosis of chronic sinonasal symptoms and assess for systemic manifestations in the history and physical examination.

Although obtaining biopsies of suspicious lesions is critical for establishing a diagnosis, specimens often demonstrate nonspecific chronic inflammation and necrosis. Helpful adjunctive tests include inflammatory markers (erythrocyte sedimentation rate and C-reactive protein), complete blood cell count, various autoimmune serologies, chest X-ray, urinalysis, and bacterial and fungal cultures.

The goals of managing the sinonasal manifestations of these diseases are to provide symptomatic relief of nasal obstruction and crusting and to reduce the incidence and severity of secondary sinusitis from ostial obstruction by reducing mucosal edema and facilitating mucociliary clearance. Patients may also require concurrent systemic therapy.

WEGENER'S GRANULOMATOSIS

ESSENTIALS OF DIAGNOSIS

- Severe nasal crusting with friable underlying mucosa, septal perforation, and saddle nose deformity.
- ANCA (antineutrophil cytoplasmic autoantibodies), chest X-ray, and urinalysis.
- Nasal biopsy of suspicious lesions; possible renal biopsy.

General Considerations

Wegener's granulomatosis is an idiopathic vasculitic and autoimmune process that typically involves the upper and lower respiratory tracts. It occurs in all age groups and predominantly affects white populations. The spectrum of disease presentation ranges from localized to disseminated forms, but the majority of patients have otolaryngologic manifestations. Classically, Wegener's granulomatosis involves a triad of necrotizing granulomas of the upper and lower airways, glomerulonephritis, and disseminated vasculitis. Upper respiratory tract symptoms may occur in up to 90% of patients, and sinonasal symptoms may be the only systemic manifestation in 30%. The previously undiagnosed patient may present with a pattern of chronic or recurrent sinusitis, managed medically and often surgically with variable clinical improvement.

Clinical Findings

A. Symptoms and Signs

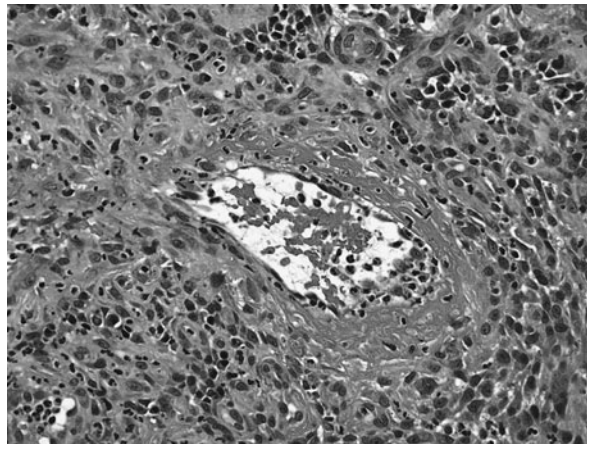
The more limited, localized form of Wegener's granulomatosis typically presents with a several-week history of upper respiratory infection symptoms that are unresponsive to standard medical treatment, with the presence of serosanguineous nasal drainage and characteristic pain over the dorsum. Nasal exam is notable for significant bilateral nasal crusting with underlying friable mucosa, particularly over the nasal turbinates, with possible extension to the nasopharynx. Septal perforations may be found with progressive disease, and can lead to saddle-nose deformity due to loss of cartilaginous support and a resultant a dorsal concavity.

Other potentially involved head and neck sites are (1) the orbit, with nasolacrimal duct obstruction, orbital pseudotumor, episcleritis, or peripheral ulcerative keratitis; (2) the ear, including serous otitis media, with or without mastoiditis, and possible sensorineural hearing loss; and (3) the larynx and trachea, with subglottic stenosis and tracheal stenosis. Oral cavity ulcerations, gingival hyperplasia, and sialadenitis are rare manifestations of Wegener's granulomatosis. Systemic symptoms may include weakness, night sweats, and migratory arthralgias. More advanced systemic disease manifests as clinically significant pulmonary and renal pathology, although most patients have renal involvement, even if it is subclinical.

The classification criteria for Wegener's granulomatosis are the following: (1) oral ulcers and purulent or serosanguineous nasal discharge; (2) abnormal chest X-ray (which may include nodules, cavities, or fixed infiltrates); (3) abnormal urinalysis suggesting renal involvement; and (4) granulomatous inflammation evident on biopsy.

B. Laboratory Findings

Although the specificity of antineutrophil cytoplasmic antibodies (c-ANCA) for Wegener's granulomatosis is as high as 98%, the sensitivity varies with disease activity and is 90% in patients with active systemic disease, 60% in patients with localized disease, and 30% for patients in a remission phase. Typically, a positive c-ANCA on immunofluorescence is followed by a confirmatory PR3-ANCA (proteinase 3) on enzyme immunoassay. In a majority of patients, c-ANCA titers parallel disease activity and a titer increase may herald relapse. A positive biopsy characterized by necrotizing granulomata, multinucleated giant cells, and palisading histiocytes is highly suggestive of the diagnosis (Figure 13–1).



▲ **Figure 13–1.** Active vasculitis with fibrinoid necrosis and acute inflammatory cell infiltrate in vessel wall in Wegener's granulomatosis. (High power, H&E stain. Contributed by Dr. Adam Gersten, Weill Medical College of Cornell University, Department of Pathology and Laboratory Medicine.)

Treatment

The goals of therapy are to induce remission of active disease, maintain remission, and to control adverse effects of disease. The initial goal of therapy is remission induction with cyclophosphamide (2 mg/kg/day) and high-dose glucocorticoids (prednisone 0.5-1 mg/kg/day). Methotrexate may be used instead of cyclophosphamide in more limited forms of the disease. After 1 month of treatment, steroids can be slowly tapered over several months. Cyclophosphamide should be continued for 6–12 months until symptoms disappear and then switched to a less toxic immunosuppressant, such as methotrexate or azathioprine. Investigational therapies include tumor necrosis factor antagonists (etanercept), T-cell inhibitors (lefunomide), and monoclonal antibody therapy (rituximab). Trimethoprim/sulfamethoxazole may have a role for either the limited form of Wegener's granulomatosis, for pneumocystis pneumonia prophylaxis while on immunosuppressants, or to prevent relapse.

Sinonasal manifestations may be managed medically with low-dose systemic steroids, topical nasal steroids, saline irrigations, and anti-staphylococcal antibiotics when bacterial superinfection is suspected. The role of surgical intervention is limited and may include repair of saddle-nose deformity during a period of remission, septal prosthesis, and conservative endoscopic sinus surgery.

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SARCOIDOSIS

ESSENTIALS OF DIAGNOSIS

- Chest X-ray (bilateral hilar adenopathy).
- Angiotensin-converting enzyme (ACE) levels positive in 60% of patients with active disease.
- Serum calcium level elevated in 15% of patients.
- Biopsy of suspicious mucosal lesions, labial minor salivary gland, or transbronchial lymph nodes.

General Considerations

The incidence of systemic sarcoidosis is approximately 16.5/100,000 in men and 19/100,000 in women. Approximately 1–4% of patients with sarcoidosis have sinonasal manifestations. The disease is more common in women and in African American and Latin populations, with a peak incidence between the ages of 20 and 40 years and a second peak in women greater than 50.

Sarcoidosis is a chronic granulomatous disease with predominantly pulmonary manifestations, although almost any organ system may become involved. Classic head and neck manifestations include xerostomia and salivary gland enlargement, xerophthalmia, and supraglottic laryngeal lesions causing hoarseness. Other manifestations include lupus pernio (cutaneous sarcoid), neurosarcoidosis, and uveoparotid fever (Heerfordt's disease), which is the association of uveitis, parotitis, and facial nerve paralysis with sarcoidosis.

Pathogenesis

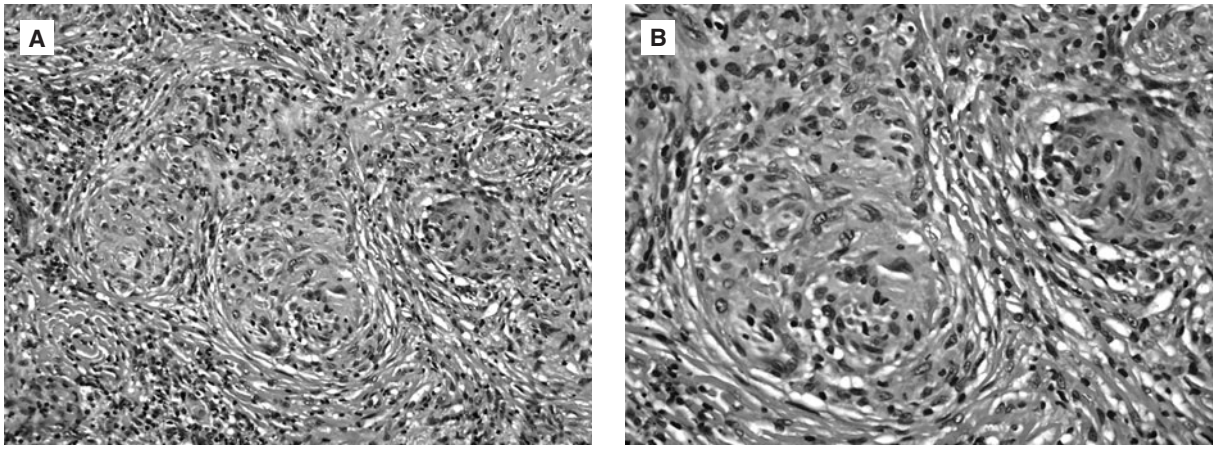
The etiology of sarcoidosis is unknown. The histopathology reveals noncaseating granulomas without necrosis or vasculitis (Figures 13–2A and 13–2B).

Clinical Findings

The clinical symptoms associated with sinonasal sarcoidosis are usually nonspecific and include nasal obstruction, chronic crusting, anosmia, epistaxis, postnasal drainage, headache, and recurrent sinus infections. In patients with sinonasal symptoms and coexisting lung disease, sarcoidosis should be in the differential diagnosis. Classic intranasal findings include hypertrophied mucosa and submucosal granulomatous nodules. Other intranasal features suggestive of sarcoidosis include severe nasal obstruction and crusting with friable mucosa, nasal polyps, turbinoseptal synechiae, septal perforation, and external nasal deformity such as saddle nose. A thorough history and head and neck examination may reveal other manifestations. Ultimately, directed intranasal biopsy may be needed to definitively establish the diagnosis. Positive laboratory studies, including elevated ACE and calcium levels, and a chest X-ray, showing bilateral hilar adenopathy are highly suggestive.

Treatment

Depending on the severity of sinonasal disease, patients may be managed with topical steroids, intralesional steroid



▲ **Figure 13–2.** Low-power **(A)** and high-power **(B)** H&E stains demonstrating sarcoidosis with confluent nonnecrotizing granulomatous inflammation with epithelioid histiocytes. (Images contributed by Dr. Syed A. Hoda, Weill Medical College of Cornell University, Department of Pathology and Laboratory Medicine, Anatomic Pathology Division.)

injections, or systemic steroids. Nasal irrigation may allow for the mechanical debridement of crusting and thick mucus. Surgical intervention should be avoided when possible but may be necessary for refractory cases of nasal obstruction and chronic sinusitis. For systemic sarcoidosis, oral corticosteroids are the mainstay of therapy. Treatment regimens may also include cytotoxic agents (methotrexate, azathioprine, cyclophosphamide, chlorambucil), anti-malarial drugs (chloroquine and hydroxychloroquine), thalidomide, and TNF-alpha inhibitors (infliximab, adalimumab, etanercept). Overall, therapy should be designed to minimize the use of long-term systemic steroids if the patient's systemic disease is well controlled.

Kay DJ, Har-El G. The role of endoscopic sinus surgery in chronic sinonasal sarcoidosis. *Am J Rhinol* 2001;15(4):249–254 [PMID: 11554657]. (Discussion of the risks and benefits of endoscopic sinus surgery in sarcoidosis patients.)

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CHURG–STRAUSS SYNDROME

ESSENTIALS OF DIAGNOSIS

- Criteria based on definitions of the American College of Rheumatology in 1990:
  - (1) Asthma.
  - (2) Peripheral blood eosinophilia > 10%.
  - (3) Neuropathy.
  - (4) Migratory pulmonary infiltrates.
  - (5) Paranasal sinus abnormalities.
  - (6) Tissue eosinophils.
- The presence of four of the above six findings results in a diagnostic sensitivity of 85%, with a specificity of 99%.

General Considerations

Churg–Strauss syndrome is a rare granulomatous vasculitis involving small to medium sized vessels and is characterized by asthma, hypereosinophilia, and extravascular eosinophilic granulomas. The cause of the disease is unknown, but factors implicated include vaccinations, desensitization, and various medications such as leukotriene-receptor antagonists. Approximately 50% of patients have a positive ANCA, which is usually perinuclear (p-ANCA) on immunofluorescence with myeloperoxidase (MPO-ANCA) specificity on enzyme immunoassay.

Clinical Findings

The symptoms and signs of Churg–Strauss syndrome generally occur in three phases, and shorter transition intervals to progressive stages are associated with more severe disease:

1. The **prodromal stage** may last for years and is characterized by adult-onset asthma and allergic rhinitis with nasal polyposis (70%) and recurrent sinusitis. Septal perforation is rare.
2. The second stage consists of **peripheral blood and tissue eosinophilia**, primarily in the lungs (Löffler's syndrome) and gastrointestinal system.
3. The third stage consists of the development of **systemic vasculitis,** which may involve the peripheral nervous system, integument, heart, gastrointestinal system, and kidneys, although renal dysfunction is usually not as severe as in Wegener's granulomatosis.

Treatment

The administration of corticosteroids (prednisone 1 mg/kg/d) usually results in a rapid regression of symptoms. Although a steroid taper can be initiated after approximately 1 month, long-term low-dose corticosteroid treatment is often necessary due to persistent asthma. Cyclophosphamide is indicated for first-line therapy when poor prognostic indicators are present or as second-line treatment with failure of corticosteroid therapy.

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Ishiyama A, Canalis RF. Otologic manifestations of Churg-Strauss syndrome. *Laryngoscope* 2001;111(9):1619–1624 [PMID: 11568616]. (Review of Churg-Strauss signs and symptoms.)

NEOPLASTIC DISEASES

T-CELL LYMPHOMA

ESSENTIALS OF DIAGNOSIS

- Nasal obstruction and epistaxis.
- Rapidly progressive with aggressive local destruction.
- May have systemic symptoms such as fever, chills, night sweats, and weight loss.
- Tissue biopsy with immunophenotyping and Epstein–Barr virus (EBV) studies for diagnosis.
- Multiple biopsy specimens required due to friable tissue with large areas of secondary necrosis.

General Considerations

Extranodal nasal natural killer (NK)/T-cell lymphoma, previously described as lethal midline granuloma or polymorphic reticulosis, is rare in the United States and Europe but is common in East Asia and Central America. In China, it is the second most common type of extranodal non-Hodgkin lymphoma. The ratio of male to female patients who present with T-cell lymphoma is approximately three to one, with a median age of presentation in the fifth decade. Overall, patients with T-cell lymphoma tend to be younger than patients with conventional lymphomas. These tumors tend to resist traditional non-Hodgkin regimens, resulting in poor outcomes.

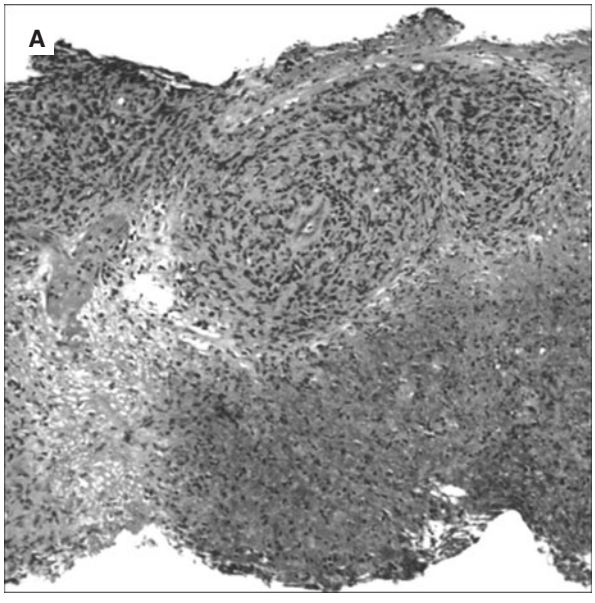
Pathogenesis

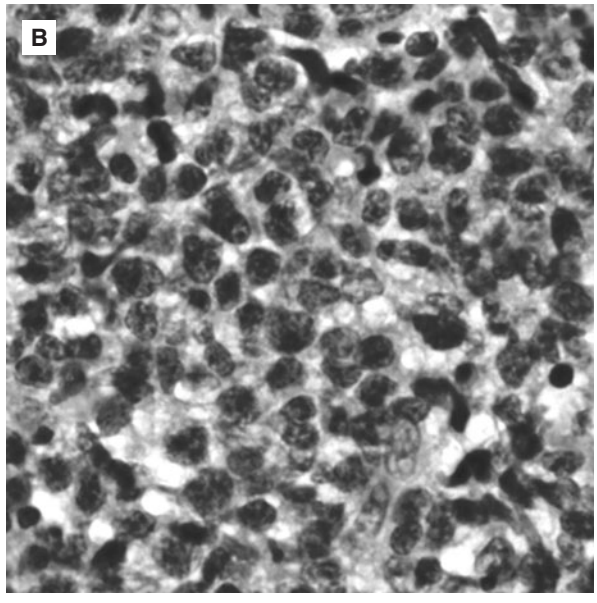
Histologically, nasal extranodal NK/T-cell lymphoma is characterized by mixed cellular infiltrates with angiocentric lymphoid invasion and occlusion of blood vessels, resulting in ischemic necrosis of normal and neoplastic tissues (Figures 13–3A and 13–3B).

Extranodal NK/T-cell lymphoma has a strong association with EBV irrespective of ethnic origin, strongly suggesting that the virus plays a pathogenic role. The lymphoma cells characteristically express CD2, CD45RO, CD7, CD43, CD3 epsilon, and the NK-cell marker CD56, which is usually not present in inflammatory mucosa. However, other T-cell antigens, such as CD3 and CD5, are often absent. Lymphoma cells also express cytotoxic molecules, including perforin and TIA-1.

Clinical Findings

A high index of suspicion is required for early diagnosis of extranodal NK/T-cell lymphoma, as patients typically





▲ **Figure 13–3. (A)** Low power H&E stain showing extranodal NK/T-cell lymphoma with angiocentric invasion and necrosis. **(B)** High power H&E stain showing extranodal NK/T-cell lymphoma with pleomorphic lymphoma cells demonstrating irregular nuclei and vesicular chromatin. (Images contributed by Dr. Wayne Tam, Weill Medical College of Cornell University, Department of Pathology and Laboratory Medicine, Hematopathology Division.)

Table 13–1. Conditions that may Present Clinically as Midline Nasal Destructive Lesions.

Cocaine abuse
Trauma
Infectious diseases
Bacterial: brucellosis, syphilis, rhinoscleroma, leprosy, actinomycosis, tuberculosis
Fungal: histoplasmosis, candida, mucormycosis, blastomycosis, rhinosporidiosis, coccidiomycosis
Parasitic: leishmaniasis, myiasis
Inflammatory diseases
Sarcoidosis
Wegener's granulomatosis
Systemic lupus
Polyarteritis nodosa
Hypersensitivity angiitis
Idiopathic midline destructive disease
Neoplastic diseases
Squamous cell carcinoma
Basal cell carcinoma
Esthesioneuroblastoma
Adenoid cystic carcinoma
Sinonasal lymphoma

Reprinted, with permission, from Rodrigo JP, Suarez C, Rinaldo A, et al. Idiopathic midline destructive disease: fact or fiction. *Oral Oncol* 2005;41(4):340–348.

present initially with nasal obstruction and epistaxis. Patients may also have facial or orbital swelling, sore throat, or hoarseness, depending on the extent of tumor involvement. Systemic symptoms of fever or weight loss are also present in some cases. Clinical findings include ulceration and necrotic granulomatous tissue with a friable surface. Exam often demonstrates septal perforation, and eventual palatal destruction may occur.

The tumor is highly invasive locally and often involves surrounding tissues, including the paranasal sinuses, orbit, and skin, resulting in an extensive destructive midline process. The oropharynx, hypopharynx, and larynx may also be involved. If disseminated, the tumor may be found in the gastrointestinal tract or genital organs. Cocaine abuse may present similarly as an impressive midline nasal destructive process, and its use should be ascertained in the patient's history. Table 13–1 lists the complete differential diagnosis of midline nasal destructive lesions.

Treatment

If untreated, the complications can range from local tissue destruction to death. In most cases a combination of chemotherapy and radiation therapy appears to be more effective than either modality alone. Radiation therapy alone may be sufficient in localized nasal disease. However, a 50% rate of relapse exists despite high initial efficacy with radiation. Surgical management is limited to reconstruction of bony and soft tissue defects after treatment, particularly in cases of hard palate or orbital floor destruction.

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Rodriguez J, Romaguera JE, Manning J, et al. Nasal T-cell and NK-cell lymphomas: a clinicopathologic study of 13 cases. *Leuk Lymphoma* 2000;39(1–2):139–144 [PMID: 10975392]. (Therapeutic outcomes of nasal T-cell lymphoma management.)

INFECTIOUS DISEASES

RHINOSCLEROMA

ESSENTIALS OF DIAGNOSIS

- High index of suspicion in individuals from endemic regions.
- Extensive nasal polyposis adherent to nasal septum, with minimal sinus involvement.
- Cultures with Klebsiella pneumoniae rhinoscleromatis (typically not normal nasal flora).
- Nonenhancing, well-defined borders on CT scans; bone and cartilage rarely involved.
- Biopsies of actively involved areas (septum or inferior turbinates) diagnostic.

General Considerations

Rhinoscleroma is a rare, chronic progressive granulomatous disease of the upper respiratory tract caused by *Klebsiella rhinoscleromatis.* Nasal disease presents with three typical stages: (1) **catarrhal (atrophic),** with nonspecific rhinitis; (2) **proliferative (granulomatous),** characterized by granulomatous reaction and the presence of Mikulicz

cells; and (3) **cicatricial (sclerotic),** in which mucosal fibrosis is seen. The rise in the incidence of rhinoscleroma in the United States may be due to the increased number of immigrants from endemic regions such as Eastern and Central Europe, Central and South America, East Africa, and the Indian subcontinent. Rhinoscleroma may be found in all age groups, but most frequently affects adolescents and young adults. Poor hygiene, crowded living conditions, and poor nutrition contribute to its spread via airborne transmission.

Pathogenesis

The chronicity of this disease is believed to be a result of the ability of the bacteria to evade the host defenses during the proliferative stage. During the catarrhal phase, the organism gains access to the subepithelial layer via ulcerations that allow deep colonization. The bacteria then spread to other areas through the subepithelium and are phagocytosed by histiocytes, forming Mikulicz cells. The organism continues to multiply intracellularly until the Mikulicz cells rupture and deliver viable bacteria interstitially. This cycle continues and eventually leads to clinically evident granuloma formation and pseudoepitheliomatous hyperplasia.

Clinical Findings

Rhinoscleroma manifests primarily in the nose, but it can affect any part of the upper respiratory tract, including the eustachian tube, maxillary antrum, oral cavity, larynx, orbit, trachea, and bronchi. In advanced disease, nasal obstruction (94%), nasal deformity (32%), epistaxis (11%), and crusting (94%) are the main symptoms. Laryngeal involvement may present as hoarseness with associated findings of interarytenoid hyperemia, exudates, and vocal cord edema. Late laryngeal fibrosis typically involves the glottis and subglottis, with subsequent stridor and potential airway obstruction.

Treatment

A combination of conservative surgical debridement and long-term antibiotic coverage is the mainstay of therapy for rhinoscleroma. Tetracycline has been shown to be effective and inexpensive for patients unless contraindicated. Fluoroquinolones may be used as an alternative, given their excellent gram-negative activity, intracellular efficacy, and low toxicity. The organism is often difficult to eradicate, and relapse can occur even with aggressive therapy due to the organism's ability to remain dormant in its spore form.

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RHINOSPORIDIOSIS

ESSENTIALS OF DIAGNOSIS

- High index of suspicion in individuals from endemic regions.
- Nasal obstruction and epistaxis, frequent ocular involvement
- Friable, polypoid, vascular nasal mass with red "strawberry" appearance.
- Histopathology showing thick-walled sporangium filled with endospores, pseudoepitheliomatous hyperplasia.

General Considerations

Rhinosporidiosis is a chronic granulomatous inflammatory disease caused by *Rhinosporidium seebri*. It is endemic in India and Sri Lanka and has been reported sporadically in multiple other locations, including South America and Africa. The organism is found in stagnant water and soil and is thought to be spread by contaminated water and inoculation of spores into traumatized epithelium.

The disease follows an indolent course and typically involves the nose and nasopharynx (70–85%) and the eye, particularly the conjunctiva or lacrimal sac (15%), but it can also involve other sites, including the skin, paranasal sinuses, palate, tonsil, larynx, tracheobronchial tree, parotid gland, and genitalia. The rare disseminated form is fatal and involves skin, bone, and brain.

Pathogenesis

Rhinosporidium seebri is difficult to isolate in cultures and some aspects of its epidemiology and life cycle remain controversial. After a period of growth, the early spore begins a series of mitotic divisions. With each division the number of nuclei and spores increases, and the spore wall thickens. The mature sporangium discharges its contents, releasing copious spores into the nasal secretions. Staining with hematoxylin–eosin stain reveals pseudoepitheliomatous hyperplasia, thick-walled fungal sporangia containing numerous endospores, and fibrous stroma with chronic inflammatory cells. The organism is present in all stages of development.

Clinical Findings

Patients typically present with symptoms of progressive nasal obstruction, chronic epistaxis, and watery rhinorrhea that becomes purulent during infection. Clinical exam reveals a polypoid, friable nasal mass with a red surface that bleeds easily due to its underlying vascularity. The mass grows slowly and is usually painless. The surface of the lesions contains pin-sized yellow spots bulging through attenuated epithelium that represent the mature sporangia and give the mass its classic "strawberry" appearance.

Treatment

Treatment is surgical excision with cauterization of the base. Antifungals, steroids, dapsone, and radiotherapy have been used with limited efficacy.

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HUMAN IMMUNDEFICIENCY VIRUS (HIV)

ESSENTIALS OF DIAGNOSIS

- HIV serology is diagnostic.
- CD4 cell counts and viral titers are indicative; lower CD4 counts and higher viral titers correlate with symptomatic immunodeficiency.
- Opportunistic pathogens can be seen with CD4 <50 cells/mm^3. Empirically treat for Pseudomonas aeruginosa in HIV patients with sinusitis when CD4 <200 cells/mm^3.
- Endoscopic cultures should be used to guide antibiotic coverage.
- Biopsy nasal masses and suspicious skin lesions to rule out malignant neoplasms.

General Considerations

Rhinosinusitis may affect up to 68% of patients infected with the human immunodeficiency virus (HIV), with an incidence and severity that correlate with the stage of HIV infection. As immune function deteriorates, the incidence of opportunistic infections increases, especially with CD4 counts below 50 cells/mm^3.

Pathogenesis

HIV infection results in a gradual depression of humoral and cellular immunity, primarily due to the depletion of helper T lymphocytes. The result is an increased susceptibility to infection. With respect to sinonasal disease, HIV-infected patients have been found to have increased mucociliary transport time, resulting in stasis and thick, tenacious nasal secretions that increase the risk of sinonasal infection. Some studies have suggested that polyclonal B-cell activation with increased immunoglobulin production may result in increased atopy in HIV-positive patients and thus a higher incidence of allergic symptoms. However, the relationship between HIV infection and increased atopy is unclear at this time.

Clinical Findings

The typical presentation of rhinosinusitis in these patients is no different from that in seronegative patients; common findings consist of fever, facial pain or pressure, headache, postnasal drip, purulent nasal discharge, periorbital swelling, and nasal congestion. As the HIV infection progresses, the inflammatory response is reduced, resulting in less mucosal edema and rhinorrhea. The microbiology is usually the same as in seronegative patients when the CD4 count is > 50 cells/mm^3, with *Streptococcus pneumoniae, Haemophilus influenzae,* and *Moraxella catarrhalis* being common for acute infection and *Staphylococcus aureus, Pseudomonas aeruginosa,* and anaerobes being common for chronic infection. When the CD4 count falls below 50 cells/mm^3, the risk of infection by opportunistic bacterial, fungal, protozoal, and viral organisms increases. Although extrasinus complications of sinusitis are not known to have a greater incidence in these patients, a high index of suspicion is required with progressive immunodeficiency. These patients are also at risk for life-threatening invasive fungal sinusitis, particularly if the absolute neutrophil count is less than 600/mm^3. Skin lesions such as Kaposi's sarcoma, herpetic ulcerations, and seborrhea-like dermatitis are common cutaneous processes that affect the nose and surrounding facial skin. These lesions may herald progression from asymptomatic HIV infection to AIDS. Nasopharyngeal lymphoid hypertrophy affects 56–88% of patients early in the disease course, causing nasal obstruction and serous otitis media, and may warrant biopsy to rule out lymphoma.

Treatment

The level of immunodeficiency should guide initial antibiotic therapy, and endoscopically obtained cultures should be performed to further tailor therapy. When the CD4 count

is greater than 200 cells/mm^3, therapy should include coverage for *Streptococcus*, *Staphylococcus*, and *Haemophilus influenzae*. First-line choices include amoxicillin, amoxicillin/clavulanate, cefuroxime, trimethoprim/sulfamethoxazole, or a macrolide. With incomplete response to initial antibiotic therapy, the development of chronicity, or a CD4 count below 200 cells/mm^3, coverage should expand to include *Pseudomonas aeruginosa* and anaerobes. Clindamycin and metronidazole may improve response in these cases. Antibiotic therapy should be continued for a minimum of 3 weeks, along with systemic decongestants, mucolytics, and nasal saline irrigation. In chronic disease, topical nasal steroids may reduce inflammation and rhinorrhea. Prophylactic treatment with trimethoprim/sulfamethoxazole has been shown to decrease the risk of sinusitis and otitis media. When medical measures fail or in the case of extrasinus complications, functional endoscopic sinus surgery has been shown to be safe and effective. A low CD4 count is not a contraindication for surgical management.

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We would like to acknowledge Ashish R. Shah, MD, John M. Ryzenman, MD, and Thomas A. Tami, MD for their contribution to this chapter in the previous editions of CDT.

14 Nonallergic & Allergic Rhinitis

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Rhinitis is defined as an inflammatory condition that affects the nasal mucosa. The symptoms of rhinitis include nasal obstruction, hyperirritability, and hypersecretion. Rhinitis can be caused by a variety of different allergic and nonallergic conditions (Table 14–1). The incidence of rhinitis seems to have increased since the industrial revolution. One in five Americans is estimated to be afflicted with rhinitis.

Allergic rhinitis is one of the most common chronic conditions in the United States. Of the approximately 50 million US individuals who have rhinitis, many do not have an allergic cause to their rhinitis. The symptoms of nonallergic rhinitis include nasal obstruction, hypersecretion, and irritability, none of which is due to allergy.

ANATOMY & PHYSIOLOGY

Airflow through the nose is more efficient in gas exchange and requires less energy than mouth breathing. The nose serves as the initial conduit into the airway. As such, it has important functions of warming, humidifying, and cleansing the air that we breathe. The nasal cycle consists of simultaneous sympathetic and parasympathetic modulation in opposite directions on opposite sides of the nose. The nasal cycle can alter airflow in one nostril by up to 80%, while maintaining total airflow.

From anterior to posterior, the different structural elements of the nose act together to achieve these functions. The nasal vestibule is lined by vibrissae that filter large particulates as they enter the nose. The vestibule then communicates with the nasal valve region, where the nasal mucosa becomes a ciliated, pseudostratified, columnar epithelium. This type of epithelium permeates the entire sinonasal cavity; its importance is underscored when considering conditions such as Kartagener syndrome in which immotile cilia lead to chronic crusting from mucus stasis. Under the mucosa lie stromal cells, inflammatory cells, nerves, blood vessels, and seromucous glands. Each of these elements may play a role in nasal inflammation.

The nose is divided into left and right chambers by a septum comprised of cartilage and bone. Laterally, three bony projections—superior, middle, and inferior turbinates—project into the nasal cavity. These turbinate bones are lined by mucosa, thereby increasing the nasal surface area and covering important sinus ostia. The nasolacrimal duct drains into the inferior meatus. The frontal, maxillary, and anterior ethmoid sinuses drain into the middle meatus; the posterior ethmoid sinuses drain into the superior meatus. Finally, the sphenoid sinus ostia are superior to the choana and drain medially to the superior turbinate. Inflammation in these critical drainage sites can lead to epiphora or sinus disease.

Nasal vascularity includes the internal and external carotid arteries, which feed the nose. The anterior and posterior ethmoid arteries are terminal branches of the ophthalmic artery, a branch of the internal carotid artery. The external carotid artery supplies the sphenopalatine artery. The venous drainage of the nose is primarily through the pterygoid and ophthalmic plexuses.

Finally, the character of the nasal mucus itself is significant. Nasal and sinus mucus typically exists in two layers on the epithelial surface. The deeper layer is thinner and less viscous than the outer layer and therefore allows the cilia to beat with less resistance. The outer layer traps inhaled particulates and has a greater density of inflammatory mediators and leukocytes to protect against infectious agents and foreign substances.

NONALLERGIC RHINITIS

Nonallergic rhinitis typically presents with clear rhinorrhea and nasal obstruction. Sneezing and itchy, watery eyes do not typically present with nonallergic rhinitis. There is an increasing incidence of nonallergic rhinitis with advancing age. Patients with nonallergic rhinitis should always be questioned about the use of over-the-counter nasal sprays, previous trauma, work or chemical exposure, and previous intranasal drug use. Epistaxis, pain, and unilateral symptoms may be harbingers of a neoplasm and should be noted.

Table 14–1. Types of Rhinitis.

Allergic Rhinitis	Infectious Rhinitis	Nonallergic, Noninfectious Rhinitis	Miscellaneous
• Seasonal • Perennial	• Viral • Bacterial rhinosinusitis	Eosinophilic syndromes • NARES • Nasal polyposis Noneosinophilic syndromes • Vasomotor rhinitis • Rhinitis medicamentosa • Occupational rhinitis • Rhinitis of pregnancy • Hypothyroidism • Medication (eg, birth control pills)	• Granulomatous rhinitis • Atrophic rhinitis • Gustatory rhinitis

VIRAL RHINITIS

Viral rhinitis is very common and often associated with other manifestations of viral illness, which can include headache, malaise, body aches, and cough. Nasal drainage in viral rhinitis is most often clear or white and can be accompanied by nasal congestion and sneezing.

OCCUPATIONAL RHINITIS

A number of different indoor and outdoor pollutants may affect the nose. These agents include dust, ozone, sulfur dioxide, cigarette smoke, garden sprays, and ammonia. Irritant agents can be found in a variety of work environments. Typically, these agents cause nasal dryness, reduced airflow, rhinorrhea, and sneezing. Decreased ciliary movements within the nose have been seen in chronic cigarette smoke exposure and in exposure to wood particles. Environmental control is critical in these patients. Limiting exposure through removal of the causal agent, avoidance, improving ventilation, and the use of protective particulate respirator masks are all helpful.

VASOMOTOR RHINITIS

Patients with vasomotor rhinitis present with symptoms of nasal obstruction and clear nasal drainage. The symptoms are often associated with changes in temperature, eating, exposure to odors and chemicals, or alcohol use. Some clinicians suggest that abnormal autonomic regulation of nasal function leads to vasomotor rhinitis.

NONALLERGIC RHINITIS WITH EOSINOPHILIA

Nonallergic rhinitis with eosinophilia (NARES) is a recently described syndrome in which patients present with nasal obstruction and congestion; these patients frequently experience more severe exacerbations, including the development of sinusitis and polyposis. These patients also display marked eosinophilia on nasal smears (> 25%) but are not allergic to any inhalant allergens by skin testing or in vitro testing. The cause of NARES remains unknown.

RHINITIS MEDICAMENTOSA

Patients with rhinitis medicamentosa often present with nasal obstruction that has worsened over a number of years. They typically have been using over-the-counter topical vasoconstrictive nasal sprays. Many times these patients need increasing doses of these sprays as tachyphylaxis occurs. The use of these sprays for prolonged periods leads to rebound rhinitis in which the patient experiences severe obstruction as the effects of the topical agents subside.

RHINITIS DURING PREGNANCY

Another common presentation of nonallergic rhinitis is rhinitis associated with pregnancy. The systemic concentration of estrogen rises throughout pregnancy. This rise in estrogen leads to a rise in hyaluronic acid in the nasal tissue, which can result in increasing nasal edema and congestion. Moreover, there is an increase in mucous glands and a decrease in nasal cilia during pregnancy, both of which heighten nasal congestion decreasing mucus clearance. Rhinitis is usually most severe during the second and third trimesters of pregnancy.

VASCULITIDES, AUTOIMMUNE & GRANULOMATOUS DISEASES

The physical examination of a patient with rhinitis should include a thorough head and neck exam. Externally, the nose is evaluated for evidence of previous trauma or saddling, which can be indicative of septal deficiency. Internally, the nasal septal position and character are examined. Signs of chronic inflammation, vasculitis, and septal perforation can be indicative of a variety of systemic problems ranging from Wegener granulomatosis to cocaine abuse. The size and character of the turbinates are also important to note, as is the

character of any rhinorrhea. Moreover, the physician should examine the patient for nasal polyposis or other intranasal masses or tumors.

A more in-depth examination of the nasal cavity can be accomplished—after applying topical anesthesia—with the use of either a rigid or flexible nasal endoscope. A 4.0-mm rigid nasal endoscope may be used for adults and a 2.7-mm nasal endoscope for children. This affords visualization of the middle meatus, sphenoethmoidal recess, and nasopharynx regions otherwise not seen with anterior rhinoscopy. In addition, nasal cytology can be helpful to determine both cell types and the presence of ciliary motility.

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Treatment of Nonallergic Rhinitis

A. Nonsurgical Measures

1. Irritant avoidance—The treatment of nonallergic rhinitis includes the avoidance of offending agents such as chemicals, perfumes, cigarette smoke, and other fumes. In addition, for patients with workplace exposure, a particulate mask can be useful in limiting irritants.

2. Saline irrigation—Saline irrigation is an important adjunctive treatment to help avert intranasal stasis and reduce crusting. The use of saline not only increases the efficacy of intranasal topical medications but also improves ciliary function.

3. Topical steroids—Topical intranasal steroids work in the nasal mucosa to reduce eosinophil and neutrophil chemotaxis; they also reduce inflammation, suppress mast cell-related reactions, and decrease intracellular edema. Although primarily used for allergic rhinitis, some nonallergic patients respond to topical intranasal steroids

4. Adrenergic agents—Other treatments for nonallergic rhinitis include the adrenergic agents. There are two main families of adrenergic drugs: (1) phenylamines (eg, ephedrine, pseudoephedrine, phenylephrine, and phenylpropanolamine) and (2) imidazolines (eg, xylometazoline, oxymetazoline, and naphazoline). Phenylamines are oral agents, whereas imidazolines are topical agents. The primary role of phenylamines is to decrease mucosal capacitance vessels by agonizing α-adrenergic receptors; this leads to a decongestant effect. Phenylamines can cause dose-related adverse effects such as tremulousness, irritability, tachycardia, hypertension, and urinary retention. They are contraindicated in patients with hypertension, severe coronary artery disease, and in patients on monoamine oxidase inhibitors. Topical imidazolines decrease nasal blood flow by affecting α_1- and α_2-adrenergic receptors. Potent vasoconstriction can cause rebound congestion upon withdrawal of the drug (rhinitis medicamentosa) if used for more than 5 days. In light of this, patients should be cautioned when using these sprays for prolonged periods (rhinitis medicamentosa).

5. Additional agents—Anticholinergic agents such as ipratropium bromide can be used topically to block parasympathetic input and thereby decrease rhinorrhea. Ipratropium bromide is available in a 0.03% formulation for noninfectious rhinitis and a 0.06% concentration for viral rhinitis. Anticholinergic agents can be used in combination with intranasal steroids. They should be avoided in patients with narrow-angle glaucoma, prostatic hypertrophy, or bladder neck obstruction.

Newer therapies that have been tried for vasomotor rhinitis include the use of intranasal antihistamine sprays. Azelastine spray (eg, Astepro 0.15%) and olopatadine (eg, Patanase) are new, once-a-day intranasal antihistamines that may relieve vasomotor rhinitis.

Some over-the-counter sprays, such as cromolyn sodium, are safe to be used repetitively. These intranasal sprays act to stabilize mast cell membranes. They must be given prior to mast cell degranulation to be effective and have relatively short half-lives, so their administration must be frequent. Finally, some clinicians are using leukotriene inhibitors as adjuvant treatments in the treatment of nonallergic rhinitis. However, more studies on the efficacy of these agents in nonallergic rhinitis are warranted.

B. Surgical Measures

1. Septal procedures—The surgical treatment for nonallergic rhinitis is focused on correcting structural abnormalities that may contribute to patient symptoms. Septal deviation is a common defect that can contribute to nasal obstruction. Septoplasty or nasoseptal reconstruction is used to correct cartilaginous or bony abnormalities of the septum. Septal perforations can contribute to crusting or epistaxis. The surgical correction of septal perforations may include the placement of septal buttons, advancement flap closures of perforations, and, more recently, free-tissue transfers for large perforations.

2. Turbinate surgery—Inferior turbinate surgery is also commonly used to counteract nonallergic rhinitis. The type and extent of surgery on the inferior turbinate continues to be a source of debate. Various techniques for turbinate surgery exist and include outfracture, cauterization, radiofrequency ablation, submucous resection, submucosal reduction via a microdebrider, and partial or complete turbinate resection. In general, the current trend is to preserve as much turbinate mucosa as possible to allow normal physiologic function to continue.

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ALLERGIC RHINITIS

ESSENTIALS OF DIAGNOSIS

- May be seasonal, perennial, or both.
- Characterized by sneezing, itching, rhinorrhea, and congestion.
- Can be associated with other chronic conditions, including asthma, otitis media with effusion (OME), rhinosinusitis, and nasal polyposis.
- Typical symptoms of sneezing, rhinorrhea, and nasal congestion can be associated with viral, bacterial, allergic, and nonallergic etiologies.
- Can have multiple triggers, both inhaled and ingested.

General Considerations

Allergy is a clinical manifestation of an adverse immune response after repeated contact with usually harmless substances such as pollens, mold spores, animal dander, dust mites, foods, and stinging insects. Allergic rhinitis is an inflammation of the nasal mucous membranes caused by an IgE-mediated reaction to one or more allergens. The prevalence of allergic rhinitis can vary considerably among age groups and locales.

Allergic rhinitis is one of the most common allergic diseases in the United States, affecting between 20% and 25% of the population (approximately 40 million people). Allergic rhinitis may have its onset at any age, but the incidence of onset is greatest in adolescence, with a decreasing incidence with advancing age. Its peak prevalence is during the third and fourth decades (Figure 14–1).

The economic costs of allergic rhinitis, both direct and indirect, are considerable. The largest portion of the direct costs is the expenditure for both prescription and nonprescription medications (approximately 4 billion dollars annually). The largest indirect costs are from both the allergy itself and also from the negative side effects of allergy medication (primarily over-the-counter antihistamines).

Although allergic rhinitis is not life threatening, its symptomatic effects are considerable, resulting in a significantly diminished quality of life for many sufferers. A number of quality of life studies have shown that in almost every facet of daily life, including social and physical functionality, energy and fatigue levels, and a lack of sleep and mental health, patients with allergic rhinitis have a significant loss of the quality of life compared with nonallergic individuals. In fact, patients with allergic rhinitis have been shown to have a lower quality of life than many asthmatics. In addition, allergic rhinitis may contribute to sleep disorders, fatigue, and—of particular importance with children—learning problems.

▲ **Figure 14–1.** Prevalence of allergic rhinitis by age group.

Pathogenesis

The allergic response is mediated primarily by a type I hypersensitivity reaction. This response involves the excess production of IgE antibodies and is termed an atopic reaction. In addition to allergic rhinitis, most cases of asthma and atopic dermatitis are considered to have an atopic cause.

In patients with an atopic disposition (a genetic trait), an allergic reaction begins with sensitization to a specific allergen (in allergic rhinitis, these are usually airborne), which induces IgE-antibody production. This occurs through a T-cell, B-cell, and plasma cell cascade. On subsequent exposure, the specific antigen attaches to two specific IgE antibodies attached to the surface of mast cells, which are prevalent in the submucosa of the respiratory and gastrointestinal tracts, the subconjunctiva of the eye, and the subcutaneous layer of the skin. Consequently, this IgE-mediated reaction causes degranulation of the mast cell, which then provokes an inflammatory response with the release of mediators such as histamine, leukotrienes, cytokines, prostaglandins, and platelet-activating factor. This is referred to as the **early-phase** or **humeral reaction** and occurs within 10–15 minutes of allergen exposure; the release of histamine causes the symptoms of sneezing, rhinorrhea, itching, vascular permeability, vasodilatation, and glandular secretion.

The release of cytokines and leukotrienes subsequently causes an influx of inflammatory cells (mainly eosinophils) into the affected area (chemotaxis). This inflammatory response is called the **late-phase** or **cellular reaction,** which can begin 4–6 hours after the initial sensitization and may prolong and enhance the allergic cascade for as long as 48 hours. This response is the main cause of the symptoms of nasal congestion and postnasal drip in allergic rhinitis.

In addition, these mediators produce a hyperreaction to both specific allergens and nonspecific irritants such as tobacco smoke and chemical fumes, referred to as the **priming effect.**

Causes

The development of atopy may be influenced by the following: (1) genetic susceptibility (ie., family history); (2) environmental factors (eg, dust and mold exposure); (3) exposure to allergens (eg, pollens, animal dander, and foods); (4) passive exposure to tobacco smoke (especially in early childhood); and (5) diesel exhaust particles (in urban areas)—among other factors.

In infancy and childhood, food allergens such as milk, eggs, soy, wheat, dust mites, and inhalant allergies such as pet dander are the major causes of allergic rhinitis and the comorbidities of atopic dermatitis, otitis media with effusion, and asthma. In older children and adolescents, pollen allergens become more of a causative factor.

Classification

A. Seasonal Allergic Rhinitis

The symptoms of seasonal allergic rhinitis, as its name implies, occur or are increased during certain seasons, usually depending on the pollination of plants to which the patient is allergic. Trees pollinate in the spring, grasses in the late spring and summer, and weeds in the fall. In addition, molds may cause symptoms in the fall.

Characteristic symptoms of seasonal allergies include sneezing, watery rhinorrhea, itching of the nose, eyes, ears, and throat, red and watering eyes, and nasal congestion. Symptoms are usually worse in the morning and are aggravated by dry, windy conditions when higher concentrations of pollen are distributed over a wider area.

B. Perennial Allergic Rhinitis

The symptoms of perennial allergic rhinitis are usually constant, with little seasonal variation, although they may vary in intensity. Characteristic symptoms are predominantly nasal congestion and blockage, and postnasal drip. Rhinorrhea and sneezing are less common. Eye symptoms are less common, except with animal allergies. Seasonal pollen may cause the exacerbation of any of these symptoms.

Common allergens that cause perennial allergic rhinitis are indoor inhalants, predominantly dust mites, animal dander, mold spores, and cockroaches (in inner cities). Certain occupational allergens may also cause perennial allergic rhinitis; these are not usually constant because they depend on workplace exposure.

Food allergens may also contribute to perennial allergic rhinitis. In addition, food allergies are often associated with other symptoms, including gastrointestinal problems, urticaria, angioedema, and even anaphylaxis after food is ingested.

Infections and nonspecific irritants may influence perennial allergic rhinitis. In children with allergies, there may be a higher incidence of respiratory tract infections, which in turn tend to aggravate allergic rhinitis and may lead to the development of complications, especially rhinosinusitis and otitis media with effusion. Other irritants such as tobacco smoke, chemical fumes, and air pollutants can also aggravate symptoms.

C. Other Classifications

Recently, other classifications of allergic rhinitis have been introduced. One of these is related to both the temporal incidence and the quality of life. Symptoms are classified (1) as being intermittent (<4 d/wk or <4 weeks' duration) or persistent (>4 d/wk or >4 weeks' duration) and (2) by the intensity of the symptoms, with either minimal or moderate to severe changes in the quality of life. In another classification system, symptoms are based according to the type of symptom (eg, patients who experience sneezing and a runny nose or those who are congested) without a temporal relationship.

Clinical Findings

A. Patient History

The diagnosis of allergic rhinitis should determine whether the patient is atopic and, if so, what the causative allergen is. To determine these, a basic clinical evaluation should be performed, which should consist of a patient history, a physical examination, and confirmatory tests.

A careful history provides important clues for the diagnostician. Genetic factors determine the likelihood of an individual becoming sensitized and producing IgE antibodies (ie., being atopic). A family history of allergies, eczema, or asthma increases this possibility. Children with parents who have allergies have been shown to have a >50% chance of becoming allergic themselves. If only one parent or a sibling has allergies, this rate is lower but still significant.

A thorough allergy history should determine whether symptom patterns are seasonal or perennial. Symptoms may include clear and watery nasal discharge, nasal congestion, postnasal drip, and itching of the nose, throat, and eyes. Persistent symptoms are presumed to be due to exposure to an indoor allergen. Seasonal symptoms or symptoms that are reproducible from an inciting factor, such as cat exposure, are most likely to be allergic. If the use of medication, especially antihistamines (both prescription and nonprescription) or intranasal corticosteroids improves symptoms, allergy is probable. This is not the case with either intranasal or oral decongestants, which affect both allergic and nonallergic symptoms. A history of an anaphylactic reaction following ingestion of a particular food or being stung by an insect usually indicates an atopic patient.

Patients should be questioned about the onset, duration, type, progression, and severity of their symptoms. A relationship to the seasons is important, with seasonal symptoms usually indicating a pollen allergy or possibly a mold allergy, but temperate climates can blur these seasonal distinctions. Perennial symptoms usually mean an allergy to dust mites, mold, or animals. An increase in symptoms at night usually suggests an allergy to dust mites or pet dander.

Associated ocular, pharyngeal, and systemic symptoms, including recurrent rhinosinusitis, ear infections, asthma flare-ups, gastrointestinal symptoms, and skin rashes and hives, are important facts to ascertain in the history taking.

The patient should always be questioned about the impact of the symptoms on the quality of his or her life because the correct diagnosis and, ultimately, symptomatic relief from the appropriate treatment will play a large part in the functional impact on the patient's life.

B. Physical Examination

A physical examination should include inspection of the ears, throat, and nasal passages (including after decongesting with a topical decongestant). Typical findings in the nose in patients with seasonal allergic rhinitis include bluish, pale, boggy turbinates; wet, swollen mucosa; and nasal congestion with nasal obstruction. With perennial allergies, nasal congestion is the predominant sign, but the nasal examination may appear normal. Anatomic abnormalities, such as a deviated nasal septum, concha bullosa, and nasal polyps, may be present. It should be determined whether these abnormalities are the main cause or merely contributing factors to the patient's symptoms. If nasal polyps are suspected, an endoscopic nasal exam is also warranted. Other possible physical findings include conjunctivitis, eczema, and, possibly, asthmatic wheezing.

In children, allergic "shiners" (dark circles under the eyes), facial grimacing, mouth breathing, and the "nasal salute" (constant rubbing of the tip of the nose with the hand) are common physical findings. In addition, in this age group, a concomitant otitis media with effusion is also a possibility.

C. Special Tests

1. Allergy testing—Allergy testing is performed to establish objective evidence of atopic disease. It also can determine the causative allergens responsible, which would then lead to specific therapeutic recommendations. Two major types of testing are available for identifying and quantifying allergen sensitivity: skin testing and in vitro serum assays.

2. Skin testing—Skin testing can be epicutaneous, intradermal, or a combination of both.

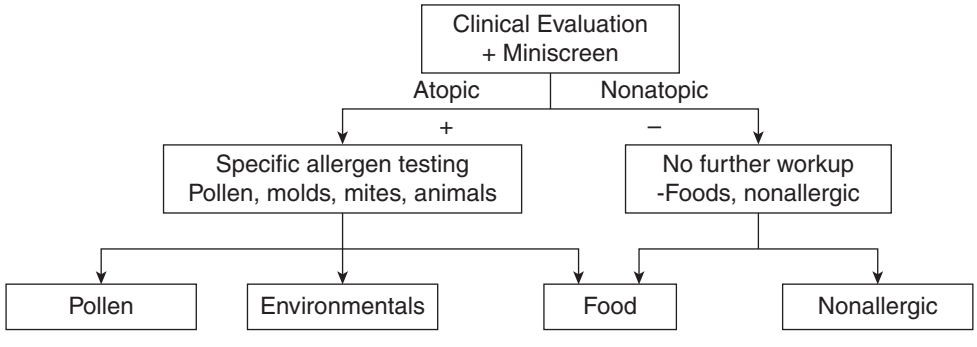
A. Skin prick test—The skin prick test is the most common epicutaneous test used. In general, it is a quick, specific, safe, and cost-effective test. With new multitest systems available, it is an easy and simple office procedure to perform and also allows for uniformity in the testing procedure. When a test result is equivocal, it is often followed by an intradermal test.

B. Intradermal testing—Intradermal testing, using quantitative 1:5 serial dilutions, is the skin testing method used by most otolaryngic allergists. This type of testing, termed **intradermal dilutional testing** (IDT) and formerly known as serial endpoint titration (SET), is an excellent quantifier of allergen sensitivity, and, as such, is of benefit in the preparation of safe subcutaneous immunotherapy treatment. Today, as IDT is both time consuming and costly, many otolaryngologists use the skin prick multitest alone, or as a screening test prior to performing IDT, that is, Modified Quantitative Testing (MQT)

3. In vitro testing—Allergen-specific serum IgE testing is an easy and accurate method for determining the presence of atopic allergy, and with newer in vitro technology available, in vitro testing is at least equivalent to skin testing in efficacy. In vitro assays are safe, specific, cost-effective, and reproducible, and do not require the patient to be free of antihistamines and other medications that may interfere with skin testing. They are also easy and quick and are therefore preferred, especially in children and in anxious patients.

Although the original in vitro assay, the RAST test (radioallergosorbent test), is no longer performed, its name is still used today to generally describe IgE-specific blood testing. The newer assays are not only truly quantitative but are also faster, more reliable, and more efficient than previous tests. The ImmunoCap is an excellent example of this newer technology. However, not all in vitro assays available today are alike, and their results are often not interchangeable. Not using a reliable assay may affect the diagnosis of atopy and therefore the prescribing of appropriate therapy (Figure 14–2).

In vitro testing can be cost-effective if an initial, appropriately chosen inhalant screening battery of 10–12 allergens



▲ **Figure 14–2.** In vitro testing process.

consisting of the most prevalent pollens, molds, dust mites, and animals in the local environment is used. In children, common allergenic foods are substituted or added. No further testing is necessary if this battery is negative. If the screening battery is positive and if no immunotherapy is considered, additional allergy testing can be performed.

A new finger-stick in vitro screening test (ImmunoCap Rapid), which gives semiquantitive results for ten common inhalant allergens in 20 minutes, is due to be launched in early 2010. Because of its ease of use, requiring only a few droplets of whole blood, this assay should be of great benefit for infants and children suspected of having inhalant allergies.

Differential Diagnosis

The differential diagnoses of allergic rhinitis include the following: (1) infectious rhinitis (acute or chronic); (2) perennial nonallergic rhinitis (eg, vasomotor rhinitis); (3) pollutants and irritants; (4) hormonal rhinitis (eg, pregnancy or hypothyroidism); (5) medication-induced topical rhinitis (rhinitis medicamentosa); (6) anatomic deformity (eg, a deviated septum, nasal polyps, or a concha bullosa); and (7) tumors or foreign bodies.

Treatment

The appropriate management of these common respiratory diseases differs substantially, particularly when allergy is a contributing component. The treatment of allergic rhinitis must consider the main symptoms, their severity, the patient's quality of life, the cost of therapy, as well as the allergens involved in order to individualize the patient's treatment options. In addition, in the treatment of nasal allergies, consideration must be given to both the patient's desire for rapid long-lasting relief of symptoms without side effects and the relief of any particular idiosyncratic symptoms, such as persistent rhinorrhea.

In general, three options are available for the management of allergic rhinitis: (1) avoidance and environmental controls, (2) pharmacotherapy, and (3) immunotherapy.

A. Environmental Controls

Even if environmental controls are not complete, reducing the allergic load may significantly decrease symptoms. Methods of minimizing exposure to pollen are to avoid outdoor activities during relevant pollen seasons (eg, mowing the lawn and gardening), to keep home and car windows closed, and to use air conditioning when possible. To control dust mites, mold, and pet dander, the following practices should be used: (1) reduce household humidity to below 50%; (2) wash bed linens in hot water; (3) remove carpets and pets from the most often used living areas, especially bedrooms; (4) encase pillows, mattresses, and box springs in hypoallergenic coverings (for dust mite protection); and (5) in poor and urban settings, eliminate cockroaches (Table 14–2). For airborne allergens (eg, animal dander), air purifiers can be used.

Table 14–2. Environmental Control of Indoor Aeroallergens.

Allergen	Environmental Control
House dust mites	• Encase mattress, box spring, and pillows in occlusive covers • Wash all bedding in water >130° F weekly • Dehumidify (<50% level) • Remove reservoirs (especially carpeting)
Pets	• Remove pet from home or at least from patient's bedroom • Remove reservoirs (carpeting, stuffed furniture), if feasible • Wash animal frequently

B. Pharmacotherapeutic Measures

When selecting a pharmacologic treatment for allergic rhinitis, consideration must be given to the patient's underlying condition, the likely pathophysiology, the dominant symptoms, the patient's age and condition, the coexistence of related airway disorders, the patient's preference, and the patient's compliance history. In addition, before initiating any pharmacotherapy, the patient's use and response to previous treatment should be considered (Table 14–3).

1. Antihistamines—Antihistamines are frequently used as a first-line therapy; many are available without a prescription. They block H_1 receptor sites and prevent histamine-induced reactions, including inhibiting increased vascular permeability, smooth muscle contraction, increased mucus production, and pruritus. Antihistamines also inhibit the "wheal and flare" response of the skin and therefore they affect skin

Table 14–3. Pharmacologic Agents in the Management of Allergic Rhinitis.

Class	Mechanism of Action
Antihistamines	Antagonize the H_1 receptor-mediated effects of histamine
Decongestants	Act predominantly on α-adrenergic receptors of the mucosa of the respiratory tract
Intranasal and oral corticosteroids	Exert a wide range of effects on multiple cell types and mediators
Mast cell stabilizers	Inhibit the release of mediators from mast cells
Anticholinergic agents	Antagonize the action of acetylcholine at muscarinic receptors
Leukotriene modifiers	Antagonize the action of leukotriene receptors or inhibit 5-lipoxygenase and the formation of leukotrienes

testing unless withdrawn a few days before skin testing. They do not affect in vitro testing. Antihistamines are effective in early-phase reaction and therefore reduce sneezing, rhinorrhea, and itching. They have little effect on nasal congestion, a late-phase phenomenon.

Nonprescription, first-generation antihistamines can cause sedation and impair performance and have been associated with a higher risk of both automobile and work-related accidents, decreased work performance and productivity, and impaired learning and academic performance. These side effects can be significantly exacerbated by alcohol, sedatives, antidepressants, and hypnotics. Many have anticholinergic effects and cause dry mouth. These include diphenhydramine (eg, Benadryl), hydroxyzine (eg, Atarax), chlorpheniramine, and brompheniramine. The latter two are found in most nonprescription cold remedies.

Second-generation antihistamines have an antihistamine activity comparable to that of first-generation antihistamines but have a better safety profile with little, if any, sedation as they have little affinity for central H_1 receptors. They have no anticholinergic activity and are well absorbed, with a rapid onset of action and symptom relief usually within 1 hour. Second-generation antihistamines are typically dosed once daily and are rarely associated with drug tolerance with prolonged use. Those available orally in the United States are fexofenadine (eg, Allegra), loratadine (eg, Claritin), desloratadine (eg, Clarinex), cetirizine (eg, Zyrtec), and levocetirizine (eg, Xyzal).

Newer once a day, second-generation intranasal antihistamines, azelastine (eg, Astepro 0.15%), and olopatadine (eg, Patanase) are now available. These intranasal antihistamines also tend to decrease nasal congestion more than the oral antihistamines.

2. Intranasal corticosteroids—Intranasal corticosteroids may be the most effective medications for the overall control of allergic rhinitis symptoms. They relieve sneezing, itching, and rhinorrhea, and also nasal congestion. Maximal effect may take from 1 to 2 weeks after the onset of their use. Their effectiveness depends on regular use and an adequate nasal airway for application. They act on the late-phase reaction and therefore prevent a significant influx of inflammatory cells. The newer formulations (mentioned below) have minimal systemic absorption with no systemic side effects, and they have been approved for use in children. They have no systemic side effects with regard to HPA axis suppression and do not affect long-bone growth in children. In young adults and children, they are considered the drugs of choice in the treatment of allergic rhinitis. Local side effects, such as dryness and epistaxis, can be reduced by careful patient instruction on their use, that is, to administer the spray away from the nasal septum in a head-down position, and also the regular, concomitant use of intranasal saline. Commonly available intranasal corticosteroids in the United States include triamcinolone (eg, Nasacort), budesonide (eg, Rhinocort), fluticasone propionate (eg, Flonase), mometasone (eg, Nasonex), fluticasone furoate (eg, Veramyst), and ciclesonide (eg, Omnaris)

These newer steroid preparations have extensive first-pass metabolism in the liver and therefore very low systemic bioavailability. Thus, the systemic side effects seen with oral steroid administration are rarely encountered with the newer nasal steroids.

3. Systemic corticosteroids—Systemic corticosteroids may be necessary for severe, intractable symptoms. They can be administered either by intramuscular injection or orally. With the latter, a tapering dose is usually given over 3–7 days. Systemic corticosteroids act on inflammation and significantly reduce all the symptoms of allergic rhinitis. The repeated use of these agents can cause serious side effects, such as HPA axis suppression, as well as other common side effects of steroid use.

4. Decongestants—Decongestants act on α-adrenergic receptors of the nasal mucosa, producing vasoconstriction and thus reducing turbinate congestion. They improve nasal patency but do not relieve rhinorrhea, pruritus, and sneezing. These preparations are found mostly in nonprescription cold medicines and should be used with care in patients with cardiac problems and hypertension. Intranasal decongestants (eg, oxymetazoline) can cause rebound nasal congestion and cause dependency if used for more than 3–4 days (rhinitis medicamentosa).

5. Intranasal anticholinergics—These agents tend to control only rhinorrhea and have no other effects on allergy symptoms. One of the most commonly used intranasal anticholinergics is ipratropium bromide (eg, Atrovent). These agents can be combined with other allergic medications to control rhinorrhea in perennial allergic rhinitis.

6. Intranasal cromolyn—Intranasal cromolyn (eg, Nasalcrom) must be used before the onset of symptoms to be effective. This medication must be used throughout the entire exposure; it is considered to be very safe. The recommended dosage is four times daily.

7. Leukotriene inhibitors—Montelukast "Singulair" is a newer medication for the treatment of allergic rhinitis. To date, clinical studies have shown its efficacy to be greater than that of placebo, but less effective than antihistamines and intranasal steroids in the treatment of allergic rhinitis (Table 14–4).

C. Immunotherapy

Immunotherapy attempts to increase the threshold level of the appearance of symptoms after aeroallergen exposure. The exact mechanism of how immunotherapy works is being investigated. It is believed that increased production of so-called "blocking" antibodies, as well as regulation of the immune cascade that causes allergic reactions both transpire via immunotherapy.

Table 14–4. Pharmacotherapies for Allergic Rhinitis.

Agent	Inflammation	Congestion	Rhinorrhea	Sneezing	Nasal Itch	Ocular Symptoms
Antihistamines						
1st generation	–	–	+	+	+	+
2nd generation	±	–	+	+	+	+
Topical antihistamines	±	±	+	+	+	±
Decongestants	–	+	–	–	–	–
Intranasal steroids	+	+	+	+	±	±
Oral steroids	+	+	+	+	±	+
Intranasal cromolyn	±	±	±	±	±	±

Indications for immunotherapy include long-term pharmacotherapy for prolonged periods of time, the inadequacy or intolerability of drug therapy, and significant allergen sensitivities. Before beginning immunotherapy, the physician must first confirm the atopic diagnosis by testing IgE specific to the offending allergen (or allergens).

Most immunotherapy administered in the United States today is by subcutaneous injection (SCIT), with a gradual increase in the dose of the antigen(s) given until either a mild systemic symptom or a large local reaction at the SCIT site occurs (optimal dose therapy). SCIT, while being effective, requires administration by a trained health care professional and is contraindicated in certain patient populations. These factors, as well as cost and convenience, have fostered the development of other methods for delivering immunotherapy.

Sublingual immunotherapy (SLIT) is a new, safe, efficacious and more convenient method for delivering immunotherapy. While SLIT is still not yet widely used in the United States, there is a significant body of literature concerning its efficacy and safety in Europe. In some European countries, for example, Italy, SLIT is the method of choice for immunotherapy delivery.

While possessing most of the benefits of SCIT, SLIT tends to be easy and safe to administer at home by the patients themselves, and therefore is likely to be more cost-effective. SLIT also appears to be safe in many patients where SCIT is contraindicated, for example, young children, asthmatics, and those who may be at risk for anaphylaxis.

SLIT allows specific antigens placed under the tongue to induce immunologic tolerance. There is no adequate test available to indicate to the patient how long immunotherapy, either SCIT or SLIT, must be continued. Therefore, a clinical response with a reduction in symptoms dictates the duration of specific treatment. A minimum of 2–3 years is usually given to avoid a rapid recurrence of symptoms in uncomplicated allergic rhinitis.

Novak N, Haberstok J, Bieber T, Allam JP. The immune privilege of oral mucosa. *Trends in Molecular Medicine* 2007;14(5): 191–198.

Nouri-Aria, KT, Wachholz PA, Francis JN, Jacobson MR et al. Grass pollen immunotherapy induces mucosal and peripheral IL-10 responses and blocking IgG activity. *J Immunol* 2004;172:3252–3259.

Emanuel IA, Parker M, Traub O. Undertreatment of allergy: exploring the utility of sublingual immunotherapy. *Otolaryngol Head Neck Surg*. 2009;140(5):615–621.

D. Other Treatment Considerations

The first aspect of treating patients who have not responded well to therapeutic measures, including immunotherapy, is determining to what degree therapeutic compliance has occurred. The next steps are to adjust drug dosages, try one or two other agents, and consider combination therapy. In addition, the physician should determine whether allergy exposure has increased and should also review the environmental control measures. Finally, it may be necessary to reconsider the diagnosis and reevaluate the patient.

Baraniuk JN. Pathogenesis of allergic rhinitis. *J Allergy Clin Immunol* 1997;99:S763 [PMID: 9042069].

Bousquet J, Vignola AM, Campbell AM, Michel FB. Pathophysiology of allergic rhinitis. *Int Arch Allergy Immun* 1996;110:207 [PMID: 8688666].

Jarvis D, Burney P. ABC of allergies: the epidemiology of allergic disease. *BMJ* 1998;316:607 [PMID: 9518918].

Poon AW, Goodman CS, Rubin RJ. In vitro and skin test testing for allergy: comparable clinical utility and costs. *Am J Manag Care* 1998;4(7):969 [PMID: 10181996].

Acute & Chronic Sinusitis

15

Jeffrey D. Suh, MD & Alexander G. Chiu, MD

ESSENTIALS OF DIAGNOSIS

- The vast majority of cases of acute rhinosinusitis are self-limiting viral events.
- Chronic rhinosinusitis is an inflammatory disease whose causes are often multifactorial.
- In chronic rhinosinusitis, nasal endoscopy and/or CT scan may be necessary to make the diagnosis if symptoms do not correlate well with findings.

General Considerations

Rhinosinusitis is one of the most commonly diagnosed medical conditions in the United States, affecting an estimated 16% of the adult population annually. Direct health care costs are significant, estimated to be over $5.8 billion per year. According to the recent 2007 data from the National Health Interview Survey, rhinosinusitis continues to be one of the top 10 leading diagnoses of office visits in the United States. Of all antibiotics prescribed in 2002, 9% of pediatric prescriptions and 18% of adult prescriptions were written for a diagnosis of acute sinusitis.

Anand VK. Epidemiology and economic impact of rhinosinusitis. *Ann Otol Rhinol Laryngol* 2004;193(Suppl):S3–S5. (This article sheds light on the enormous direct and indirect costs associated with sinusitis.)

Glikilich RE, Metson R. The health impact of chronic sinusitis in patients seeking otolaryngologic care. *Otolaryngol Head Neck Surg* 1995;113:104–109. (The authors demonstrate the significant national health impact of chronic sinusitis.)

Rhinosinusitis: Classification and Diagnosis

Rhinosinusitis is broadly defined as symptomatic inflammation of the paranasal sinuses and nasal cavity. The term rhinosinusitis is used because sinusitis is almost always accompanied by inflammation of the contiguous nasal mucosa. There have been a number of iterations of the actual definition that are described in this section. The Rhinosinusitis Task Force in 1997 classified rhinosinusitis based on both symptom duration and by history. A history suggestive of rhinosinusitis includes two or more major factors, or one major and two minor factors (Table 15–1). In 2003, another task force that included the American Academy of Otolaryngology – Head and Neck Surgery (AAO-HNS) proposed revised guidelines that required physical exam findings for the diagnosis of chronic rhinosinusitis (CRS). Findings on nasal endoscopy or anterior rhinoscopy should include one or more of the following: purulent drainage, polyps, polypoid changes in the mucosa, and edema or erythema of the middle meatus. These guidelines also suggest that CT scans can be a helpful to confirm the diagnosis of symptomatic patients with equivocal physical exam findings. In 2004, a multidisciplinary panel further classified CRS as *CRS with nasal polyps*, *CRS without nasal polyps*, and *allergic fungal rhinosinusitis* (AFS) to better guide clinical research and patient care.

- *Acute rhinosinusitis:* ≤4 weeks
- *Subacute rhinosinusitis:* Duration of 4–12 weeks
- *CRS*: ≥12 weeks
- *Recurrent acute rhinosinusitis:* Greater than four or more episodes of acute rhinosinusitis per year, with each episode lasting ≥7–10 days, with symptom resolution between episodes
- *Acute exacerbations of CRS* are a sudden worsening of CRS with a return to baseline after treatment.

Most recently in 2007, new clinical practice guidelines were developed to improve and update the diagnosis of rhinosinusitis. CRS is now defined as 12 weeks or longer of two or more of the following symptoms:

- Mucopurulent drainage (anterior, posterior, or both)
- Nasal obstruction (congestion)

Table 15–1. Major and Minor Factors in the Diagnosis of Rhinosinusitis (1997 Task Force).

Major factors
Facial pain or pressure
Facial congestion or fullness
Nasal obstruction or blockage
Nasal discharge, purulence, or discolored postnasal drainage
Hyposmia or anosmia
Purulence in nasal cavity
Fever (in acute rhinosinusitis only)
Factors
Headache
Fever (in chronic sinusitis)
Halitosis
Fatigue
Dental pain
Cough
Ear pain, pressure, or fullness

Adapted from Lanza DC et al. Adult rhinosinusitis defined. *Otolaryngol Head and Neck Surg* 1997;117:S1.

- Facial pain-pressure-fullness
- Decreased sense of smell.

And inflammation as seen by one or more of the following:

- Purulent mucus or edema in the middle meatus or ethmoid region
- Polyps in the nasal cavity or the middle meatus
- Radiographic imaging showing inflammation of the paranasal sinuses.

Lanza DC, Kennedy DW. Adult rhinosinusitis defined. *Otolaryngol Head Neck Surg* 1997 Sep;117(3 Pt 2):S1–S7. (In 1997, Drs. Lanza and Kennedy proposed a major and minor classification system to define chronic sinusitis by symptoms.)

Benninger MS, Ferguson BJ, Hadley JA. Adult chronic rhinosinusitis: definitions, diagnosis, epidemiology, and pathophysiology. *Otolaryngol Head Neck Surg* 2003 Sep;129(3 Suppl):S1–32. (This task force summarized the impact of CRS and proposed an updated definition in 2003.)

Meltzer EO, Hamilos DL, Hadley JA. Rhinosinusitis: establishing definitions for clinical research and patient care. *Otolaryngol Head Neck Surg*. 2004 Dec;131(6 Suppl):S1–62. (Five national societies reached a consensus on definitions and strategies for clinical research to improve the diagnosis and future research in rhinosinusitis.)

Rosenfeld RM, Andes D, Bhattacharyya N et al. Clinical practice guideline on adult sinusitis. *Otolaryngol Head Neck Surg*. 2007 Sep;137(3):365–377. (The most recent guidelines illustrating the current recommendations on the diagnosis and treatment of rhinosinusitis.)

Basic Physiology of the Nasal Cavity and Paranasal Sinuses

The nasal cavity serves to warm and humidify inhaled air. There are a variety of theories on the function of the paranasal sinuses. Proposed functions include (1) acting as resonating chambers for the voice, (2) providing protection to the brain and orbit from trauma, (3) moisturizing and humidifying ambient air, and (4) lightening the weight of the facial skeleton.

The sinonasal mucosa is lined by pseudostratified columnar ciliated epithelium. This respiratory epithelium is made up of a variable number of ciliated cells (~75%), mucus-secreting goblet cells (~20%) and basal cells (~5%). There are approximately 50–200 cilia on the apical surface of epithelial cells that beat in a coordinated fashion. Under normal conditions, the entire mucus blanket of the nose or sinus is cleared in 10 minutes. Ciliary beat frequency can vary in response to chemical, thermal, mechanical, and hormonal stimuli. Additionally, changes in pH have a profound impact on ciliary beat frequency. Impairment of mucociliary clearance may result in mucus stasis, which under the proper conditions can support bacterial growth and infection.

The mucus secreted by goblet cells is comprised of primarily of water, gycoproteins, immunoglobulins, leukocytes, salts, and neurotransmitters. The mucus consists of 2 layers: the superficial *gel* phase and the inner *sol* phase. Aerosolized pathogens and particles larger than 0.5–1 μm are trapped in the mucus gel layer and eventually transported posteriorly to the nasopharynx and oropharynx to be swallowed. Within the sinuses, the mucus blanket is transported toward the natural sinus ostia, despite the presence of accessory ostia. Mucus also plays a critical role in olfaction. Airborne olfactants must dissolve in the nasal mucosa overlying the olfactory epithelium before the olfactory response is initiated. Surgical antrostomies that do not include the true sinus ommNstium can result in mucus recirculation, which can be a source of persistent postoperative symptoms.

Antunes MB, Gudis DA, Cohen NA. Epithelium, cilia, and mucus: their importance in chronic rhinosinusitis. *Immunol Allergy Clin North Am*. 2009 Nov;29(4):631–643. (An excellent review article on sinus physiology.)

Pathogenesis & Clinical Features

A. Acute Rhinosinusitis

Acute rhinosinusitis, in contrast to CRS, is most often caused by an infectious agent. Acute rhinosinusitis is defined as up to 4 weeks of purulent nasal drainage accompanied by nasal

obstruction, facial pain, facial pressure, or fullness. The clinician must then distinguish between *viral rhinosinusitis* (VRS) and *acute bacterial rhinosinusitis* (ABRS). This distinction is made based on illness pattern and duration.

- Viral Rhinosinusitis
  - Symptoms of acute rhinosinusitis are present less than 10 days
  - Symptoms are not worsening.
- Acute Bacterial Rhinosinusitis
  - Signs or symptoms of acute rhinosinusitis are present 10 days or more beyond the onset of upper respiratory symptoms
  - Signs or symptoms of acute rhinosinusitis worsen within 10 days after an initial improvement.

In most cases, bacterial sinusitis is preceded by a viral upper respiratory infection. Other common conditions that can predispose a patient to acute sinusitis are cigarette smoke, anatomical factors such as nasal septum deformities, concha bullosa, and allergies. More than 200 different viruses are known to cause the symptoms of the common cold. The most frequently detected viruses include rhinovirus, respiratory syncytial virus, influenza virus, and parainfluenza virus. Approximately 2% of VRS progresses to bacterial rhinosinusitis in adults.

Three cardinal symptoms have been found to have high sensitivity and specificity for ABRS. These include purulent rhinorrhea, facial pain/pressure, and nasal obstruction. Secondary symptoms that support the diagnosis include anosmia, fever, aural fullness, cough, and headache. Another finding suggestive of ABRS is if patients worsen after an initial improvement in symptoms. The most common organisms responsible for ABRS include *Streptococcus pneumoniae*, *Haemophilus influenzae*, *and Moraxella catarrhalis.*

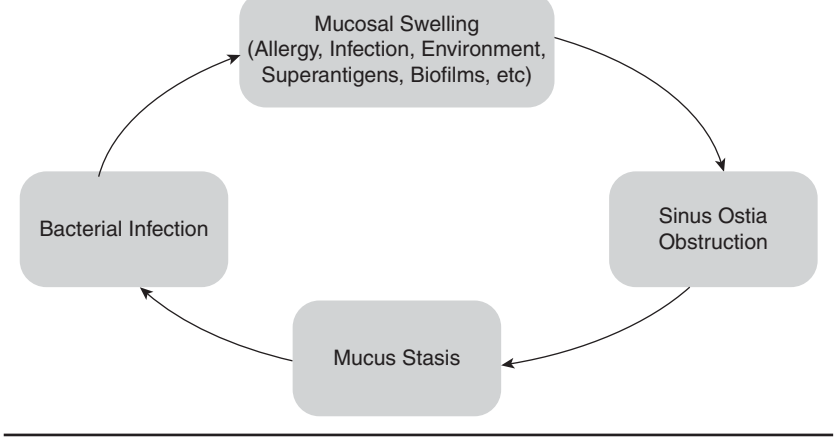
Benninger MS, Ferguson BJ, Hadley JA. Adult chronic rhinosinusitis: definitions, diagnosis, epidemiology, and pathophysiology. *Otolaryngol Head Neck Surg* 2003 Sep;129(3 Suppl):S1–32. (This task force summarized the impact of CRS and proposed an updated definition in 2003.)

Rosenfeld RM, Andes D, Bhattacharyya N et al. Clinical practice guideline on adult sinusitis. *Otolaryngol Head Neck Surg* 2007 Sep;137 (3):365–377. (The most recent guidelines illustrating the current recommendations on the diagnosis and treatment of rhinosinusitis.)

B. Chronic Rhinosinusitis

CRS is defined as an inflammatory condition of the nasal cavity and paranasal sinuses lasting for longer than 12 weeks. The pathophysiology of CRS remains incompletely understood, but it is believed to be multifactorial, resulting from interactions between host anatomy, genetics, and the environment. A simplified way to approach CRS is illustrated in Table 15–2. CRS can be thought of first resulting from mucosal inflammation, causing swelling and obstruction at the sinus ostium. This can lead to mucus stasis, which can then lead to bacterial superinfection. The signs and symptoms of CRS often vary in severity and prevalence. Nasal obstruction (81–95%), is the most common symptom, followed by facial congestion-pressure-fullness (70–85%), discolored nasal discharge (51–83%), and hyposmia (61–69%). High fevers are usually absent, although fatigue and myalgias are common (Table 15–1).

Table 15–2. Pathogenesis of Rhinosinusitis.



Unlike in acute rhinosinusitis, which is usually caused by an infectious agent, there is no one causative factor that accounts for CRS. There is evidence of numerous factors contributing to CRS including:

- Biofilms
- Osteitis
- Allergy
- Superantigens from *Staphylococcus aureus*
- Fungi
- General Host Factors
- Infectious

1. Biofilms

There is growing evidence that bacterial biofilms may play a role in certain cases of recalcitrant chronic sinusitis that do not respond to traditional medical and surgical therapies. Biofilms are three-dimensional aggregates of bacteria encased in a protective extracellular matrix. Biofilms are initiated when free-floating planktonic bacteria anchor to various biological or inert surfaces. The most common biofilm formers in CRS are *Pseudomonas aeruginosa*, *S. aureus,* and *Haemophilus influenzae*. Bacteria in biofilms are more resistant to host defenses such as immune system phagocytosis, and can be up to 1000 times more resistant to antibiotic treatment. Biofilms have been shown to have an adverse effect on postoperative outcomes of CRS patients. Patients with bacterial biofilms show worse postoperative endoscopy scores and increased mucosal inflammation.

2. Osteitis

Changes in bone have been appreciated clinically and radiographically in CRS. The presence of inflammation and remodeling within the bone of the paranasal sinuses has been demonstrated in both animal and human studies. Histologically, there is bony remodeling, an inflammatory infiltrate, and bony sclerosis, likely due to an increase in local inflammatory mediators. Studies suggest that the inflammation associated with CRS may spread through the Haversian system within the bone to involve other sinuses. Despite aggressive treatment of the overlying sinus mucosa, chronic inflammation can persist in the underlying bone, which may contribute to some cases of recalcitrant CRS.

3. Allergy

There is some epidemiologic data supporting a link between allergy and CRS. Approximately 20% of the population of the United States has allergy. Allergic rhinitis is an IgE-mediated disease in which exposure to an inhaled antigen elicits inflammatory changes in the nasal mucosa. Allergy is thought to cause a proportion of CRS and all cases of allergic fungal sinusitis (by definition). There is an increased prevalence of allergy among patients who have CRS, and when present, it can increase the severity of CRS. In these patients, treatment of allergies can improve the course of the disease, hastens symptom recovery, and improve mucosal appearance. Still, the precise mechanism that allergic rhinitis may predispose people to CRS remains unclear.

4. Bacterial Superantigens

Recent evidence has suggested that exotoxins secreted by colonizing *S. aureus* play a role in the pathophysiology of a subset of patients with CRS with nasal polyposis. Superantigens have the ability to activate up to 30% of the T-cell population by bypassing normal antigen processing within antigen-presenting cells. In this theory, the superantigens result in immune activation, cytokine release, and inflammation. This theory suggests that superantigens can play an important role in polyp formation or maintenance of patients with CRS with nasal polyps.

5. Fungi

Over the last 10 years, there has been a significant amount of interest in the role of fungi in CRS, and the potential use of antifungal medications to treat CRS. Work from the Mayo clinic has demonstrated fungal hyphae in 96% of patients with CRS. Select fungi such as *Alternaria* and *Candida* have been shown to up-regulate IL-5 and IL-13 in some individuals, which are important chemokines involved in the eosinophilic response. This theory suggests that, in a susceptible host, an immunologic response is mounted that includes the proliferation or recruitment of eosinophils, which results in the clinical expression of CRS. However, others have disputed the role of fungus in CRS. A recent European multicenter randomized controlled study demonstrated that topical amphotericin B had no significant beneficial effect for patients with CRS with and without nasal polyps. Another study found that nasal amphotericin B spray was is ineffective in treating objective markers of sinus inflammation, and actually worsened patient symptoms. Further studies are needed to clarify the exact role of fungi in CRS pathogenesis.

6. General Host Factors

Genetic factors and immune deficiency can significantly increase the potential for patients to develop CRS. These general host factors can lead to diffuse inflammation of the sinonasal mucosa. This inflammation can cause obstruction at the sinus ostium that can trigger a cascade of impaired mucociliary clearance, mucus stasis, and subsequent bacterial overgrowth. Systemic diseases include autoimmune/granulomatous diseases such as Wegener's granulomatosis, aspirin sensitivity triad (Samter's Triad), cystic fibrosis, immunodeficiency, and primary ciliary dyskinesia. Patients with these conditions are at a high risk for failing conventional medical and surgical management for CRS.

7. Infectious

Bacterial, viral, and fungal infections can all be sources of sinonasal inflammation in CRS. Bacteria may play both direct and indirect roles in the pathophysiology of CRS, as seen with the biofilm and superantigen theories. The most common organisms isolated in CRS patients include *S. aureus,* coagulase-negative staphylococci, anaerobes, *Pseudomonas aeruginosa.*

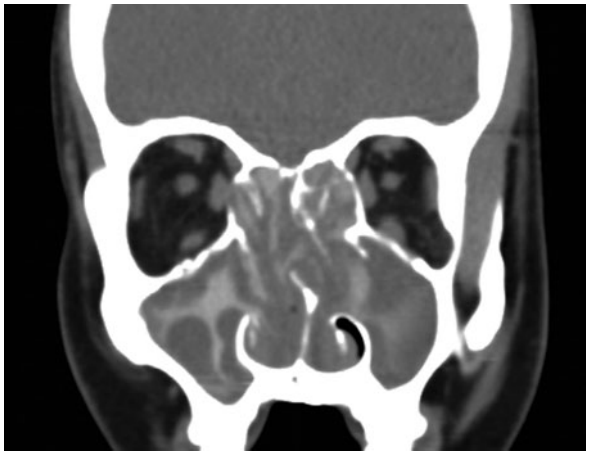
C. Fungal Rhinosinusitis

Many different genera of fungus have been documented to cause sinus disease including Aspergillus, Bipolaris, Rhizopus, and Alternaria. Fungal sinusitis can vary from a relatively benign process to an acute life-threatening disease depending on the host and a variety of factors including diabetes, immunosupression, and allergy.

1. Fungal ball—A fungal ball is the development of a non-invasive conglomeration of fungal hyphae into a mass. This condition arises due to the implantation of fungus into an otherwise normal sinus. Patients are usually immunocompetent with no other risk factors. The maxillary sinus is most commonly involved, followed by the sphenoid and ethmoid sinuses. Treatment is simple surgical removal of the fungal ball with aeration of the affected sinus. Antifungal therapy is usually unnecessary after surgery.

2. Allergic fungal rhinosinusitis (AFS)—Allergic fungal sinusitis is a subtype of CRS characterized by the presence of allergic mucin, which is thick inspissated mucus with eosinophils and fungal hyphae. The widely accepted diagnostic criteria for AFS were described by Bent and Kuhn in 1994. The five criteria are type I hypersensitivity to fungi, nasal polyps, characteristic CT scan findings (Figure 15–1), eosinophilic mucin without fungal invasion into sinus tissue, and positive fungal stains. Typically, polypoid tissue is seen anterior to a mass consisting of mucin, fungal elements, Charcot-Leyden crystals, and eosinophils. Sinus expansion and bony remodeling are hallmark features of this process. Typical CT scan findings include heterogeneous areas of signal intensity within the affected sinuses. The areas of increased signal intensity are thought to be due to the accumulation of heavy metals such as iron, manganese, and calcium within the inspissated allergic mucin. Magnetic resonance imaging (MRI) scans can also assist in the diagnosis. Treatment is primarily surgical with postoperative topical and systemic steroids. Immunotherapy, systemic steroids, and postoperative management by an allergist may be necessary to reduce recurrence.

3. Invasive fungal sinusitis—Invasive fungal sinusitis is a disease seen almost exclusively in immunocompromised individuals. This condition is characterized by the rapid development of progressive invasive fungal infection. The typical fungal pathogens are *Aspergillus, Mucor*, and *Rhizopus.* Gillespie and O'Malley reviewed 25 patients with invasive fungal sinusitis, and looked at their presentation. Nearly two-thirds presented with either fever or facial periorbital pain, and up to half presented with nasal congestion and headache. In this study, 88% presented with two or more of these findings, and just over a quarter had visual complaints or ophthalmoplegia. Rapid diagnosis and treatment is essential to limit the disease progression. In one small study, biopsy of the middle turbinate at had a 75% sensitivity and 100% specificity in diagnosing invasive fungal sinusitis. Pathologic examination of the black necrotic intranasal or palatal debris demonstrates arterial and venous thrombosis due to direct fungal invasion. The treatment consists of (1) debriding all involved structures, (2) aggressive intravenous antifungal therapy, and (3) normalizing the underlying immunocompromised state (usually neutropenia or uncontrolled diabetes).



▲ **Figure 15–1.** Coronal CT scan: Allergic fungal sinusitis. Note the heterogeneous signal characteristics in the maxillary sinuses.

Benninger MS, Ferguson BJ, Hadley JA. Adult chronic rhinosinusitis: definitions, diagnosis, epidemiology, and pathophysiology. *Otolaryngol Head Neck Surg.* 2003 Sep;129(3 Suppl):S1–32. (This task force summarized the impact of CRS and proposed an updated definition in 2003.)

Meltzer EO, Hamilos DL, Hadley JA. Rhinosinusitis: establishing definitions for clinical research and patient care. *Otolaryngol Head Neck Surg.* 2004 Dec;131(6 Suppl):S1–62. (Five national societies reached a consensus on definitions and strategies for clinical research to improve the diagnosis and future research in rhinosinusitis.)

Rosenfeld RM, Andes D, Bhattacharyya N et al. Clinical practice guideline on adult sinusitis. *Otolaryngol Head Neck Surg.* 2007 Sep;137(3):365–377. (The most recent guidelines illustrating the current recommendations on the diagnosis and treatment of rhinosinusitis.)

Chiu AG. Osteitis in chronic rhinosinusitis. *Otolaryngol Clin North Am.* 2005 Dec;38(6):1237–1242. (The author describes the possible association between bone infection and inflammation with chronic sinusitis.)

Krouse JH. Allergy and chronic rhinosinusitis. *Otolaryngol Clin North Am* 2005 Dec;38(6):1257–1266. (A nice review on the possible role of allergy in chronic sinusitis.)
Seiberling KA, Grammer L, Kern RC. Chronic rhinosinusitis and superantigens. *Otolaryngol Clin North Am* 2005 Dec;38(6):1215–1236. (This group describes the possible association between bacterial superantigens and CRS.)
Chakrabarti A, Denning DW, Fergusuon BJ et al. Fungal rhinosinusitis: a categorization and definitional schema addressing current controversies. *Laryngoscope* 2009 Sep;119(9):1809–1818. (This article reviews the recent literature on fungal sinusitis.)
Weschta M, Rimek D, Formanek M et al. Topical antifungal treatment of chronic rhinosinusitis with nasal polyps: a randomized, double – blind clinical trial. *J Allergy Clin Immunol* 2004 Jun;113(6):1122–1128. (These authors showed that nasal amphotericin B was not effective in treating CRS.)
Ebbens FA, Georgalas C, Luiten S et al. The effect of topical amphotericin B on inflammatory markers in patients with chronic rhinosinusitis: a multicenter randomized controlled study. *Laryngoscope* 2009 Feb;119(2):401–408. (This article demonstrated no appreciate benefit on objective markers of CRS with nasal amphotericin B.)
Gillespie MB, O'Malley BW. An algorithmic approach to the diagnosis and management of invasive fungal rhinosinusitis in the immunocompromised patient. *Otolaryngol Clin North Am* 2000;33:323–334. (Review of the diagnosis and management of invasive fungal sinusitis.)

Staging Systems

Many staging systems have been used to stratify patients with CRS according to objective levels of disease. Two commonly used staging systems found in the literature will be described briefly in this section.

A. Lund–Mackay Staging

The Lund–Mackay staging system is widely used in radiologic assessment of CRS. The scoring system is based on CT scan findings that are obtained after an adequate trial of medical treatment. Each sinus group is then assigned a numeric grade: 0 = no abnormality, 1 = partial opacification, and 2 = total opacification. The sinus groups include the maxillary, frontal, sphenoidal, anterior ethmoidal, and posterior ethmoidal sinuses. The ostiomeatal complex is scored only as 0 (not obstructed) or 2 (obstructed). Thus, a total score of 0–24 is possible, and each side can be considered separately (0–12).

B. Lund–Kennedy Endoscopic Scores

In this staging system, the endoscopic appearances of the nose are also quantified for the presence of polyps (0 = none, 1 = confined to middle meatus, 2 = beyond middle meatus), discharge (0 = none, 1 = clear and thin, 2 = thick and purulent), and edema, scarring or adhesions, and crusting (for each: 0 = absent, 1 = mild, 2 = severe).

Lund VJ, Kennedy DW. Staging for rhinosinusitis. *Otolaryngol Head Neck Surg* 1997 Sep;117(3 Pt 2):S35–S40.

Diagnostic Modalities

A. Physical Examination

A complete head and neck exam with anterior rhinoscopy is essential in all patients suspected of having rhinosinusitis. Findings of mucopurulence, edema, septal deflection, and polyps should be noted. The middle meatus is often well visualized after appropriate decongestion.

B. Endoscopic Evaluation

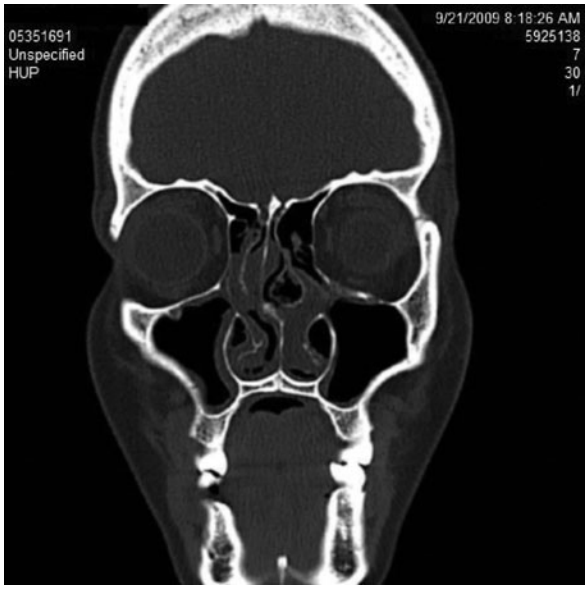
Rigid endoscopy or flexible fiberoptic endoscopy are useful to better evaluate the nasal cavity, sinuses, and nasopharynx. Findings that should be noted in the examination are septal deviations, edema of the turbinates, and the presence of mucus, pus, polyps, or erythema. Two critical areas to examine are the osteomeatal complex lateral to the middle turbinate and the sphenoethmoidal recess. Endoscopically guided cultures should be taken of any purulence in the nasal cavity or sinuses and sent for aerobic, anaerobic, fungal, and acid-fast bacilli cultures.

C. Imaging Studies

Computed tomography (CT) scanning is currently the method of choice for sinus imaging. Because a viral upper respiratory infection may cause abnormalities on CT that are indistinguishable from rhinosinusitis, imaging in ABRS has limited usefulness except when complications are suspected. On the other hand, symptoms of CRS do not correlate well with findings. Therefore, CT and/or nasal endoscopy is necessary to make the diagnosis. In addition to providing excellent visualization of mucosal thickening, air fluid levels, and bony structures, coronal scans give optimal visualization of the osteomeatal complex and are conveniently oriented for the surgeon in terms of surgical planning. Sagittal views can help delineate frontal sinus anatomy and confirm the presence of Onodi cells (Figure 15–2).

When compared to CT scans, MRI of the sinuses provides better soft tissue contrast resolution and tissue characterization. MRI offers better differentiation of benign obstructed secretions from tumor, and can be a helpful modality with suspected orbital or intracranial extension. For these reasons, MRI scanning should be the imaging method of choice in the evaluation of soft tissue masses, complicated sinus inflammatory diseases, and intracranial or intraorbital extension of sinus pathology.

Historically, standard radiographs were used to evaluate the sinuses. The conventional paranasal sinus evaluation included the following views: Caldwell (to visualize the frontal and ethmoid sinuses), Waters (for the maxillary sinuses), lateral (for the anterior and superior walls of the frontal, maxillary, and sphenoid sinuses), and submental vertex views (for the ethmoid and sphenoid sinuses).



▲ **Figure 15–2.** Coronal CT scan in a patient with chronic rhinosinusitis and allergic rhinitis. Note the left concha bullosa.

D. Laboratory Tests

Laboratory tests and immunologic studies may be helpful for patients who fail to improve with conventional medical and surgical treatments. A variety of conditions such as Wegener granulomatosis, Churg–Strauss syndrome, and sarcoidosis can be causes of recurrent sinusitis. Nasal crusting can occur secondary to dryness of the mucosa in Sjogren syndrome. Some common laboratory tests for these conditions include cytoplasmic-antineutrophil cytoplasmic antibody, perinuclear-antineutrophil cytoplasmic antibody, IgE, erythrocyte sedimentation rate, c-reactive protein, rheumatoid factor, and antinuclear antibody. Testing for HIV and IgG levels should be also considered in refractory patients.

Differential Diagnosis

The differential diagnoses of acute and chronic sinusitis are many and include the following: the common cold, temporomandibular joint (TMJ) pain, headache (including migraine), trigeminal pain, and sinus neoplasms. Allergic and odontogenic causes of symptoms should also be excluded. The symptoms of facial pressure and pain, purulent nasal discharge, nasal congestion, hyposmia, tooth pain, and a poor response to nasal decongestants can help differentiate these entities.

Sinus neoplasms are relatively uncommon, but are critical to exclude. A history of unilateral nasal obstruction and epistaxis warrants further workup, including CT scan and nasal endoscopy. Changes in vision and cranial nerve deficits, particularly in the distribution of the infraorbital nerve, should also cause suspicion. Palatal numbness or dry eyes can also be due to lesions in the pterygopalatine fossa (see Chapter 17, Paranasal Sinus Neoplasms).

Treatment of Chronic Rhinosinusitis

Medical management of CRS can be simplified into three groups: antimicrobial, anti-inflammatory, and mechanical. It is helpful to break down treatments from each group, and combine them when appropriate into a comprehensive treatment plan. Also, it is important at this time to consider the side effects of each therapy, and weigh them with the patient's symptom severity and other medical conditions. In general, medical management of CRS should include 3–4 weeks of culture directed (or broad spectrum) antibiotics, a nasal steroid spray, and nasal saline irrigation. Strong consideration should be given to a tapered course of oral steroids unless contraindicated.

Benninger MS, Ferguson BJ, Hadley JA. Adult chronic rhinosinusitis: definitions, diagnosis, epidemiology, and pathophysiology. *Otolaryngol Head Neck Surg* 2003 Sep;129(3 Suppl):S1–32.

Lund VJ. Maximal medical therapy for chronic rhinosinusitis. *Otolaryngol Clin North Am* 2005 Dec;38(6):1301–1310. (Well-written review of the current medical treatments of chronic sinusitis.)

A. Antibiotics

Antimicrobial medications are best given for patients with CRS after cultures have been performed. After the correct antibiotic is chosen, there are multiple ways to deliver it, including oral, intravenous, or topical. Oral antibiotics are the mainstay of treatment in the management of CRS to clear infection and to treat exacerbations of CRS. In contrast to antibiotic therapy for acute sinusitis, antibiotics should be used for at least 3–4 weeks. Ideally, antibiotic therapy should be culture-directed, particularly after failure of prior antibiotic use.

Topical antibiotics have the theoretical advantage of high local levels of drug with minimal systemic absorption, lower costs, and decreased morbidity when compared to IV antibiotics. A study by Vaughn and Carvalho showed that after a 3-week course of culture directed nebulized antibiotics, patients demonstrated improvements in posterior nasal discharge, and facial pain/pressure. These patients also had a longer infection-free period, and improved endoscopic exams. There were no major side effects to treatment, and minor side effects were usually benign and self-limiting.

Antifungal therapy for CRS is still controversial at this time. Recent double-blind, placebo controlled trials have not shown substantial improvement in CRS based on objective

and subjective criteria after treatment with amphotericin B. Nonetheless, some patients with CRS treated with oral antifungals do benefit.

Vaughan WC, Carvalho G. Use of nebulized antibiotics for acute infections in chronic sinusitis. *Otolaryngol Head Neck Surg* 2002 Dec;127(6):558–568.
Rosenfeld RM, Andes D, Bhattacharyya N et al. Clinical practice guideline on adult sinusitis. *Otolaryngol Head Neck Surg* 2007 Sep;137(3):365–377.
Weschta M, Rimek D, Formanek M et al. Topical antifungal treatment of chronic rhinosinusitis with nasal polyps: a randomized, double–blind clinical trial. *J Allergy Clin Immunol* 2004 Jun;113(6):1122–1128.
Ebbens FA, Georgalas C, Luiten S et al. The effect of topical amphotericin B on inflammatory markers in patients with chronic rhinosinusitis: a multicenter randomized controlled study. *Laryngoscope* 2009 Feb;119(2):401–408.

B. Steroid Nasal Sprays and Oral Steroids

Mucosal inflammation and polyposis, which can lead to the obstruction of sinus ostia, are critical in the pathogenesis of most cases of CRS. Nasal steroid sprays directly address this problem by reducing mucosal inflammation and the site of polyps, thereby limiting postoperative recurrence. Common adverse effects with nasal steroids include nasal irritation, mucosal bleeding, and crusting. Systemic side effects are uncommon, and therefore nasal steroids are often prescribed for maintenance therapy in those with CRS. For better frontal sinus penetration, an eyedropper can be used to instill standard nasal steroid spray solution. Placement of drops at home can be done by the patient kneeling and then placing the forehead on the floor (Moffit's position) or with the head hanging off the bed (Mygind's position).

Systemic steroids are highly effective at reducing mucosal inflammation and nasal polyp bulk in CRS. Oral steroids decrease white blood cell migration, production of inflammatory mediators, antibody production, histamine release, and swelling through a variety of mechanisms. However, a thorough discussion with patients regarding the risks of systemic steroid administration is mandatory. A tapered regimen may be given during severe CRS flare-ups and in the postoperative period, but their use should be limited and carefully monitored.

C. Nasal Irrigation and Other Mechanical Treatments

Nasal saline irrigation is an important component in the treatment of CRS. Frequent rinsing prevents the accumulation of nasal crusts and promotes mucociliary clearance. Hypertonic saline may increase the rate of clearance in certain cases. Nasal irrigation is well tolerated by patients, without any evidence of significant harmful side effects. Work by the senior author has demonstrated the efficacy of 1% baby shampoo nasal irrigations for patients with CRS recalcitrant to surgery and isotonic saline irrigations. Patients with CRS were treated with twice-a-day sinus irrigation with 1% baby shampoo, which led to improvement in SNOT-22 scores for nearly 50% of patients who remained symptomatic despite surgical and conventional medical management. Greatest improvements were in reducing thickened nasal secretions and postnasal drainage. Baby shampoo nasal irrigation has promise as an inexpensive, well-tolerated adjuvant therapy to conventional medical therapies for symptomatic patients after FESS.

Rosenfeld RM, Andes D, Bhattacharyya N et al. Clinical practice guideline on adult sinusitis. *Otolaryngol Head Neck Surg* 2007 Sep;137(3):365–377.
Chiu AG, Palmer JN, Woodworth BA et al. Baby shampoo nasal irrigations for the symptomatic post-functional endoscopic sinus surgery patient. *Am J Rhinol* 2008 Jan–Feb;22(1):34–37. (Novel research illustrating the use of diluted baby shampoo irrigation for patients with thick mucus and chronic sinusitis.)

D. Decongestants, and Leukotriene Antagonists, and Other Therapies

Systemic decongestants and mucolytic agents such as guaifenesin may provide some symptomatic relief. Given the favorable side effects of these agents, they are often added to the therapeutic regimen. Leukotriene receptor antagonists (montelukast, zafirlukast) and macrolide antibiotics, which have anti-inflammatory effects, may also prove to be useful therapeutics.

Budesonide is used for the maintenance treatment of asthma and as prophylactic therapy in children aged 12 months to 8 years. While not FDA approved for use in CRS, use of budesonide respules (Pulmicort Respules; AstraZeneca LP, Wilmington, Delaware) for patients with nasal polyps or significant mucosal edema has been gaining popularity in the United States. A recent study for patients with chronic sinusitis found that use of budesonide 0.25 mg once a day for 30 days improved SNOT-20 scores without suppression of the hypothalamic–pituitary–adrenal axis. Budesonide can be used both in nasal irrigation or can be applied directly from respules.

Oxymetazoline hydrochloride and other topical nasal decongestant sprays cause intense vasoconstriction of the nasal mucosa. Rebound swelling (rhinitis medicomentosa) may incite a vicious cycle, leading to complete nasal obstruction and subsequent sinus disease. Oxymetazoline spray may be used for very short periods of time (less than 3 days) for symptomatic relief usually in ABRS or acute exacerbations of CRS.

Sachanandani NS, Piccirillo JF, Kramper MA et al. The effect of nasally administered budesonide respules on adrenal cortex function in patients with chronic rhinosinusitis. *Arch Otolaryngol Head Neck Surg* 2009 Mar;135(3):303–307. (Describes the use of topical budesonide respules for CRS.)

E. Allergy Management

For patients with documented allergic disease, ongoing allergy management is beneficial. Environmental avoidance, topical nasal steroids, and immunotherapy may prevent exacerbations of allergic rhinitis. Immunotherapy is most effective for pollen, dust, molds, and pet dander allergies. Traditionally, treatments are via a subcutaneous route, but more recently sublingual immunotherapy has been gaining popularity especially in Europe. There is also a potentially beneficial role in aspirin desensitization for those patients with aspirin-exacerbated respiratory disease and Samter's triad.

Krouse JH. Allergy and chronic rhinosinusitis. *Otolaryngol Clin North Am* 2005 Dec;38(6):1257–1266.

F. Sinus Surgery

Maximal medical therapy for CRS is typically defined as 4–6 weeks of broad spectrum or culture-directed antibiotics, nasal steroids, nasal irrigation, allergy management, and a short course of oral steroids. Surgical therapy may be necessary if the patient remains symptomatic, and there is evidence of persistent mucosal disease or sinus obstruction on CT scan or endoscopic evaluation. Patients with clear anatomic abnormalities, large sinonasal polyps, or allergic fungal sinusitis may be better candidates for primary surgical therapy.

Patients should be strongly encouraged to stop smoking prior to considering sinus surgery. Current tobacco use is associated with worse outcomes after endoscopic sinus surgery when compared to nonsmokers. Work by Senior et al. demonstrated active smokers have higher rates of disease relapse after sinus surgery, requiring more revision surgeries than nonsmokers. In this study, 100% of patients with severe disease required a revision operation for persistent symptoms.

Senior BA, Kennedy DW, Tanabodee J. Long-term results of functional endoscopic sinus surgery. *Laryngoscope* 1998 Feb;108(2):151–157. (Excellent paper describing the long-term benefits of FESS.)

1. Functional endoscopic sinus surgery (FESS)

A. Indications—Kennedy coined the term "functional endoscopic sinus surgery" to emphasize that surgery should aim at restoring normal sinus function and ventilation without excessive removal of potentially reversibly diseased tissue. Functional endoscopic sinus surgery is based on several key observations: (1) widely patent antrostomies in nonanatomic positions may fail to drain sinuses due to the directionality of mucociliary flow; (2) the ostiomeatal unit is anatomically constricted; and (3) the stripping of sinus mucosa leads to delayed healing and the loss of normal ciliary function. Thus, a conservative endoscopic technique has been developed. The keys to the technique are the use of "through-cutting" instruments that preserve sinonasal mucosa and the excellent visualization made possible with modern telescopes. Mucosal polyps can be carefully débrided, the natural ostia enlarged, and the ethmoid sinuses unroofed, which opens them to the nasal cavity. The improvement in symptoms with FESS may be expected in more than 90% of patients.

B. Relationship with other treatments—Sinus surgery should be considered as only a part of the treatment plan. Any underlying medical conditions, such as diabetes mellitus, immunodeficiency, tobacco use, and atopic disease, must also be addressed if ultimate success in treatment is to be obtained. Patients will require meticulous postoperative care including debridements, and, finally, long-term medical maintenance therapy.

C. Complications—The complications of surgical therapy are related to the close anatomic proximity of the paranasal sinuses to the brain and orbits. An intimate knowledge of the patient's individual anatomy is critical to reduce complications. Serious morbidity is rare, and includes cerebrospinal fluid leak (CSF) leaks, orbital injury, and intracranial hemorrhage. Injury to the medial wall of the orbit may cause the prolapse of orbital fat into the nasal cavity. A violation of the orbital wall, with subsequent hemorrhage and orbital hematoma, may lead to compression of the optic nerve and blindness. Damage to the cribriform plate region may lead to CSF leak, herniation of cranial contents, meningitis, or intracranial bleeding. In one large meta-analysis of patients who underwent FESS, the authors found the major complication rate was 0.85%, with CSF leak being the most common complication. Minor complications occurred in 6.9% of patients, with orbital penetration and middle turbinate adhesions being the most common.

Kennedy DW, Zinreich SJ, Rosenbaum AE, Johns ME. Functional endoscopic sinus surgery: theory and diagnostic evaluation. *Arch Otolaryngol* 1985;111:576–582. (Landmark paper describing the theory of endoscopic sinus surgery.)

May M, Levine HL, Mester SJ et al. Complications of endoscopic sinus surgery: analysis of 2108 patients – incidence and prevention. *Laryngoscope* 1994 Sep;104(9):1080–1083. (These authors compared their experience with FESS to 11 other series to look at the complications of sinus surgery.)

Complications of Rhinosinusitis

A. Orbital Infection

Chandler divided the progression of sinonasal orbital infections into five stages (Table 15–3). The first stage is *periorbital edema*, which presents with cellulitis of the eyelids without visual loss or ophthalmoplegia. The second stage describes infection extending through the orbital septum and is classified as *orbital cellulitis*. These patients present

Table 15–3. Potential Orbital Complications of Sinusitis.

Periorbital edema
No limitation of extraocular movements and vision is normal.
Infection is anterior to the orbital septum
Orbital cellulitis
Infection of the soft tissue posterior to the orbital septum
Subperiosteal abscess
Pus collection beneath the periosteum of the lamina papyracea.
Globe is usually displaced in inferolateral direction
Orbital abscess
Pus collection in the orbit.
Associated with limitation of extraocular movements, exophthalmos, and visual changes.
Cavernous sinus thrombosis
Septic thrombosis of the cavernous sinuses
Fever, ophthalmoplegia, ptosis, proptosis, chemosis, blindness, meningitis

with pain, proptosis, and chemosis. With orbital cellulitis, there may be some degree of ophthalmoplegia related to edema of the extraocular muscles, and a mild decrease in visual acuity related to corneal edema. The third stage involves formation of a *subperiosteal abscess*. The fourth stage is the formation of an orbital abscess. Severe proptosis, chemosis, ophthalmoplegia, and visual loss are usually present. The fifth stage results from retrograde thrombophlebitis of the valveless ophthalmic veins that can lead to *cavernous sinus thrombosis*.

Periorbital edema can usually be treated in an outpatient setting with oral antibiotics and close follow-up in the absence of medical comorbidities such as uncontrolled diabetes. Orbital cellulitis usually responds to intravenous antibiotics, whereas subperiosteal and orbital abscesses require operative drainage of the abscess with concurrent sinus surgery. Cavernous sinus thrombosis can truly be life-threatening. Even in the post-antibiotic era, the mortality rate of cavernous sinus thrombosis is 30%. Intravenous antibiotic treatment should be instituted immediately, and, if indicated, the involved sinuses should be surgically drained. The role of anticoagulation to prevent further thrombus formation and systemic steroid therapy is controversial. The incidence of all orbital complications is higher in the pediatric population than in adults.

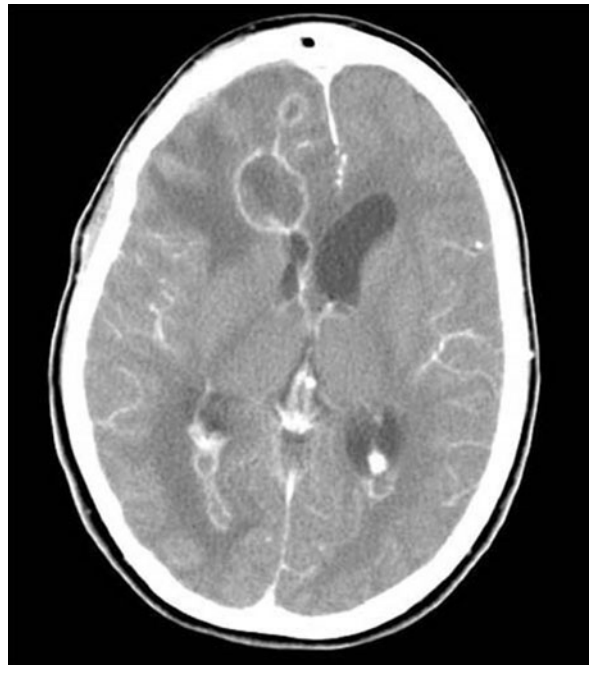
B. Intracranial Complications

In the antibiotic era, intracranial complications of sinusitis have become less commonplace, but nevertheless continue to occur and be associated with significant morbidity and mortality. Meningitis usually occurs by extension of infection from the ethmoid or sphenoid sinuses. On examination, patients with this complication may have a diminished sensorium or may be obtunded. The typical signs of meningitis, such as Kernig and Brudzinski signs, may be present. If meningitis secondary to sinus infection is suspected, a high-resolution CT scan of the brain with contrast and a sinus CT scan should be obtained. A CT scan of the brain is critical both to rule out mass effect and to delineate any other intracranial complications. Lumbar puncture is diagnostic and provides material for culture. The treatment for meningitis involves intravenous antibiotics and surgical drainage of the sinuses. Anaerobic organisms are reported to be the most common pathogens in suppurative intracranial complications of sinusitis, but aerobic and mixed infections are also common.

An epidural abscess is a collection of purulent material between the bone of the skull and the dura, typically in relation to frontal sinusitis. The further spread of infection, either by direct extension or by hematogenous seeding, may lead to subdural empyema and eventually to brain abscess (Figure 15–3). Draining both the abscess and the offending sinuses is mandatory, and long-term antibiotics are often necessary. Regardless of the treatment, morbidity is high, particularly with subdural involvement, and can result in long-term neurologic sequela.

C. Pott Puffy Tumor

Pott puffy tumor is an osteomyelitis of the frontal bone with the development of a subperiosteal abscess manifesting as a puffy swelling on the forehead or scalp. It usually occurs as a complication of frontal sinusitis. Treatment is prompt surgical drainage and initiation of broad-spectrum antibiotics.



▲ **Figure 15–3.** Axial CT scan demonstrating intracranial abscess.

May M, Levine HL, Mester SJ et al. Complications of endoscopic sinus surgery: analysis of 2108 patients —incidence and prevention. *Laryngoscope* 1994 Sep;104(9):1080–1083.

Chandler JR, Langenbrunner DJ, Stevens ER. The pathogenesis of orbital complications in acute sinusitis. *Laryngoscope* 1970;80:1414. (This important paper describes the possible orbital complications associated with sinusitis and outlines a staging system.)

Gallagher RM, Gross CW, Phillips CD. Suppurative intracranial complications of sinusitis. *Laryngoscope* 1998 Nov;108(11 Pt 1): 1635–1642. (Describes the authors experience with 22 cases of intracranial complications of sinusitis.)

Ebright JR, Pace MT, Niazi AF. Septic thrombosis of the cavernous sinuses. Arch Intern Med. 2001 Dec 10—24;161(22): 2671–2676. (This article describes a rare complication of sinusitis and its management.)

We would like to acknowledge Ashish R. Shah, MD, Frank N. Salamone, MD, and Thomas A. Tami, MD for their contribution to this chapter in the previous editions of CDT.

16 Frontal Sinus Fractures

Steven D. Pletcher, MD &
Andrew N. Goldberg, MD, MSCE, FACS

ESSENTIALS OF DIAGNOSIS

- History of head trauma.
- Visible open fracture or fracture on computed tomography (CT) scans or plain X-rays.

General Considerations

The frontal sinus begins as an outgrowth of the nasal chamber in utero but does not begin to invade the vertical portion of the frontal bone until the 4th year of life. The sinus attains adult configuration at age 15 and typically reaches adult size by age 20. A variable structure, the frontal sinuses are typically asymmetric and may be unilateral (10%) or absent altogether (5%).

The anterior wall of the fully developed frontal sinus is a thick bony arch that can withstand between 800 and 2200 pounds of force. The force required to fracture this robust structure often leads to multiple injuries; therefore, a full trauma workup of all patients with frontal sinus fractures is paramount. As with all trauma patients, the airway, circulatory system, and other organ systems must be evaluated upon arrival. All patients require ophthalmologic and neurologic examination as well as radiographic and clinical examination of the cervical spine. Intracranial injury (40–50%) and other facial fractures (75–95%) are among the most commonly associated injuries in patients with frontal sinus fractures.

Pathogenesis

Motor vehicle accidents are the most common mechanism of injury for patients with frontal sinus fractures, accounting for 60–70% of all frontal sinus fractures. Assault typically requires the use of a blunt object to fracture the frontal sinus; fists alone rarely generate sufficient force. Other mechanisms of injury include industrial accidents, recreational accidents, and gunshot wounds. Young men in their third decade of life are most at risk for frontal sinus fracture. In one study, 30% of patients with frontal sinus fractures had blood alcohol levels over the legal limit or positive urine toxicology screens.

The anterior wall of the frontal sinus is significantly thicker than the posterior wall. Injuries that provide enough force to fracture the anterior wall of the frontal sinus often have enough force to fracture the posterior wall as well.

Prevention

The use of seatbelts and airbags for passengers and drivers can decrease the incidence of severe head trauma and frontal sinus fractures. Patients in automobile accidents in which airbags are deployed have a significant decrease in the number of facial fractures. Estimates are that only 15% of young patients with frontal sinus fractures resulting from automobile accidents were wearing a seatbelt; less than 10% of patients with frontal sinus fractures from motorcycle accidents were wearing a helmet. The use of helmets with motorcycles, with bicycles, at appropriate sporting events, and in industrial situations also can protect the frontal sinuses.

Murphy RX Jr, Chernofsky MA. The influence of airbag and restraining devices on the patterns of facial trauma in motor vehicle collisions. *Plast Reconstr Surg* 2000;105(2):516 [PMID: 10697154]. (The use of restraining devices and airbags decreases the incidence of facial fractures and lacerations.)

Wright DL, Hoffman HT, Hoyt DB. Frontal sinus fractures in the pediatric population. *Laryngoscope* 1992;102(11):1215 [PMID: 1405980]. (Discussion of the similar severity and treatment of frontal sinus fractures in adult and pediatric patients.)

Clinical Findings

A. Symptoms and Signs

Most patients lose consciousness with the force required to sustain a frontal sinus fracture; estimates are that 25% of

patients remain conscious throughout the injury, 50% regain consciousness within the first 4 hours after injury, and the final fourth develop prolonged unconsciousness.

Patients who are conscious at the time of the evaluation typically report frontal pain. Forehead lacerations occur in approximately 80% of frontal sinus fractures. Other less common signs on physical examination include the following: frontal numbness; palpable step-offs or crepitus; cerebrospinal fluid (CSF) leak; exposed bone; exposed brain; and ocular abnormalities, including diplopia, ophthalmoplegia, and decreased visual acuity. Between 5% and 10% of patients have no significant physical findings on examination.

Associated injuries are the rule with frontal sinus fractures. Other facial fractures occur in up to 95% of patients; bones of the orbit and paranasal sinuses are the most commonly involved. Intracranial injuries are seen in approximately 50% of patients; of these types of injuries, frontal contusions are the most common.

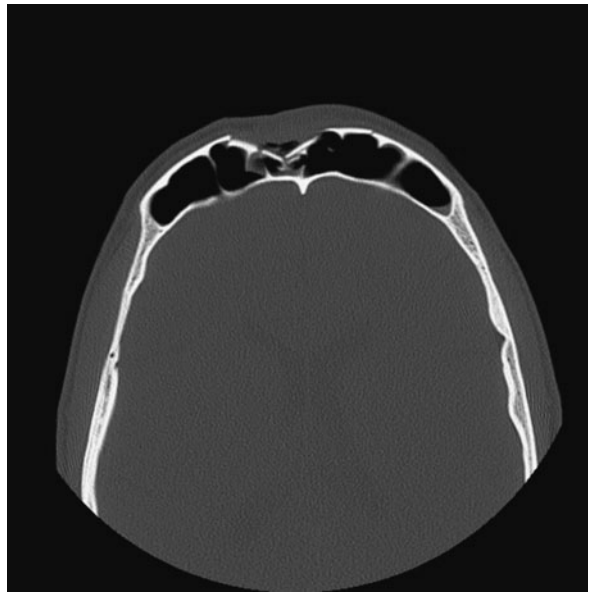
B. Imaging Studies

1. CT scans—CT scanning is the imaging examination of choice for the evaluation of frontal sinus fractures. Clinicians looking for intracranial pathology after head trauma order CT scans of the head and often discover fractures.

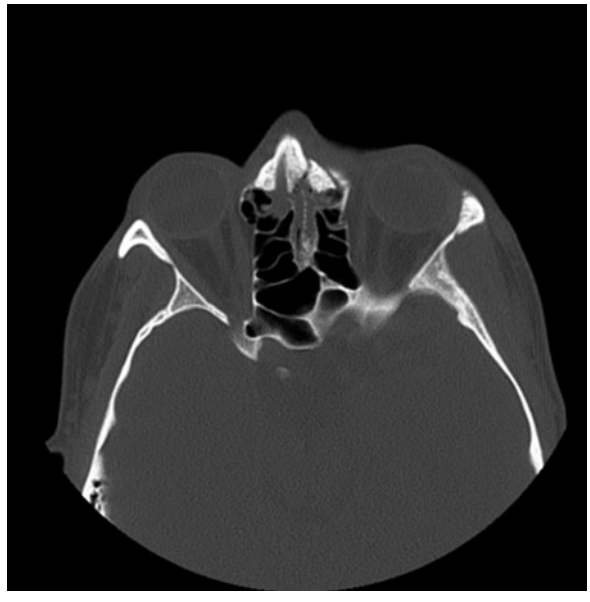
When evaluating the extent of injury and determining the operative plan for frontal sinus fractures, thin-cut axial and coronal facial CT scans are preferable to thicker-cut 5–10 mm head CT scans. Presently, fine-cut axial CT scans with coronal and saggital reconstruction are typically used for the evaluation of frontal sinus fractures. Slice thickness of 0.625 mm is ideal, although a thickness of up to 2 mm is typically adequate. Direct coronal views are less amenable to axial and saggital reconstruction and are often contraindicated in patients with frontal sinus fracture related to possible cervical spine injury and issues related to other associated injuries. Soft tissue windows should be used to evaluate intracranial and orbital injuries, which are often seen in patients with frontal sinus trauma. Many patients with associated injuries do not tolerate direct coronal images. Figures 16–1 and 16–2 are axial images of a patient with a depressed anterior table frontal sinus fracture and frontonasal recess injury, respectively.

2. X-rays—The role of plain X-ray films in the evaluation of frontal sinus fractures is limited. In patients with nonoperative fractures and fluid in their frontal sinuses, serial Caldwell views may be used to monitor resolution of the fluid, insuring patency of the frontonasal recess.

Wallis A, Donald PJ. Frontal sinus fractures: a review of 72 cases. *Laryngoscope* 1988;98:593 [PMID: 3374232]. (Review of the etiology, presenting symptoms, treatments, and complications of 72 cases.)



▲ **Figure 16–1.** Axial CT scan with a displaced fracture of the anterior table of the frontal sinus. Note aerated sinus bilaterally. (Photo contributed by Andrew N. Goldberg, MD.)



▲ **Figure 16–2.** Axial CT scan of a patient with displaced fracture of the anterior table and frontonasal recess obstruction. (Photo contributed by Andrew N. Goldberg, MD.)

Differential Diagnosis

Frontal sinus fractures should be distinguished from both simple forehead contusions and lacerations. Frontal bone fractures without the involvement of the frontal sinus may be mistaken for frontal sinus fractures. CT scans distinguish between these possibilities with ease.

Determining the extent of a fracture is more difficult than determining whether a frontal sinus fracture is present. Involvement of both the posterior table of the frontal sinus and the frontonasal recess is critical in determining the treatment of the fracture. Anterior table fractures are often easily identified on axial CT scans; however, because of the thin nature of the posterior table, nondisplaced posterior table fractures can be less obvious. A high index of suspicion for posterior table fractures is necessary in all patients. Pneumocephalus on the CT scan may provide a clue that the posterior table has been violated, but pneumocephalus also may come from fractures of the ethmoid bones or other aerated regions of the skull.

In patients with frontal sinus fractures, the frontonasal recess is the most difficult area to evaluate. When evaluating a frontal sinus fracture, it is important to assess the future function of the frontonasal recess. In the surgeon's judgment, if disruption of frontal sinus drainage is likely, then obliteration or cranialization (ie, removal of the posterior table and mucosa of the frontal sinus) of the frontal sinus should be strongly considered. Serial imaging studies may be considered in select patients in whom reliable follow-up is likely. Certain fracture patterns can be helpful in predicting frontonasal recess damage. In isolated anterior wall fractures, involvement of the frontonasal recess is rare. Patients with anterior wall fractures and associated supraorbital rim or nasoethmoid complex fractures have associated frontonasal recess injury in 70–90% of cases. Combined anterior and posterior wall fractures are also commonly associated with injury to the frontonasal recess.

Complications

There are many complications of frontal sinus fractures. More severe complications include mucoceles, severe persistent pain, and infectious intracranial complications. Such complications are uncommon, with a reported rate of 6% for meningitis and mucocele formation and 1% for severe pain and brain abscess.

Minor complications are relatively common. Wound infections, CSF leaks, numbness over the forehead area, and mild deformity are each found in approximately 10–20% of patients. Chronic sinusitis, mild chronic pain, and diplopia (ie, double vision) are significantly less common.

Well-known complications of frontal sinus fractures include (1) mucoceles and mucopyoceles; (2) intracranial complications such as meningitis, brain abscess, and CSF leak; and (3) other complications such as chronic infection and osteomyelitis. All of these complications, particularly mucoceles, may not manifest until years or decades after the original injury. With the evaluation of the extent of the injury and appropriate treatment, complications from frontal sinus fractures can be limited.

A. Mucoceles and Mucopyoceles

Mucoceles and mucopyoceles are well-known complications that typically appear years after the original injury. Because of their severity, these complications usually mandate surgical intervention.

Mucoceles are expansile, benign, but locally destructive lesions that occur when entrapped or segregated mucosa secretes mucus into a confined space, causing progressive expansion. Frontal sinus mucosa is distinct from normal pseudostratified ciliated respiratory epithelium both histologically and pathologically. Frontal sinus mucosa tends to have a flatter, more cuboidal epithelium with a greater propensity for mucocele formation. Conditions that tend to result in mucocele formation include frontonasal recess obstruction and mucosa entrapment, both commonly associated with frontal sinus fractures.

The **foramina of Breschet** are venous drainage channels located in the posterior wall of the frontal sinus. These foramina are significant not only because they provide a route for intracranial spread of infection but also because they act as sites of mucosal invagination in the posterior wall of the sinus. Failing to completely remove mucosa in an obliterated sinus predisposes the development of mucoceles. Mucoceles tend to follow an insidious course with significant bony destruction and potential erosion into the intracranial, intraorbital, or subcutaneous space.

The entrapped, static secretions within mucoceles may become infected, resulting in a mucopyocele. Mucopyoceles tend to follow a more aggressive course than mucoceles. Expansile, infectious masses, mucopyoceles carry significant risks of intraorbital infectious complications; they also may erode directly into the intracranial space.

B. Intracranial Complications

Meningitis and brain abscesses may occur as early or late sequelae of frontal sinus fractures. Frontal sinus fractures are often compound, dirty wounds at the time of injury, with bits of glass and dirt within the wound. This early contamination combined with the frequent association of posterior table fractures and even dural tears provides a direct route for bacterial entry to the intracranial space, which results in meningitis, a brain abscess, or both. Late intracranial infections are typically associated with mucopyoceles.

Traumatic CSF leaks are another form of intracranial complications. They have been noted to seal spontaneously in 80–95% of cases; however, these data may be skewed by a high percentage of temporal bone fractures. It is estimated that in patients with a traumatic CSF leak present for more than 24 hours, approximately 53% resolved spontaneously within an average of 5 days. Those leaks that go unrecognized or are not adequately repaired may result in delayed intracranial infections.

C. Other Complications

Chronic infection and osteomyelitis may occur after frontal sinus fracture. This can result in the development of a frontocutaneous fistula and chronic drainage as well as the extrusion of hardware used during frontal sinus repair. Chronic frontal sinus pain and the sensation of frontal sinus fullness may be present after both frontal sinus fracture and obliteration. Severe or unrelenting pain may be a sign of mucocele development or infectious complication and should be evaluated thoroughly. Cosmetic forehead deformities may result after inadequate reduction of anterior table fractures or the loss of anterior table bone. Mucoceles, mucopyoceles, osteomyelitis, or hardware extrusion can also result in cosmetic deformities.

Friedman JA, Ebersold MJ, Quast LM. Post-traumatic cerebrospinal fluid leakage. *World J of Surg* 2001;25(8):1062 [PMID: 11571972]. (Forty-seven percent of patients with post-traumatic CSF leaks of 24-hour duration required surgical intervention.)

Goldberg AN, Oroszlan G, Anderson TD. Complications of frontal sinusitis and their management. *Otolaryngol Clin North Am* 2001;34(1):211 [PMID: 11344074] (A review of frontal sinusitis complications and their management.)

Treatment

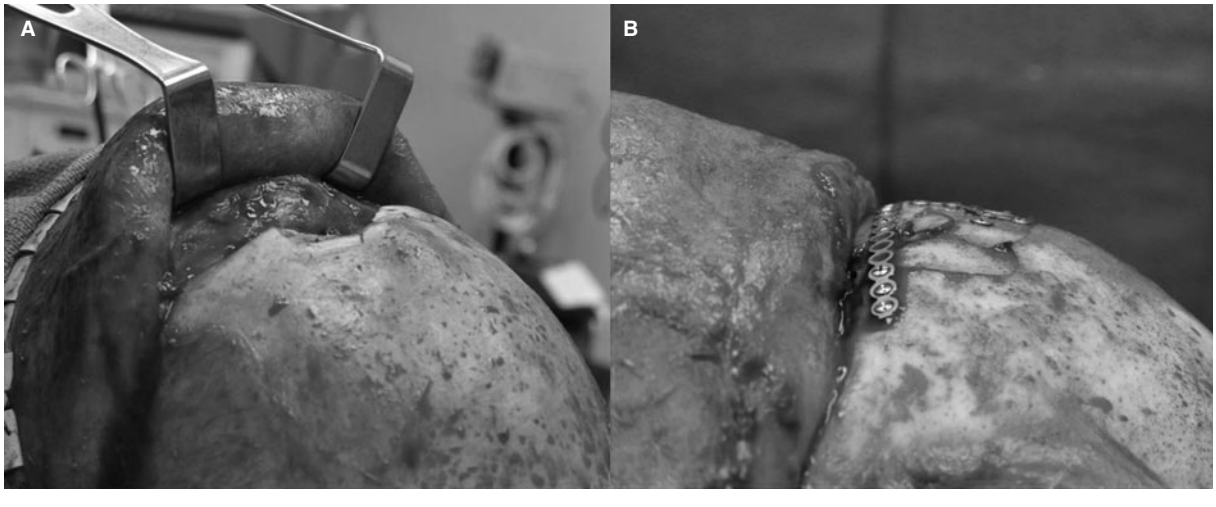
The treatment of frontal sinus fractures depends on the extent of the fracture. Fractures of the frontonasal recess and the posterior table of the frontal sinus often require operative intervention. Displaced fractures typically require open reduction. The primary goals of treatment in frontal sinus fractures include preventing complications and restoring normal forehead contour.

A. Surgical Measures

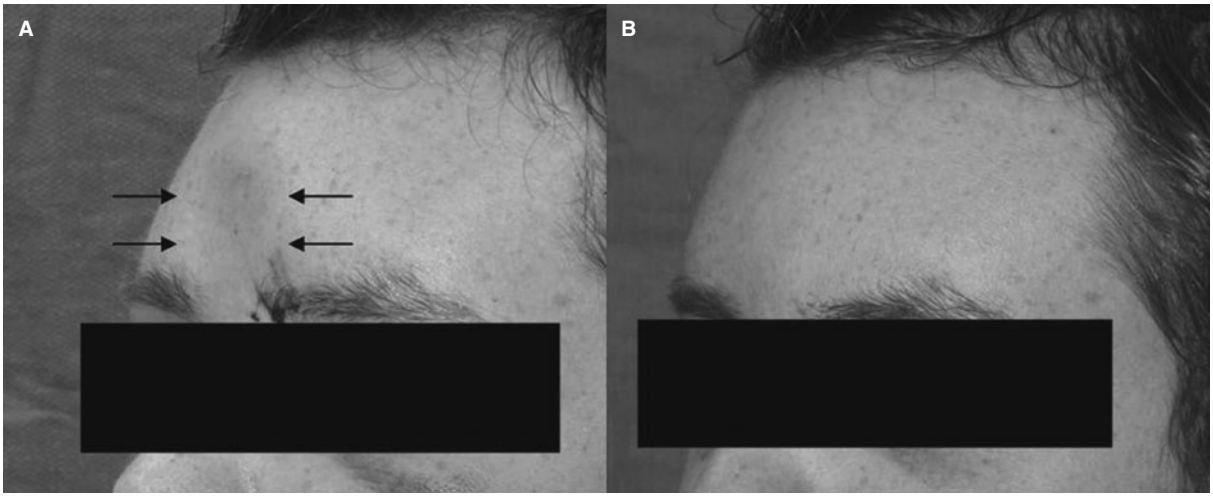
Surgical developments within the last few decades have reduced marked cosmetic deformities and a high incidence of long-term complications. Modern techniques of evaluation and treatment allow better triage of patients with frontal sinus fractures to surgical intervention or observation. Fine-cut CT scanning as well as office and intraoperative endoscopy have allowed surgeons to improve patient selection for ablative surgery. In the past, the ablative procedures of a frontal osteoplastic flap and the cranialization procedure were the two primary procedures used to repair complex frontal sinus fractures. Fractures thought in the past to require these interventions, particularly posterior table fractures, have more recently been shown in case series and animal models to be amenable to more conservative treatment. The choice of when to operate and which procedure to perform depends on the extent of the fracture and functional evaluation of the frontonasal recess.

In addition to improved methods of patient selection, more recent advances in instrumentation and technique have also allowed less invasive methods including endoscopy to be used to repair and/or camouflage fractures. Endoscopic techniques are performed through small incisions behind the hairline similar to the approach used for an endoscopic brow lift.

1. Open reduction and internal fixation—This method exposes fractured bone and replaces the fragments as close to their original configuration as possible. Fixation is typically accomplished with a combination of plates and screws contoured to the bony fragments. Approaches principally include direct approaches through lacerations, a mid brow incision, and the coronal approach (Figures 16–3 and 16–4).



▲ **Figure 16–3. (A)** Intraoperative photograph demonstrating displaced fractures. Coronal incision was used with reflected skin flap visible to the left. (Courtesy of Andrew N. Goldberg, MD.) **(B)** Intraoperative photograph demonstrating fracture reduction and plating. Coronal incision was used with reflected skin flap visible to the left. (Photo contributed by Andrew N. Goldberg, MD.)



▲ **Figure 16–4. (A)**Preoperative photograph demonstrating depression of forehead (arrows). (Photo contributed by Andrew N. Goldberg, MD.) **(B)** Postoperative photograph demonstrating restoration of contour of forehead 2 months after surgery. (Photo contributed by Andrew N. Goldberg, MD.)

2. The osteoplastic flap—The concept of removing the frontal sinus as a functioning unit was introduced in 1958 by Goodale and Montgomery with the osteoplastic flap. This flap or hinged opening of the frontal sinus is created through either a midforehead or a coronal incision and sinus obliteration; this approach may also be used through an existing forehead laceration. The procedure, which remains one of the principal means for treating frontal sinus fractures today, involves raising a subperiosteal flap from a coronal or midforehead incision down to the superior border of the frontal sinus. The anterior table of the frontal sinus is then opened at its superior and lateral margins, creating an inferiorly based bone flap. All mucosa is then stripped from the sinus, and all the bony walls of the sinus are burred down with a drill to ensure complete mucosal removal. The frontonasal recess mucosa is stripped or turned down into the ostium, and the ostium is obliterated using a muscle or fascia plug. The sinus is then obliterated, most commonly using a free fat graft. Finally, the anterior wall of the frontal sinus and the coronal or midforehead flap is replaced.

3. The cranialization procedure—In the cranialization procedure, the posterior wall of the frontal sinus is removed and the frontal dura is allowed to rest against the anterior table of the frontal sinus. This procedure also involves complete stripping of the mucosa, burring any mucosal remnants from the remaining anterior sinus wall, and plugging the frontonasal recess.

4. Endoscopic repair—Using endoscopic techniques, incisions can be made smaller and morbidity from extensive dissection minimized. At this point, endoscopic techniques are used to repair and/or camouflage frontal sinus fractures involving the anterior table only, although technique development is ongoing. Small incisions behind the hairline are used to reduce and fixate fractures and camouflage contour defects through onlay grafts and other techniques for improved cosmesis. Endoscopic transnasal reduction of anterior table frontal sinus fracture has also been reported. The endoscope can be very useful, however, in examining the frontonasal recess and other areas during surgery.

5. Surgical grafts—There has been significant debate over which material is best for obliterating the frontal sinus. One option is to remove all mucosa, plug the frontonasal recess, and allow ingrowth of fibrous tissue without obliteration. Other options involve the use of various grafts.

A. Autologous fat grafts—Free-fat grafts have been both studied and used most extensively. Overall autologous fat provides a safe obliterative material with few infectious complications. Over time fat tends to be reabsorbed and replaced with fibrous material. Serial MRI scans in patients with fat-obliterated frontal sinuses show the median half-life of the obliterated adipose tissue to be 15.4 months. In addition, the incidence of seroma in fat harvests is approximately 5%.

B. Other autologous tissue grafts—Other autologous tissues for obliteration include cancellous bone, muscle, and pericranial flaps. Autologous grafts typically involve some donor site morbidity, such as pain, infection, or the formation of sarcomas, hematomas, or both. Pericranial flaps with an inferior or lateral base offer a living tissue option for both obliteration and recreation of the anterior table with minimal donor site morbidity.

C. Grafts of synthetic materials—One difficult situation in which synthetic materials may play a role is in fractures with a loss or a severe comminution of the anterior

table. In these scenarios, bone grafts (iliac, rib, or split calvarial) or **methyl methacrylate** have been used to recreate the anterior table. **Titanium mesh** offers a synthetic alternative for severely comminuted fractures, but its use is limited in cases with significant loss of anterior table bone. **Hydroxyapatite cement** is another synthetic material that has been used both to obliterate the sinus and recreate the anterior table but experience is limited. Reoperation on patients obliterated with hydroxyapatite and some other synthetic materials is challenging.

B. Location-Related Measures

1. Anterior table fractures and frontonasal recess injuries—To treat fractures of the anterior wall appropriately, a couple of key issues need to be resolved. The first is the degree of the displacement of the fracture; this question can be answered easily with a combination of physical exam and CT scan. If a displaced fracture is present, exploration of the fracture with open reduction and internal fixation is required (Figure 16–1).

The second key issue in treating fractures of the anterior wall is whether there is significant injury to the frontonasal recess. Figure 16–2 depicts a CT scan in a patient who has a frontonasal recess injury. The frontonasal recess is more difficult to evaluate accurately on a CT scan because the functional capability of the frontal sinus drainage pathway is not clearly elucidated on CT. A 70–90% rate of frontonasal recess injury has been reported for patients who have associated fractures of the floor of the frontal sinus, the nasoethmoid complex, or the supraorbital rim. It is thus reasonable to surgically evaluate the frontonasal recess in such patients.

Traditional management of fractures involving the frontonasal recess is operative exploration and either obliteration or cranialization if injury to the frontonasal recess is noted intraoperatively. However, some studies suggest that fractures with frontonasal recess involvement do not always require obliteration or cranialization. Some physicians have managed these patients expectantly, following this approach with serial CT scans. Patients who failed to re-aerate their sinuses were treated with endoscopic frontal sinus procedures; in limited trials, favorable results were obtained. The trend in modern management of these fractures in patients for whom follow-up is feasible is toward more expectant management of frontonasal recess injury and follow-up CT scanning to assess functional patency.

For unilateral frontonasal recess injuries in which the contralateral duct has been demonstrated to work, some clinicians advocate the **Lothrop procedure:** removal of the intersinus septum and the use of mucosal flaps to allow drainage through the contralateral frontal sinus. This procedure can be performed endoscopically.

2. Posterior table fractures—Fractures of the posterior table may require surgical intervention. This is an area where treatment recommendations are in evolution secondary to improved methods of imaging and improved understanding of the role of the frontonasal recess in mucocele formation.

In general, posterior table fractures are suspicious for dural disruption and CSF leak. Dural tears with persistent CSF leak should be repaired in consultation with a neurosurgeon. In the absence of persistent CSF leak, some clinicians advocate the use of serial CT scanning and close follow-up of nondisplaced or minimally displaced posterior table fractures. The treatment of displaced posterior table fractures is controversial and may require obliteration or cranialization based on the surgeon's judgment. These fractures have a high incidence of frontonasal recess injury and, untreated, have a theoretical risk for mucocele formation. The modern trend, however, is toward expectant management and serial CT scanning in reliable patients who have posterior table injuries with good aeration of the sinuses.

Comminuted and displaced posterior table fractures are best treated with cranialization. "Through and through" injuries involve significant injury to the skin, anterior table, posterior table, and dura. These injuries can often be diagnosed by viewing the brain through the wound and are best managed with cranialization if sufficient bone remains to recreate the anterior table. In cases of severe anterior and posterior table bone loss, ablation may be the only viable alternative.

Lakhani RS, Shibuya TY, Mathog RH, Marks SC, Burgio DL, Yoo GH. Titanium mesh repair of the severely comminuted frontal sinus fracture. *Arch Otolaryngol Head Neck Surg* 2001;127(6):665 [PMID: 11405865]. (Favorable results using titanium mesh for repair of comminuted frontal sinus fractures is discussed.)

Maturo SC, Weitzel EK, Cowhart J, Brennan J. Isolated posterior table frontal sinus fractures do not form mucoceles in a goat model. *Otolaryngol Head Neck Surg* 2008 Nov;139(5):688–694 [PMID: 18984265]. (A goat model was used to demonstrate that mucocele formation in posterior table frontal sinus fractures was dependent on frontonasal recess obstruction and not extent of injury.)

Pariscar A, Har-El G. Frontal sinus obliteration with the pericranial flap. *Otolaryngol Head Neck Surg* 2001;124(3):304 [PMID:11240996]. (Favorable results using pericranial flap for frontal sinus obliteration is discussed.)

Petruzelli GJ, Stankiewicz JA. Frontal sinus obliteration with hydroxyapatite cement. *Laryngoscope* 2002;112(1):32 [PMID: 11802035]. (Favorable results using hydroxyapatite cement to obliterate the frontal sinus and recreate the anterior wall of the frontal sinus is discussed, although the authors of this chapter do not recommend this method.)

Rontal ML. State of the art in craniomaxillofacial trauma: frontal sinus. *Curr Opin Otolaryngol Head Neck Surg* 2008 Aug;16(4):381–386 [PMID: 18626259]. (Description of the paradigm shift in management of frontal sinus fractures integrating modern techniques of examination and treatment.)

Smith T. Endoscopic management of the frontal recess in frontal sinus fractures: a shift in the paradigm? *Laryngoscope* 2002;(112):784 [PMID: 12150607]. (A limited series of expectant management of frontal outflow tract injuries with endoscopic surgery for failed ventilation yields good results.)

Strong EB, Kellman RM. Endoscopic repair of anterior table frontal sinus fractures. *Facial Plast Surg Clin North Am* 2006;14(1);25.

Weber R. Osteoplastic frontal sinus surgery with fat obliteration: technique and long-term results using MRI in 82 operations. *Laryngoscope* 2000;(110):1037 [PMID: 10852527]. (An osteoplastic flap with fat obliteration is highly effective.)

Pediatric Considerations

Frontal sinus fractures in the pediatric population are more commonly associated with orbital fractures and major intracranial injury such as intraparenchymal hemorrhage and CSF leak. Patients with intracranial injury tend to be younger than those with no intracranial injury. The cribriform plate is involved to a greater degree as a site of CSF leak than in adults, and craniotomy is commonly needed for CSF leak repair.

Whatley WS, Allison DW, Chandra RK, Thompson JW, Boop FA. Frontal sinus fractures in children. *Laryngoscope* 2005;115(10):1741.

Prognosis

A. Short-Term Prognosis

The immediate prognosis for patients with frontal sinus fractures is mostly dependent on the presence and severity of the associated injuries, particularly intracranial injuries. Patients with "through and through" frontal sinus fractures have a short-term mortality rate of approximately 50% at the scene or in transport. Another 25% die in the early postoperative period.

B. Long-Term Prognosis

The long-term prognosis for patients with frontal sinus fractures has been difficult to assess. With the significant possibility of delayed complications, long-term follow-up is required to adequately evaluate the prognosis for patients with frontal sinus fractures. These patients, however, tend to be noncompliant, making long-term follow-up problematic. Because of this dilemma, the prevalence of long-term complications is likely understated in the literature.

Paranasal Sinus Neoplasms

17

Aditi H. Mandpe, MD

ESSENTIALS OF DIAGNOSIS

- Symptoms and signs mimic benign sinonasal disease.
- Malignant tumors typically present at advanced stage of disease.
- Immunohistochemical markers are often required for definitive diagnosis of tumors.

General Considerations

Paranasal sinus neoplasms, both benign and malignant, are relatively rare in the head and neck. Malignant neoplasms of the paranasal sinuses account for approximately 3.0% of head and neck cancers and 0.5% of all malignant tumors. In general, these tumors are identified and treated at advanced stages as their symptoms mimic benign inflammatory conditions. The most common malignant neoplasm of the nose and paranasal sinuses is squamous cell carcinoma. This tumor most commonly arises from the maxillary antrum and secondarily from the ethmoid sinus. Treatment includes surgical resection, radiation therapy, and, rarely, chemotherapy. Benign tumors present in a similar manner and typically necessitate surgical resection and close postoperative follow-up. As nasal endoscopes are used with increasing frequency clinically, both benign and malignant tumors will ideally be identified earlier in the disease progression.

Clinical Findings

A. Symptoms and Signs

The most common presenting symptoms in patients with paranasal sinus neoplasms are nasal obstruction, rhinorrhea, and sinus congestion that are similar to those of patients with benign sinonasal diseases. However, as the masses grow, paranasal sinus neoplasms lead to facial pain and epistaxis. In addition, orbital symptoms, such as diplopia, proptosis, visual loss, and epiphora, can occur with either neoplastic invasion or expansion into the orbit. Entry through the skull base into the anterior cranial fossa can lead to the symptoms of headache, cranial neuropathies, and occasional frontal lobe symptoms (such as personality alterations). Tumors can also invade the maxilla and present as a hard-palate mass.

B. Physical Examination

The physical examination of a patient suspected to have a paranasal neoplasm should include a complete head and neck examination, which includes diagnostic nasal endoscopy. While small tumors grow silently without symptoms, persistent nasal symptoms should be evaluated with nasal endoscopy.

1. Nose and paranasal sinus—The examination of the nose and paranasal sinus cavity can reveal a nasal mass with overlying polyps or polypoid mucosa. The septum can be markedly deviated to the contralateral side because of the expansion of the neoplasm, sometimes with tumor erosion into the contralateral nasal cavity. An endoscopic evaluation is superior at evaluating the mucosa, identifying masses and drainage.

2. Oral cavity—The teeth and hard palate need to be examined closely to determine if invasion into the maxilla has occurred. An expanded alveolar ridge or loose maxillary dentition indicates early bony invasion of the maxilla, and a mass on the hard palate indicates frank invasion into the maxilla.

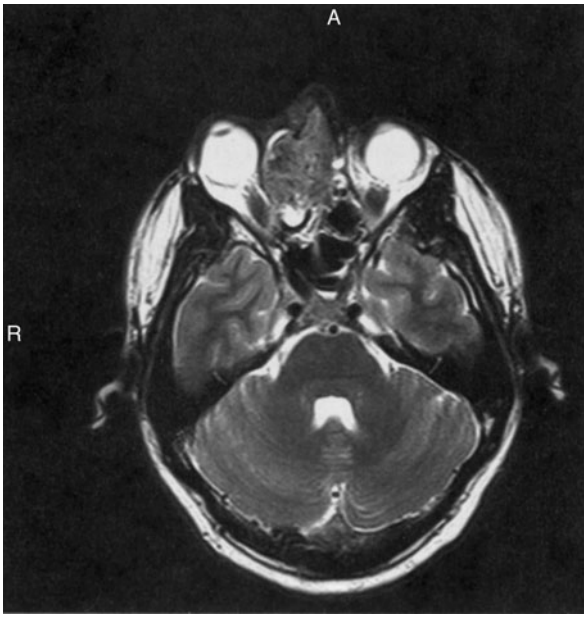
3. Face and orbit—Facial swelling and thickening of the cheek and nose skin is an indication that the neoplasm has invaded the soft tissue through the anterior bony walls. Proptosis is seen with expansion through the lamina papyracea compressing the periorbital benign disease, such as mucocele, and in malignant disease due to intraorbital invasion. Diplopia is commonly seen with proptosis, and visual loss is a sign of progressive orbital involvement; however, visual loss also can be a sign of orbital apex involvement with compression of the optic nerve.

4. Cranial nerves—Cranial nerve (CN) involvement is common in advanced malignant neoplasms of the paranasal sinuses. The olfactory nerve, CN I, is involved in esthesioneuroblastomas. Other CNs involved are the optic nerve (CN II), the oculomotor nerve (CN III), the trochlear nerve (CN IV), the abducens nerve (CN VI), and supraorbital and maxillary branches of the trigeminal nerve (CN V1 and CN V2).

5. Other physical findings—Other findings that can be identified by the physical examination are serous otitis media due to eustachian tube involvement, and neck masses due to metastatic neoplastic spread into the regional lymph nodes. The most commonly involved lymph nodes are the upper jugulodigastric nodes.

C. Imaging Studies

Imaging is critical to identify the extent of both benign and malignant diseases. A computed tomography (CT) scan can delineate the mass well and can be sufficient for both bony and benign diseases. It is excellent for determining bony invasion but limited for distinguishing between edematous mucosa and tumor involvement and in identifying the intracranial extension of tumors. Magnetic resonance imaging (MRI) with both T1- and T2-weighted images with gadolinium enhancement is superior in determining the true involvement of the anterior cranial fossa, the skull base, and the orbit (Figure 17–1). MRI is also superior at soft-tissue delineation, can distinguish a tumor from obstructed secretions in the sinus, and complements the bony architecture information obtained from the CT scan. Both scans are often needed to ensure appropriate surgical planning.



▲ **Figure 17–1.** Axial T2-weighted MRI scan showing a mass in the right ethmoid sinus.

Table 17–1. Differential Diagnosis of Nasal and Paranasal Sinus Masses.

Benign Masses	Malignant Masses
Cementoma	Adenocarcinoma
Chondroma	Adenoid cystic carcinoma
Hemangioma	Hemangiopericytoma
Inverted papilloma	Lymphoma
Juvenile angiofibroma	Malignant mucosal melanoma
Meningioma	Olfactory esthesioneuroblastoma
Neurofibroma	Sarcoma
Ossifying fibroma	Sinonasal undifferentiated carcinoma
Osteoma	Squamous cell carcinoma
Schwannoma	Teratoma or teratocarcinoma

D. Special Tests

A biopsy of the mass is critical both in diagnosing a malignant tumor and in determining its treatment. If the mass is easily visualized in the physician's office, then an in-office biopsy should be obtained of the mass itself and not just the overlying tissue. Considerations for this biopsy include the assurance that the lesion is not vascular or does not contain cerebrospinal fluid (CSF). These lesions are often soft, cystic, and expand with a Valsalva maneuver. A needle biopsy of these lesions can be considered if the diagnosis is still uncertain.

Differential Diagnosis

The differential diagnosis of a paranasal sinus mass is extensive (Table 17–1). The most common benign lesion of the paranasal sinuses is the inverted papilloma. The most common malignant neoplasm of the paranasal sinuses is squamous cell carcinoma. Additional tumors that are frequently seen are adenocarcinoma, adenoid cystic carcinoma, olfactory esthesioneuroblastoma, malignant mucosal melanoma, and sinonasal undifferentiated carcinoma.

BENIGN NEOPLASMS

INVERTED PAPILLOMAS

General Considerations

An inverted papilloma, also called a schneiderian papilloma from the name of the mucosa from which it arises, is

typically located on the lateral nasal wall; rarely it is found on the septum. The incidence of this tumor is between 0.5% and 7.0% of all nasal tumors. The etiology of this tumor is unclear; however, there is an association with human papilloma virus (HPV) but not to allergy or nasal polyps. Inverted papillomas typically involve the middle meatus and at least one sinus cavity; the most common sinuses involved are the maxillary and ethmoid sinuses, followed by the sphenoid and frontal sinuses.

Inverted papillomas are usually unilateral, but they have been reported to be bilateral in up to 13% of cases. These tumors can extend through the septum into the contralateral nasal cavity. Multifocal tumors have been documented in approximately 4% of cases. Whether because of multicentricity or incomplete excision, these neoplasms have a high rate of recurrence with any procedure—as high as 75%. Patients also have a 5–15% risk of developing squamous cell carcinoma within the inverted papilloma.

Clinical Findings

Patients diagnosed with inverted papillomas complain about nasal obstruction, rhinorrhea, and unilateral epistaxis. Other symptoms include facial pressure, headache, and anosmia. On gross examination, there are no clear distinguishing characteristics between an inverted papilloma and an inflammatory polyp, although an inverted papilloma may be firmer and less translucent than an "average" polyp. On histopathologic examination, the distinguishing feature of inverted papillomas is the proliferation of epithelium with fingerlike inversions into the underlying epithelium.

Staging

Several staging systems have been developed that range from tumors located solely in the nasal cavity to tumors that extend to the anterior cranial fossa or orbit. A new system has been proposed that provides prognostic information as defined by recurrence.

Treatment

Treatment consists of total excision of the tumor. The traditional approach has been a lateral rhinotomy or midfacial degloving approach to a medial maxillectomy for total tumor removal. An osteoplastic frontal sinus exploration is sometimes required for disease spreading into the frontal sinus. In order to ensure a more complete resection, a microscope can be used to improve visualization of the mucosa. Currently, most would proceed with an endoscopic approach. The procedures range from a transnasal resection to an endoscopic modified Lothrop and should be performed by an experienced surgeon. The advantage of an endoscopic approach is improved visualization of the diseased mucosa that requires resection. The tumors most amenable to endoscopic resection are those neoplasms with disease limited to the inferior or middle meatus or the middle turbinate.

An important feature in the management of patients with these neoplasms is that all of the excised specimens should be closely examined with multiple sections to rule out invasive squamous cell carcinoma. Endoscopic approaches tend to use microdebriders to facilitate the resection. In these cases, the debrided tissue fragments are collected into a container for histologic evaluation to ensure that no microscopic focus of squamous cell carcinoma is identified.

Prognosis

Recurrence rates for both the open and endoscopic approaches are comparable and have ranged from a low of 8–10% to a high of 49–75% in different studies.

Lawson W, Patel ZM. The evolution of management for inverted papilloma: an analysis of 200 cases. *Otolaryngol Head Neck Surg* 2009;140:330 [PMID: 19248937]. (The majority of cases can be performed endoscopically though combined approaches are necessary based on the extent of the tumor.)

Yoon BN, Batra PS, Citardi MJ, Roh HJ. Frontal sinus inverted papilloma: surgical strategy based on the site of attachment. *Am J Rhinol Allergy* 2009;23:337 [PMID: 19490812]. (Tumors attached at multiple sites often require open approaches but single site attachments can typically be approached endoscopically.)

Cannady SB, Batra PS, Sautter NB, Roh HJ, Citardi MJ. New staging system for sinonasal inverted papilloma in the endoscopic era. *Laryngoscope* 2007;117:1283 [PMID: 17632914]. (New staging system that divides patients based on anatomic sites and recurrence rates.)

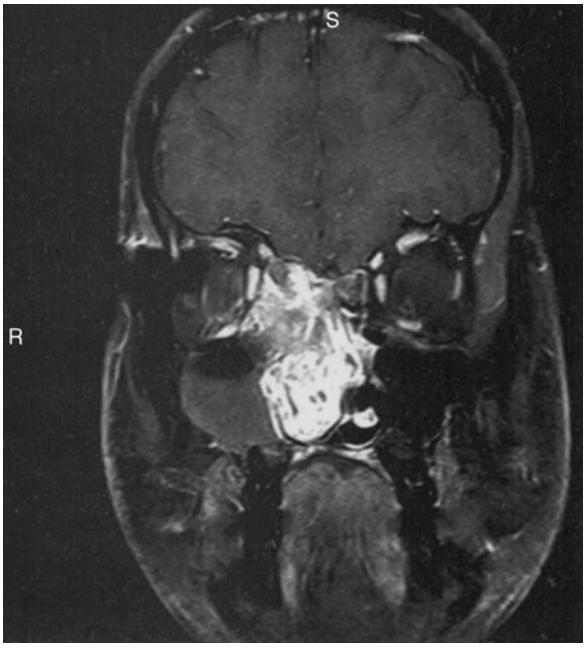
JUVENILE ANGIOFIBROMAS

Clinical Findings

These tumors occur primarily in young boys and are highly vascular. The primary symptoms are nasal obstruction and epistaxis. Juvenile angiofibromas originate in the posterior nasal cavity but by the time of presentation they have grown to fill the nasopharynx, often extending into the pterygopalatine fossa and infratemporal fossa. The rate of tumor growth is slow.

Treatment

The treatment consists of surgical resection and sometimes radiation therapy for persistent disease, despite a hypothesis that regression of these tumors occurs over time. To minimize blood loss, a preoperative angiogram with embolization and hypotensive anesthesia intraoperatively are recommended. Surgical approaches consist of a lateral rhinotomy and medial maxillectomy approach; the prognosis is excellent in patients who undergo these treatment methods.



▲ **Figure 17–2.** Coronal T1-weighted MRI scan showing a mass in the right ethmoid sinus.

MALIGNANT NEOPLASMS

SQUAMOUS CELL CARCINOMAS

General Considerations

Squamous cell carcinoma is the most common malignant neoplasm of the paranasal sinuses, accounting for 60–80% of paranasal sinus tumors. The etiology and epidemiology of this tumor are poorly understood, although nickel workers are at a markedly increased risk of developing these tumors.

Clinical Findings

Squamous cell carcinomas arise from a silent location and grow insidiously with little to no symptoms. At the time of diagnosis, these tumors are very large and, therefore, bode a very poor prognosis. Only when these neoplasms invade adjacent structures, causing symptoms of oral, ocular, or facial involvement, are patients accurately diagnosed and treated (Figure 17–2). These symptoms include pain in the maxillary teeth, erosion of the palate, diplopia, proptosis, and cheek paresthesias. These tumors arise most commonly in the maxillary antrum and account for up to 80% of all paranasal sinus squamous cell carcinoma. The ethmoid sinus is the second most common site of origin. Primary squamous cell carcinomas of the frontal and sphenoid sinuses are rare.

Staging

The revised staging system for maxillary sinus carcinoma, created by the American Joint Committee on Cancer (AJCC), is clinically more relevant and better at distinguishing survival results between T2–T3 and T2–T4 diseases than its previous staging system. The N stage designates regional lymph node involvement and is identical to staging of the neck in other head and neck cancers. The staging system for ethmoid sinus cancers is shown in Table 17–2.

Treatment & Prognosis

For nearly all patients, the treatment is surgical resection followed by radiation therapy. Treatment with this combination

Table 17–2. Staging Criteria of Primary Malignant Maxillary and Ethmoid Sinus Tumors.

Stage	Maxillary Sinus	Ethmoid Sinus
T_X	Primary tumor cannot be assessed	
T_0	No evidence of primary tumor	
T_{IS}	Carcinoma in situ	
T_1	Tumor confined to antral mucosa with no bony destruction	Tumor confined to ethmoid sinuses with no bony destruction
T_2	Tumor causing bony destruction (except for posterior wall of maxillary sinus), including extension into the hard palate or middle meatus	Tumor extends into the nasal cavity
T_3	Tumor invades any of the following: bone of the posterior wall of maxillary sinus, subcutaneous tissue, skin of cheek, floor of medial wall of orbit, infratemporal fossa, pterygoid plates, ethmoid sinuses	Tumor extends to the anterior orbit or the maxillary sinus
T_4	Tumor invades orbital contents beyond the floor or medial wall, including any of the following: the oribital apex, cribriform plate, base of skull, nasopharynx, sphenoid, frontal sinus	Tumor with intracranial extension; orbital extension including the apex or the sphenoid, the frontal external nose, or the skin of the external nose

of modalities has shown markedly improved results compared to radiation therapy alone. The 5-year survival rate for patients with maxillary sinus squamous cell carcinoma who are treated with combined surgery and radiation therapy is 46–68% versus 9–19% for those patients treated with radiation therapy alone. Surgical procedures typically start with a maxillectomy and can include orbital exenteration, infratemporal fossa dissection, and craniofacial resection. Postoperative radiation therapy is administered until at least 65 Gy is delivered. Intensity-modulated radiotherapy (IMRT) allows an even greater dosage delivery while sparing crucial structures such as the optic nerve and chiasm, the pituitary gland, and the brain. The addition of chemotherapy may improve locoregional control and 5-year disease-specific survival.

Due to the rarity of ethmoid squamous cell carcinoma, all ethmoid tumors tend to be grouped together, despite different histological features. Patients with ethmoid tumors fare no better than patients with maxillary sinus tumors; the 5-year local control and disease-specific survival rates for both are similar.

Mendenhall WM, Amdur RJ, Morris CG et al. Carcinoma of the nasal cavity and paranasal sinuses. *Laryngoscope* 2008;119:899. [PMID: 19358246]. (Combined modality therapy with surgery and postoperative radiation therapy is better than radiation therapy alone in local control rates and disease fee survival rates.)

Hoppe BS, Woldern ST, Zelefsky MJ et al. Postoperative intensity-modulated radiation therapy for cancers of the paranasal sinuses, nasal cavity, and lacrimal glands: technique, early outcomes, and toxicity. *Head Neck* 2008;30:925 [PMID: 18302261]. (IMRT minimizes the dose delivered to the optic structures while still delivering excellent target volume coverage.)

Chen AM, Daly ME, Bucci MK et al. Carcinomas of the paranasal sinuses and nasal cavity treated with radiotherapy at a single institution over five decades: are we making improvement? *Int J Radiat Oncol Biol Phys* 2007;69:141 [PMID: 17459609]. (There was no significant improvement in survival outcomes over these 5 decades but there was a decrease in treatment complications over this time period.)

ADENOCARCINOMAS & ADENOID CYSTIC CARCINOMAS

General Considerations

Adenocarcinomas arise from the epithelial surface of the sinonasal mucosa and occur more frequently than adenoid cystic carcinomas, which arise from the minor salivary glands. Together, they represent the most common mucous gland malignant neoplasms of the paranasal sinuses. Adenoid cystic carcinomas tend to arise from the maxillary antrum and can infiltrate into the surrounding tissue. They demonstrate perineural spread into the maxillary and mandibular branches of the trigeminal nerve (CN V), with extension into the foramina ovale and rotundum. Adenoid cystic carcinomas have a low incidence of regional metastases but greater distant metastases.

Clincial Findings

Adenocarcinomas arise typically from the ethmoid sinuses. While there has been no correlation with smoking in the development of adenocarcinomas, there has been a documented association with woodworkers and leather workers. Several histological types are seen with variability in mucin production and cellular differentiation. They are similar to adenoid cystic carcinomas in their growth behavior.

Treatment

The treatment for both of these tumors consists of multimodality therapy at the advanced stages of disease. For maxillary sinus tumors, the treatment usually consists of a maxillectomy. An anterior craniofacial resection is often the recommended treatment for advanced ethmoid cancers. Postoperative radiation therapy is frequently employed in treating patients with all of these tumors.

Choussy O, Ferron C, Vedrine PO et al. Adenocacinoma of Ethmoid: a GETTEC retrospective multicenter study of 418 cases. *Laryngoscope* 2008;118:437 [PMID: 18176354]. (Surgery with postoperative radiation continues to be the preferred treatment and local recurrence accounts for poor survival.)

Lupinetti AD, Roberts DB, Williams MD et al. Sinonasal adenoid cystic carcinoma: the M.D. Anderson Cancer Center experience. *Cancer* 2007;110:2726 [PMID: 17960615]. (Currently, results are best with combined modality treatment of surgery with postoperative radiation therapy.)

OLFACTORY ESTHESIONEUROBLASTOMAS

General Considerations

Olfactory esthesioneuroblastomas arise from the olfactory epithelium superior to the middle turbinate. These neoplasms account for only 1–5% of all malignant tumors of the paranasal sinuses. Olfactory esthesioneuroblastomas are initially unilateral and can grow into the adjacent sinuses and the contralateral nasal cavity; they can spread to the orbit and the brain.

Classification

No TNM staging system has been created for these tumors; a clinical grouping system has been developed that has no prognostic value. This system designates the following groups: (1) Group A consists of patients with tumors limited to the nasal cavity; (2) Group B includes patients whose tumors are localized in the nasal cavity and the paranasal

sinuses; and (3) patients in Group C have tumors that extend beyond both the nasal cavity and the paranasal sinuses. Metastasis to the neck is seen in approximately 10–20% of cases in all three groups.

Clinical Findings

Histologically, olfactory esthesioneuroblastomas can appear similar to both peripheral neuroblastomas and other sinonasal malignant tumors. Two features often seen on microscopy are rosettes and neurofibrillary processes. Immunocytochemical staining of the specimen, while showing tremendous variability, is an important and often necessary step in making an accurate diagnosis. Histologically, olfactory esthesioneuroblastomas do not appear to stain for keratin and epithelial membrane antigen. The most common positive immunoreactions are with neuron-specific enolase, S-100, microtubule-associated protein, Class III β-tubulin isotype, neurofilament, and synaptophysin.

Treatment & Prognosis

Patients with esthesioneuroblastomas are best treated with combined modality therapy, even if the tumors are designated as either Kadish Group A or B neoplasms. The 5-year disease-free survival for single modality therapy for patients in Kadish Groups A and B is 55% compared to 61% for patients in Kadish Group C. The local tumor control rate of combined therapy is 87% versus 51% for radiation alone, and 0% for surgery alone. Surgical resection may involve either local resection or craniofacial resection with radiation doses of 60–65 Gy postoperatively.

MALIGNANT MUCOSAL MELANOMAS

General Considerations

Respiratory tract mucosal melanomas occur in the nasal cavity and paranasal sinuses. They are exceedingly rare, with only 0.5–1.5% of all melanomas occurring in the sinonasal cavity. These neoplasms originate from melanocytes within the submucosa and from the mucosa of the paranasal sinuses. They are located most frequently in the anterior septum, followed by the middle and the inferior turbinates. The maxillary sinus is the most common sinus cavity involved.

Clinical Findings

Epistaxis appears to be the most frequent symptom, and nasal obstruction is also common. On examination, the mass appears to be fleshy and polypoid. Tumors in the nasal cavity tend to be smaller at the time of diagnosis than tumors that arise within the sinuses. Nodal metastasis occurs in 10–20% of cases.

Staging

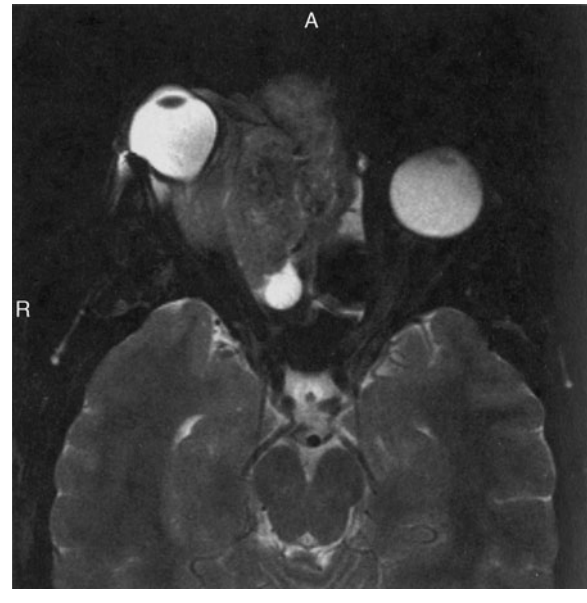
No TNM staging system exists for mucosal melanomas. However, a practical staging system has been developed: (1) Stage I designates localized disease, (2) Stage II indicates regional metastasis, and (3) Stage III signifies distant metastasis. The factors that influence clinical outcomes include the clinical stage, a lesion thickness >5 mm, the presence of vascular invasion, and the development of distant metastasis.

Treatment & Prognosis

The treatment consists of surgical excision followed by postoperative radiation therapy. As a result of this combined treatment approach, the 5-year disease-specific survival rate for sinonasal mucosal melanomas is approximately 47%.

Dauer EH, Lewis JE, Rohlinger AL, Weaver AL, Olsen KD. Sinonasal melanoma: a clinicopathologic review of 61 cases. *Otolaryngol Head Neck Surg* 2008;138:347 [PMID: 18312883]. (Mucosal melanomas continue to be aggressive tumors that are treated with surgery and postoperative radiation therapy, though better systemic treatments are needed.)

Bachar G, Loh KS, O'Sullivan B et al. Mucosal melanomas of the head and neck: experience of the Princess Margaret Hospital. *Head Neck* 2008;30:1325 [PMID: 18704964]. (These tumors have high local, regional and distant metastasis rates with poor prognosis.)



▲ **Figure 17–3.** Axial T2-weighted MRI scan of a patient with a sinonasal undifferentiated carcinoma of the right ethmoid sinus. This tumor extends into the orbit with marked proptosis.

SINONASAL UNDIFFERENTIATED CARCINOMAS

Sinonasal undifferentiated carcinomas are highly aggressive tumors of the paranasal sinuses and often appear to be histologically similar to olfactory esthesioneuroblastomas. Like inverted papillomas, sinonasal undifferentiated carcinomas appear to arise from schneiderian mucosa. They grow rapidly, with extensive local invasion into the sinuses, the orbit, and the brain (Figure 17–3). Histologically, they appear to stain for keratin and epithelial membrane antigen and do not appear to have an association with Epstein–Barr virus (EBV), which would distinguish these tumors from undifferentiated nasopharyngeal carcinoma. Surgical resection with postoperative radiation therapy is the mainstay of therapy. Even with this combined approach, the prognosis is very poor.

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Benign Diseases of the Salivary Glands

18

Fidelia Yuan-Shin Butt, MD

General Considerations

The salivary glands consist of two parotid glands, two submandibular glands, two principal sublingual glands, and a large number of minor salivary glands. Combined, the salivary glands produce serous secretions, mucous secretions, or both. The serous saliva of the parotid gland and the predominantly mucous secretions of the submandibular, sublingual, and minor salivary glands provide digestive enzymes, bacteriostatic functions, lubrication, and hygienic activities. The secretions of the parotid and submandibular glands are primarily stimulated by the autonomic nervous system.

The salivary glands consist of multiple secretory units that include an acinus at the proximal end and a distal ductal unit. The ductal unit combines a sequential array of ductal elements extending away from the acinus: the intercalated duct, the striated duct, and the excretory duct. Myoepithelial cells surround the acinus and extend to the intercalated duct. These myoepithelial cells contract, enabling the glandular cells to expel their secretions. Benign disorders of the salivary glands involve abnormalities of saliva production and secretion.

Saliva is produced by the clustered acinar cells and contains electrolytes, enzymes (eg, ptyalin and maltase), carbohydrates, proteins, inorganic salts, and even some antimicrobial factors. Approximately 500–1500 mL of saliva is produced by the acinar cells daily and transported through the ductal elements at an average rate of 1 mL per minute. Human saliva is generally alkaline.

Classification

Benign diseases of the major and minor salivary glands can often be classified as nonneoplastic and neoplastic. Most clinically significant benign diseases involve primarily the parotid and submandibular glands and less frequently the paired principal sublingual and widely distributed minor salivary glands.

A. Parotid Gland

The parotid gland is the largest of the paired major salivary glands, with an average weight of 25 grams. Each gland is located lateral to the masseter muscle anteriorly and extends posteriorly over the sternocleidomastoid muscle behind the angle of the mandible. The dermis lies laterally to the gland, and the lateral parapharyngeal space lies medially. Each encapsulated gland is artificially divided into a superficial lobe and a deep lobe by the branches of the seventh cranial nerve. The parotid duct, or **Stensen duct,** courses anteriorly from the parotid gland over the masseter muscle and pierces the buccinator muscle to enter through the buccal mucosa, usually opposite the second maxillary molar. The Stensen duct can be found approximately 1.5 cm below the zygoma.

The parotid gland has two layers of draining lymph nodes. The superficial layer lies beneath the capsule, and the deeper layer lies within the parotid parenchyma.

B. Submandibular Gland

The paired submandibular glands are the second largest salivary glands in the body, each weighing approximately 10–15 grams. Each submandibular gland is divided into superficial and deep lobes by the posterior edge of the mylohyoid muscle and occupies the submandibular triangle. The submandibular duct, also known as the **Wharton duct,** courses anteriorly above the mylohyoid muscle and ends in the anterior floor of the mouth. The submandibular duct is inelastic and therefore, when obstructed, causes pain.

C. Sublingual Glands

The principal sublingual glands are paired and located in the submucosa, superficial to the mylohyoid muscle. Each gland is bounded laterally by the inner cortex of the mandible and medially by the styloglossus muscle; the paired glands meet in the midline. The sublingual glands have multiple small or

"minor" sublingual ducts, referred to as the **ducts of Rivinus,** which open directly into the oral cavity. Some of these ducts unite to form the major **ducts of Bartholin**. These major ducts can also join the submandibular ducts.

The lingual nerve descends laterally to the anterior end of the sublingual gland and runs along its inferior border. Anteriorly, the lingual nerve and submandibular duct run parallel until the lingual nerve ascends into the tongue.

D. Minor Salivary Glands

The hard and soft palates contain the greatest concentration of minor salivary glands; however, these glands are also located in the oral cavity, lips, tongue, and oropharynx. Minor salivary glands may be identified in groups, such as the anterior lingual **glands of Blandin–Nuhn**.

NONNEOPLASTIC DISEASES

A list of nonneoplastic diseases can be found in Table 18–1.

INFECTIOUS INFLAMMATORY DISEASES

Infections can occur in an otherwise normal salivary gland or result from prolonged abnormalities of salivary function. Infections can be acute, subacute, or chronic. The primary etiologic agents include viruses and bacteria. However, infections may result secondarily from trauma, radiation, or duct obstruction, as is the case with acute sialadenitis.

ACUTE VIRAL INFLAMMATORY DISEASE

ESSENTIALS OF DIAGNOSIS

- Acute, bilateral swelling of the parotid glands accompanied by pain, erythema, tenderness, malaise, fever, and occasionally trismus.
- Peak incidence in young children aged 4–6 years.
- Incubation period is 14–21 days.
- Disease is contagious.
- Diagnosis can be confirmed with serologic testing.

General Considerations

Mumps (paramyxovirus) is the most common viral disorder causing parotitis (ie, inflammation of the parotid gland). The peak incidence occurs in children aged 4–6 years. The incubation period is 14–21 days, and the disease is contagious during this time.

Table 18–1. Nonneoplastic Diseases of the Salivary Glands.

Infectious Disease
Mumps virus
Coxsackie virus
Influenza virus
Echovirus
Human immunodeficiency virus
Bacteria
Granulomatous infections
Noninfectious, Inflammatory Disease
Sialolithiasis
Chronic sialadenitis
Sjögren syndrome
Benign lymphoepithelial lesion
Kimura disease
Necrotizing sialometaplasia
Adenomatoid hyperplasia
Sarcoidosis
Noninflammatory Disease
Sialadenosis
Branchial cleft cysts
Dermoid cysts
Congenital cysts
Mucoceles

Clinical Findings

In an acute viral inflammation of the parotid gland, bilateral swelling may be accompanied by pain, erythema, tenderness, malaise, fever, and occasionally trismus if an extensive inflammation of the adjacent pterygoid musculature exists. After a thorough history and physical exam, checking the antibodies for the mumps S, mumps V, and hemagglutination antigens can confirm the diagnosis.

Differential Diagnosis

The differential diagnoses of viral parotitis include the coxsackie A virus, cytomegalovirus, influenza A virus, and echoviruses. A serologic screen to test for these viruses may verify the diagnosis.

Complications

Complications of acute viral parotitis may involve other organs. Rare sequelae include meningitis, encephalitis, hearing loss, orchitis, pancreatitis, and nephritis.

Treatment & Prognosis

The disease course of viral parotitis is self-limiting and treatment is primarily symptomatic. The administration of the mumps vaccine has likely decreased the incidence of mumps. Viral infections in immunocompetent individuals often resolve with excellent prognosis.

Barskey AE, Glasser JW, LeBaron CW. Mumps resurgences in the United States: A historical perspective on unexpected elements. *Vaccine* 2009 Oct 19;27(44):6186–6195 [PMID: 19815120].

ACUTE SUPPURATIVE SIALADENITIS

ESSENTIALS OF DIAGNOSIS

- Acute painful swelling of the salivary glands with fever.
- Can occur in postoperative patients and in elderly patients with chronic medical conditions.
- Risk factors include dehydration, trauma, immunosuppression, and debilitation.
- Skin overlying the parotid may be warm, tender, and edematous.
- Untreated acute suppurative sialadenitis may lead to an abscess.
- Saliva from the affected gland should be cultured.

General Considerations

In addition to viruses, bacteria can cause symptoms of acute painful swelling of the salivary glands, especially the parotid gland. Acute suppurative sialadenitis accounts for 0.03% of hospital admissions and can occur in up to 30–40% of postoperative patients.

Pathogenesis

An underlying pathogenesis begins with the stasis of salivary flow in patients; stricture, or obstruction of the ducts then follows. The stasis decreases the ability of saliva to contribute to oral hygiene and promote antimicrobial activity.

Prevention

Predisposing factors for acute suppurative sialadenitis include dehydration, immunosuppression, trauma, and debilitation. Therefore, a higher incidence of this infection is found in postoperative and elderly patients, as well as in patients who have undergone chemotherapy or radiation.

Clinical Findings

In addition to acute parotid swelling in parotitis, there may be overlying skin erythema, pain, tenderness, trismus, purulent ductal discharge, induration, accompanying fevers, or any combination of these symptoms and signs. The common bacteria cultured from purulent saliva include *Staphylococcus aureus, Streptococcus pneumoniae, Escherichia coli,* and *Haemophilus influenzae.* Other organisms obtained from chronically ill, hospitalized patients are *Klebsiella, Enterobacter, Pseudomonas,* and *Candida*.

Complications

If left untreated, acute suppurative sialadenitis can progress to an abscess, a potentially fatal complication in severely debilitated patients. Clinical palpation of the parotid gland may reveal significant induration and a doughlike consistency of the gland. An ultrasound or a computed tomography (CT) scan of the parotid gland may aid in locating an area of loculation.

Treatment

The principal treatment of acute suppurative sialadenitis includes rehydration, intravenous antibiotics with penicillinase-resistant gram-positive coverage, warm compresses, massage, sialogogues, improved oral hygiene, or a combination of these therapies. If there is no clinical improvement within 48 hours of nonsurgical therapy, then an abscess may be presumed. Incision and drainage using a parotidectomy incision may be performed. Care must always be used to avoid injury to the facial nerve. An alternative method may use CT- or ultrasound-guided imaging to perform a fine-needle aspiration of an abscess.

Prognosis

Most patients with acute suppurative sialadenitis respond to medical therapy. However, mortality rates may be higher in patients with severely debilitating or complicated medical conditions. In the case of submandibular sialadenitis, failure of improvement warrants consideration of other pathology: duct obstruction, abscess, salivary stones, or tumors. Submandibular abscesses can mimic Ludwig angina, a severe infection involving the floor of mouth and the submental and submandibular spaces. If not treated, Ludwig angina can lead to airway obstruction.

Fattahi TT, Lyu PE, Van Sickels JE. Management of acute suppurative parotitis. *J Oral Maxillofac Surg* 2002;60(4):446 [PMID: 111928106].

Brook, I. Acute Bacterial Suppurative Parotitis: Microbiology and Management. *J Craniofac Surg* 2003 Jan;14(1):37–40 [PMID: 12544218].

Mandel L. Differentiating acute suppurative parotitis from acute exacerbation of a chronic parotitis: case reports. *J Oral Maxillofac Surg* 2008 Sept;66(9):1964–1968 [PMID: 18718411].

HIV INFECTION

ESSENTIALS OF DIAGNOSIS

- Painless, bilateral enlarged parotid glands.
- Xerostomia.
- Known risk factors for HIV.
- Associated cervical lymphadenopathy may be associated.
- Presence of amylase in the cyst fluid helps confirm the diagnosis.

General Considerations

Lymphoepithelial cysts associated with human immunodeficiency virus (HIV) occur almost exclusively in the parotid gland; however, anecdotal reports cite some occurrences of these cysts in the submandibular glands as an unusual finding. One possible explanation for the predominant presence of these cysts within the parotid gland is that this gland, unlike the submandibular gland, has intraglandular lymph nodes.

Clinical Findings

A. Symptoms And Signs

HIV infection should be considered in a young individual with bilateral symmetric parotid swelling, especially if the parotid swelling appears multicystic; this finding may be the initial presenting symptom of HIV infection for some patients.

B. Diagnostic Evaluation

A CT scan or ultrasound may reveal bilateral multiple cystic masses in the parotid gland. Serologic testing for HIV antibodies confirms the diagnosis. Fine-needle aspiration of these cysts can reveal amylase in the fluid, which also leads to the diagnosis (see Figure 18–1).

Treatment

Observation or serial drainage of symptomatic cysts is the recommended treatment. A recent treatment modality includes sclerotherapy of the cysts. Rarely is parotidectomy indicated; however, when it is performed, the histopathology often shows multiple lymphoepithelial lesions and florid follicular hyperplasia with follicle lysis. Similarly, cysts involving the submandibular gland may require gland excision.

Prognosis

The parotid cysts found in HIV-infected patients are often associated with the histologic finding of benign lymphoepithelial lesions. There is little malignant transformation.

Gupta N, Gupta R, Rajwanshi A, et al. Multinucleated giant cells in HIV-associated benign lymphoepithelial cyst-like lesions of the parotid gland on FNAC. *Diagn Cytopathol* 2009 Mar;37(3): 203–204 [PMID: 19170173].

Berg EE, Moore, C. Office-based sclerotherapy for benign parotid lymphoepithelial cysts in the HIV-positive patient. *Laryngoscope* 2009 May;119(5):868–870 [PMID: 19358192].

CHRONIC GRANULOMATOUS SIALADENITIS

ESSENTIALS OF DIAGNOSIS

- Chronic unilateral or bilateral salivary gland swelling.
- Minimal pain.
- Fine-needle aspiration biopsy of the gland can aid in diagnosis.
- Risk factors such as exposure to tuberculosis, animal exposure, trauma, and multiorgan system involvement should be considered.
- Uveitis, facial palsy, and parotid enlargement are suggestive of sarcoidosis.

Clinical Findings

Granulomatous disorders may present with acute salivary gland swelling or chronic unilateral glandular swelling. The glandular mass is not usually accompanied by significant pain. Primary tuberculosis should be considered if there are risk factors for exposure.

Differential Diagnosis

The diagnosis of tuberculous sialadenitis may be made with acid-fast staining for organisms, a culture of the saliva, and placement of a purified protein derivative skin test. A fine-needle aspirate of the gland helps to obtain material for diagnosis. Treatment of primary tuberculous sialadenitis includes multidrug antituberculous medications.

The differential diagnoses of granulomatous sialadenitis include animal cat-scratch disease, sarcoidosis, actinomycosis, Wegener granulomatosis, and syphilis.

A. Cat-Scratch Disease

Cat-scratch disease does not directly involve the parotid gland; instead, it affects the periparotid and intraparotid

lymph nodes. In the submandibular gland, it can present as an acute submandibular mass without causing ductal obstruction, which suggests the involvement of the adjacent lymph nodes. The offending organism is a gram-negative rod, *Bartonella henselae,* and diagnosis may be made using indirect fluorescent antibody tests with rising IgG titers, or with the Warthin–Starry silver stain looking for gram-negative bacilli. Cat-scratch disease is usually self-limiting and treatment is supportive while the mass lesions slowly resolve.

B. Sarcoidosis

Sarcoidosis is noninfectious and involves the parotid gland in less than 10% of cases. It is a diagnosis of exclusion and is confirmed by histologic findings of noncaseating granulomas. Sarcoidosis may occur as part of a syndrome known as uveoparotid fever or **Heerfordt syndrome**. This syndrome is characterized by parotid enlargement, facial palsy, and uveitis. The involvement of the parotid and lacrimal glands leads to xerostomia and xerophthalmia. The disease often affects adults in their twenties and thirties with spontaneous resolution occurring in the ensuing months to years.

C. Actinomycosis

Actinomycosis is easily diagnosed with special histologic stains that demonstrate sulfur granules. Actinomycosis should be suspected if a patient has painless parotid swelling with a history of recent dental infection or trauma. Trismus may develop with progression of the infection. Penicillin is the drug of choice for treatment of actinomycosis.

D. Wegener Granulomatosis

Wegener granulomatosis can present as an acute unilateral mass in the gland, often with pain. This diagnosis, characterized histologically by necrotizing inflammation and vasculitis, is confirmed with serologic testing for the cytoplasmic antineutrophil cytoplasmic antibody (C-ANCA) and histopathologic examination.

The treatment of Wegener disease depends on the involvement of other organs; Wegener granulomatosis can be a rapidly fatal disease if it is untreated and involves other major organs. The initial treatment consists of several weeks of steroids with the addition of cyclophosphamide or other immunosuppressive agents. A more indolent subtype of Wegener, as often seen in the head and neck region, can be controlled with immunosuppressive therapy. The prognosis is excellent for many of the granulomatous diseases.

Frantz MC, Frank H, vonWeyhern C, et al. Unspecific parotitis can be the first indication of a developing Wegener's granulomatosis. *Eur Arch Otorhniolaryngol* 2008 Jan;265(1):131–134 [PMID: 17653747].

Saha AK, Rachapalli S, Steer S et al. Bilateral parotid gland involvement in Wegener granulomatosis. *Ann Rheum Dis* 2009 Jul; 68(7):1233–1234 [PMID: 19525411].

NONINFECTIOUS INFLAMMATORY DISEASES

SIALOLITHIASIS

ESSENTIALS OF DIAGNOSIS

- Acute, painful swelling of the major salivary gland, especially the submandibular gland, which may be recurrent.
- Aggravation of symptoms with eating; swelling may subside after approximately 1 hour.
- History of gout or xerostomia.
- A stone in the floor of the mouth may be palpated; treatment depends on the location of the calculus.
- Calculus may be extracted intraorally, or if distal, then the submandibular gland may be indicated.
- Complications include acute suppurative sialadenitis, ductal ectasia, and stricture.

General Considerations

Approximately 80–90% of salivary calculi occur in the submandibular gland, whereas only 10–20% is reported in the parotid gland; a very small percentage of salivary calculi are found in the sublingual and minor salivary glands. Sialolithiasis is a common cause of salivary gland disease and can occur at any age with a predilection in men. Risk factors for salivary stone obstruction include long illnesses with dehydration. There are also associations with gout, diabetes, and hypertension.

Pathogenesis

Normal saliva contains abundant hydroxyapatite, the primary compound in salivary stones. Aggregates of mineralized debris in the duct can form a nidus, promoting calculi formation, salivary stasis, and eventually obstruction. The submandibular gland is more susceptible to calculi formation than the parotid gland because of the longer course of its duct, higher salivary mucin and alkaline content, and higher concentrations of calcium and phosphate.

Submandibular calculi consist primarily of calcium phosphate and hydroxyapatite; because of the high calcium content of these calculi, the majority is radiopaque and visualized on X-rays. Parotid calculi are less likely to be

radiopaque. Approximately 75% of the time, a single stone is found in the gland. If the obstruction is not relieved, local inflammation, fibrosis, and acinar atrophy ensue.

Clinical Findings

A. Symptoms and Signs

Recurrent swelling and pain in the submandibular gland exacerbated with eating is the common presentation of salivary calculi. Prolonged obstruction can lead to acute infection with increasing pain and erythema of the gland. Patients may also report a history of xerostomia and occasionally gritty, sand-like foreign bodies in their oral cavity. A physical exam is essential as stones often are palpated in the anterior two thirds of the submandibular duct. In addition, an induration of the mouth floor is sometimes observed. Stones located within the body of the gland are not easily palpated.

B. Imaging

X-rays with lateral and colossal views can reveal a radiopaque stone, but these views are not always reliable. Intraoral views may be more helpful. Sialography is the most accurate imaging method to detect calculi. Sialography can be combined with CT scanning or magnetic resonance imaging (MRI), especially as CT scans are sensitive to calcium salts. Ultrasound has not proven to be useful.

C. Endoscopy

Recent advances in endoscopy have allowed endoscopic examination of the submandibular duct to detect calculi.

Complications

Persistent obstruction from sialolithiasis leads to salivary stasis. It also predisposes the gland to recurrent acute infections and even abscess formation.

Treatment

A. Intraoral Extraction

Treatment is based on the location of the salivary stone. If the stone is palpated or visualized in the anterior portion of the submandibular duct and does not pass spontaneously, it can be extracted intraorally. The ductal papilla can be dilated serially with ease using graded lacrimal probes; the stone is then expressed. If the stone is too large, a more extensive intraoral procedure under local or general anesthesia may be attempted. The duct is cannulated, and an incision over the stone is created to allow extraction. No closure of the incision is made and careful attention must be paid to the adjacent lingual nerve.

B. Surgical Excision

Larger stones embedded in the hilum or the body of the submandibular gland causing symptoms may require surgical excision of the gland. Similarly, a symptomatic stone embedded in the body of the parotid gland will necessitate a parotidectomy.

C. Endoscopic Techniques

Recent endoscopic techniques allow an intraoral endoscopic examination of the duct and extraction of salivary calculi. Sialoendoscopy alone or combined with open sialolithectomy has been performed with minimal morbidity and carries the advantage of avoiding a transverse cervical incision.

D. Other Measures

Other methods for calculi removal include wire basket extraction under radiologic guidance, pulsed dye laser lithotripsy, and extracorporeal shock wave lithotripsy.

Prognosis

The recurrence of stones is approximately 20%. If the risk factors are corrected, this may decrease the rate of recurrence.

Su Y, Liao GQ, Zheng GS, et al. Sialoendoscopically assisted open sialolithectomy for removal of large submandibular hilar calculi. *J Oral Maxillofac Surg* 2010 Jan;68(1):68–73 [PMID: 20006157].

Walvekar R, Bomeli R, Carrau RL, et al. Combined approach technique for the management of large salivary stones. *Laryngoscope* 2009 Jun;119(6):1125–1129 [PMID: 19358166].

CHRONIC SIALADENITIS

General Considerations

Chronic sialadenitis results from either a decreased production of saliva or alterations in the salivary flow leading to salivary stasis. There may or may not be associated obstruction. This slow, progressive inflammatory process is usually found in adults, but it can affect children as well.

Pathogenesis

A decreased flow or stasis compromises the salivary functions, creating an environment at risk for infection. Chronic sialadenitis may be caused by retrograde infection from normal oral flora and chronic inflammation from repeated acute infections. In the latter, chronic inflammation causes changes in the ductal epithelium; this commonly leads to increased mucin in secretions, decreased flow, and formation of mucous plugs.

Histologically, the ductal epithelium in chronic sialadenitis may demonstrate mucous cell, squamous, or oncocytic metaplasia. There may be ductal dilatation and atrophy of the acinar cells. Prolonged inflammation can lead to fibrosis and infiltration with lymphocytes. If a stone obstruction is the cause, calculi may be seen within the ducts.

Prevention

A variety of conditions can cause chronic nonobstructive sialadenitis; these include repeated acute infections, trauma, radiation, and immunocompromised conditions. Histologic changes from radiation are likely permanent. Some patients may develop salivary gland swelling, xerostomia, and taste alterations after receiving intravenous iodine contrast. Smoking has also been found to predispose an individual to chronic sialadenitis because it reduces the antimicrobial activity of salivary secretions. Another condition known descriptively as chronic sclerosing sialadenitis or Kuttner tumor may be indistinguishable from neoplasia until a pathologic examination is done.

Clinical Findings

Presenting symptoms consist of chronic, intermittent painful swelling of the salivary gland, especially with eating. Swelling is often bilateral and may or may not be associated with an acute infection.

A thorough history and physical examination can elicit risk factors and direct the search for treatable causes, such as a salivary stone. A CT scan or MRI may help to exclude a malignant tumor, especially if there is an associated fibrous mass in the parotid gland. Sialography and fine-needle aspiration have not been consistently diagnostic; however, sialographs can be helpful in finding obstructions, acinar atrophy, and irregular dilatations of the ducts.

Differential Diagnosis

The differential diagnoses include granulomatous diseases, sialolithiasis, sarcoidosis, benign lymphoepithelial lesion, inflammatory pseudotumors, Sjögren syndrome, and Mikulicz syndrome.

Complications

As a reactive process to trauma or disease, chronic nonobstructive sialadenitis may progress to a fibrous mass formation or an inflammatory pseudotumor. Other complications of the disease include pain and permanent damage to the acinar unit and ductal epithelium. Progressive changes further compromise the function of the acinar units, which clinically manifest as bulging, irregular, and nodular glands.

Treatment

Conservative therapy and surgical gland excision are the most successful treatment methods of chronic nonobstructive sialadenitis. If no treatable cause is identified, patients are encouraged to improve oral hygiene with increased hydration, massage of the affected gland, adequate nutrition, and use of sialagogues. Antibiotics are administered with acute exacerbations.

Superficial parotidectomy is the common surgical treatment of persistent symptoms in the parotid gland. Alternative treatments include iatrogenic fibrosis of the gland with 1% methyl violet and low-dose radiation therapy. Procedures such as parotid duct ligation and tympanic neurectomy, used to cease secretion, also may prove therapeutic.

Prognosis

The prognosis depends on treating an identifiable underlying cause; few recurrences have been reported following these treatments.

Grewal RK, Larson SM, Pentlow CE, et al. Salivary gland side effects commonly develop several weeks after initial radioactive iodine ablation. *J Nucl Med* 2009 Oct;50(10):1605–1610 [PMID: 19759114].

Geyer JT, Ferry JA, Harris NL et al. Chronic sclerosing sialadenitis (Kuttner tumor) is an IgG4-associated disease. *Am J Surg Pathol* 2010 Feb;34(2):202–210 [PMID: 20061932].

SJÖGREN SYNDROME

ESSENTIALS OF DIAGNOSIS

- Salivary gland swelling with dryness of the mouth and eyes leading to oral and ocular pain and sensitivity.
- Often associated with another connective tissue disease.
- More commonly seen in postmenopausal women.
- Detection of autoantibodies SS-A and SS-B and others, along with minor salivary gland biopsy, may confirm the diagnosis.
- Slowly progressive disease.
- High risk for development of malignant lymphoma in primary Sjögren syndrome

General Considerations

Sjögren syndrome is an autoimmune disorder classically characterized by parotid enlargement, xerostomia, and kera-

toconjunctivitis sicca. It also may be associated with a connective tissue disease such as rheumatoid arthritis or systemic lupus erythematosus. Sjögren syndrome occurs 90% of the time in females, usually in their sixth decade. It is the second most common connective tissue disorder; only rheumatoid arthritis occurs more frequently.

Clinical Findings

A. Symptoms and Signs

Patients often present with bilateral, nontender salivary gland enlargement. The parotid swelling may occur intermittently or stay constant. Other symptoms include dry eye, dry mouth, altered taste, dry skin, myalgia, vaginal dryness, vasculitis, and arthritis.

B. Laboratory Findings

Useful laboratory tests showing the presence of SS-A or SS-B autoantibodies, rheumatoid factor, or antinuclear antibodies can aid the diagnosis. The microscopic examination of a minor salivary gland biopsy, such as from the lip, can confirm Sjögren disease. According to histologic criteria, a focus score of greater than 1 focus/4 mm^2 is diagnostic. Characteristic histopathologic findings include a lymphocytic infiltrate in acinar units and epimyoepithelial islands surrounded by lymphoid stroma.

Differential Diagnosis

The differential diagnoses include benign lymphoepithelial lesion, also known as Mikulicz syndrome, and chronic nonobstructive sialadenitis.

Complications

Complications of primary Sjögren syndrome result from chronic progression of the disease. The deterioration of salivary function can cause patients to have difficulties with speaking, swallowing, and masticating; in addition, increased dental decay with loss of teeth and oral mucosal discomfort can result. More importantly, there is an approximate 10% incidence of lymphoma in patients with primary Sjögren syndrome.

Treatment

Treatment is symptomatic and supportive. Steroids and topical steroid eyedrops may be indicated for severe symptoms. Superficial parotidectomy may be required for severe recurrent parotid infections.

Prognosis

The prognosis for those affected with Sjögren syndrome is generally favorable. However, there is an increased incidence in malignant lymphoma or lymphoepithelial carcinoma in patients with this syndrome. Therefore, careful observation with appropriate diagnostic studies is recommended.

BENIGN LYMPHOEPITHELIAL LESIONS

ESSENTIALS OF DIAGNOSIS

- Unilateral firm or cystic swelling of the parotid gland, with bilateral involvement in approximately 20% of cases.
- Parotid gland most often involved, but the submandibular gland may also be involved.
- Most often seen in HIV-infected populations.
- Fine-needle aspiration aids in diagnosis, showing acinar atrophy with diffuse lymphocytic infiltration, and foci of epimyoepithelial islands.
- Disease may progress to near total or total replacement of acinar tissue in the gland.
- Higher probability of progression to low-grade B-cell lymphoma of mucosa-associated lymphoid tissue (MALT).

General Considerations

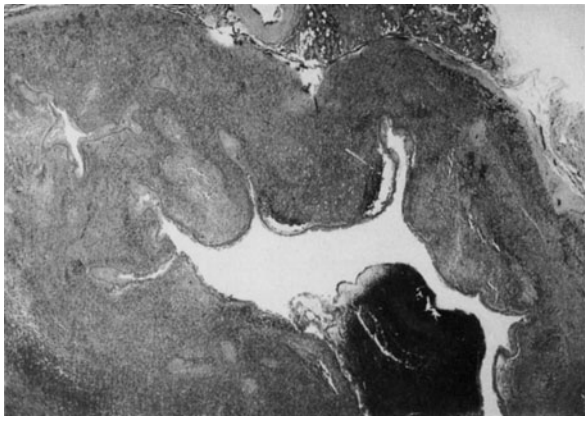
Benign lymphoepithelial lesions are also known as **Godwin tumor, Mikulicz syndrome,** or punctate parotitis. Benign lymphoepithelial lesion has a predilection for females, especially in the fifth and the sixth decades of life. It is also associated with multicystic disease in HIV-infected patients.

Pathogenesis

A benign lymphoepithelial lesion is an inflammatory process characterized by lymphocytic infiltration around salivary gland ducts and parenchyma (Figure 18–1). With increasing lymphocytic infiltration, progressive acinar atrophy and even replacement of the acini result. Upon further progression, the ductal epithelia proliferate and eventually cause ductal obstruction.

Clinical Findings

Patients often present with recurrent unilateral firm or cystic swelling of the parotid gland with or without pain. Bilateral involvement occurs in 20% of cases. Fine-needle aspiration of the parotid mass is helpful. Sialography is rarely indicated unless a stone is suspected.



▲ **Figure 18–1.** Benign lymphoepithelial cyst. (Image contributed by Christina Kong, MD, Stanford University School of Medicine, Stanford, CA.)

This condition often affects the parotid gland and rarely affects the submandibular gland; when it does affect the submandibular gland, it presents as a painless mass. There may be an associated reactive lymphadenopathy. The diagnosis is best made on histopathologic findings of acinar atrophy with diffuse lymphocytic infiltration, with or without the presence of epimyoepithelial islands. There is an association with Sjögren syndrome.

Complications

Cases of progression to neoplastic disease can result, including lymphoepithelial carcinoma, low-grade B-cell lymphoma of MALT pseudolymphoma, and non-Hodgkin lymphoma. There is also an association with Kaposi sarcoma in HIV-infected patients.

Treatment & Prognosis

The treatment of benign lymphoepithelial lesion is symptomatic unless the parotid enlargement is severe enough to warrant a superficial parotidectomy. Complete submandibular excision is an adequate treatment of the rare benign lymphoepithelial cyst. Infrequently, there is malignant transformation; however, careful observation is warranted even after complete excision of the gland.

Wu L, Cheng J, Maruyama S, et al. Lymphoepithelial cyst of the parotid gland: its possible histopathogenesis based on clinicopathologic analysis of 64 cases. *Hum Pathol* 2009 May; 40(5):683–692 [PMID: 19157503].

KIMURA DISEASE

ESSENTIALS OF DIAGNOSIS

- Slowly growing, painless mass in the major salivary gland, primarily in Asians.
- Commonly seen in the second and third decades; 80% of patients are male.
- Enlargement of gland accompanied by regional lymphadenopathy.
- Serologic tests often demonstrate peripheral eosinophilia and elevated IgE levels.
- Recurrence may occur after surgical excision of the gland.

General Considerations

Kimura disease is a rare, benign chronic inflammatory disease mimicking a tumor in regions of the head and neck. It occurs predominantly in young Asian males in their twenties and thirties. About 80% of patients are male.

Clinical Findings

When Kimura disease occurs in the head and neck regions, the major salivary glands are usually involved. In the parotid and submandibular glands, this disease presents as painless, slowly growing, superficial swellings often accompanied by regional lymphadenopathy. The formation of lymphoid follicles and the aggregation of eosinophils in the affected tissues are found on histologic examination.

Laboratory Findings

Serologic tests often demonstrate peripheral eosinophilia and elevated IgE levels.

Differential Diagnosis

The differential diagnoses of Kimura disease include the following: (1) angiolymphoid hyperplasia with eosinophilia, (2) reactive lymphadenopathy, (3) parotid tumor, (4) extranodal manifestations of Rosai–Dorfman disease, and (5) benign lymphoepithelial lesion. Angiolymphoid hyperplasia with eosinophilia differs from Kimura disease in the lack of lymphadenopathy and decreased eosinophilia. **Rosai–Dorfman disease** is an idiopathic benign condition characterized by histiocytic proliferation and massive lymphadenopathy, including involvement of the intraparotid lymph nodes.

Treatment

The treatment of choice when Kimura disease is found in the parotid gland is parotidectomy with continued observation for potential recurrence. Kimura disease of the submandibular gland is usually treated with excision of the gland and the adjacent lymph nodes. Recurrence may occur after surgical excision of the gland. Because Kimura disease often affects other sites, systemic therapy with steroids and radiation also may prove beneficial.

NECROTIZING SIALOMETAPLASIA

Necrotizing sialometaplasia is a benign, self-healing inflammatory process mainly involving the minor salivary glands. It has a predilection in males and occurs over a wide age range. It presents as a spontaneously appearing, painless ulceration or swelling usually over the hard palate, but can occur wherever there are salivary gland tissues. The lesions are usually unilateral and can present with burning sensations and numbness. The cause is unknown, but there are associations with trauma and radiation therapy. The pathogenesis is thought to be ischemic.

The diagnosis of necrotizing sialometaplasia is confirmed on biopsy. Histology shows the characteristic pseudoepitheliomatous hyperplasia and squamous metaplasia. Care must be taken to avoid confusing the diagnosis with squamous cell carcinoma or mucoepidermoid carcinoma; the main complication is misdiagnosis. Lesions in necrotizing sialometaplasia are self-healing, usually by secondary intention, and recurrences are rare.

ADENOMATOID HYPERPLASIA

Adenomatoid hyperplasia is a rare swelling of the minor salivary glands that occurs most commonly in the palate. Local trauma, environmental irritation, and chronic inflammation are the proposed causes of this condition. Patients present with painless swellings that have been present for an indeterminate length of time. The overlying mucosa usually appears normal. Adenomatoid hyperplasia must be distinguished from minor salivary gland tumors. The differential diagnoses include benign and malignant tumors.

Histologic examination reveals glandular hypertrophy and inflammatory infiltrates, but no change in the general architecture of the gland and no evidence of neoplasia or atypia. Complete excision is the treatment of choice. Because of the higher incidence of malignant tumors within the hard palate, the key is to distinguish malignant tumors from benign adenomatoid hyperplasia.

Shimoyama T, Wakabayashi M. Adenomatoid hyperplasia of the palate mimicking clinically as a salivary gland tumor. *J Oral Sci* 2001;43(2):135 [PMID: 11515598].

NONINFLAMMATORY DISEASES

SIALADENOSIS

ESSENTIALS OF DIAGNOSIS

- Bilateral, occasionally unilateral, diffuse enlargement of the salivary glands, particularly the parotid glands.
- Pain may or may not be associated.
- The condition usually begins between the ages of 20 and 60 years and may persist for more than 20 years.
- In half of the cases, there are associated underlying systemic factors, including endocrine disorders, malnutrition, and drugs.
- Biopsy of the affected gland shows acinar enlargement.
- The cause is peripheral autonomic neuropathy of the salivary glands; present treatments are not entirely satisfactory as they do not address this underlying cause.
- Surgery should be reserved if cosmetic deformity of the gland is unacceptable.

General Considerations

Sialadenosis, or sialosis, is a rare, noninflammatory condition that causes bilateral, diffuse, and painless enlargement of the salivary glands. This condition may also cause degenerative changes to the autonomic innervation of the glands. The parotid gland is the most affected, followed by the submandibular gland.

Prevention

Although the etiology is not clear, several metabolic and medical conditions are associated with sialadenosis. These include obesity, alcoholic cirrhosis, diabetes, hyperlipidemia, hypothyroidism, anemia, pregnancy, malnutrition, menopause, and even certain medications (eg, clozapine).

Clinical Findings

A thorough physical exam and screening are necessary. Fine-needle aspiration complemented with CT scanning can establish the diagnosis. Histopathologic findings show acinar enlargement.

Treatment & Prognosis

The treatment of sialadenosis is directed at the underlying conditions. Parotidectomy is considered if the parotid enlargement is cosmetically unacceptable. Surgical resection of the

affected submandibular gland is the treatment of choice; but unless correction of the underlying disorder is addressed, there may be persistent enlargement of any residual glands. The prognosis is therefore dependent on treatment of the underlying conditions.

PAROTID CYSTS

ESSENTIALS OF DIAGNOSIS

- Fluctuant swellings of the salivary glands.
- Cysts of the parotid gland may be acquired or congenital.
- Congenital cysts may be either Type I or Type II branchial arch cysts.
- Acquired cysts may occur secondary to trauma, sialolithiasis, ductal stricture, or benign lymphoepithelial lesions.
- HIV should be considered in the differential diagnosis.

True cysts of the parotid gland account for 2–5% of parotid lesions.

Classification

A. Congenital Parotid Cysts

1. Branchial cleft anomalies—Congenital cysts may result from branchial cleft anomalies; these anomalies are subdivided into Type I and Type II cysts.

a. Type I cysts—Type I cysts are a duplication anomaly of the ectodermal external auditory canal. The cyst may be located anteroinferior to the ear lobule.

b. Type II cysts—Type II cysts consist of ectodermal and mesodermal elements and may open anteriorly to either the sternocleidomastoid muscle or the external auditory canal.

Both Type I and Type II branchial cleft anomalies may have sinus tracts, which are intimately related to the facial nerve. Therefore, excision of these congenital parotid cysts requires a parotidectomy approach and preservation of the facial nerve.

2. Dermoid cysts—A second type of congenital cyst occurring in the parotid gland is a dermoid cyst. This cyst results from trapped embryonic epidermis and presents as a rounded mass. It contains keratinizing squamous epithelium, sweat glands, and other associated skin appendages. Excision to prevent recurrent infections, with attention to the facial nerve, is the most successful treatment.

B. Acquired Parotid Cysts

Acquired cysts of the parotid gland may result from other parotid disorders such as tumors, trauma, chronic sialadenitis, sialolithiasis, and radiation injury. Cysts related to HIV infection have been discussed earlier in this chapter.

CONGENITAL SALIVARY FISTULAS OF THE SUBMANDIBULAR GLAND

Congenital salivary fistulas and sinus tracts are exceedingly rare. They are thought to arise from aberrant salivary gland tissue or aberrant gland formation during the end of the sixth week of gestation. These fistula and sinus tracts may form cutaneous openings in the submandibular skin with discharge. A fistulogram or MRI may help with the diagnosis. Complete surgical excision is the recommended treatment.

Inohara H, Akahani S, Yamamoto Y, et al. The role of fine-needle aspiration cytology and magnetic resonance imaging in the management of parotid mass lesions. *Acta Otolaryngol* 2008 Oct; 128(10):1152–1158 [PMID: 18607904].

Zhang S, Bao R, Abreo F. Fine needle aspiration of salivary glands: 5-year experience from a single academic center. *Acta Cytol* 2009 Jul–Aug;53(4):375–382 [PMID: 19697720].

MUCOCELES

ESSENTIALS OF DIAGNOSIS

- Painless, cystic lesions commonly seen on the lip, oral cavity, and often with mucous extravasation.
- Cystic lesion in the floor of mouth may be localized or extend into the neck, presenting as a neck mass.
- Presentation may be preceded by minor trauma to soft tissue or oral mucosa.

General Considerations

Mucoceles represent dilatations of the minor salivary gland ducts due to both accumulated mucous secretions and, often, mucous extravasations into the connective tissue. Mucoceles are fairly common and are seen frequently in the lip (60–70%), buccal mucosa, floor of the mouth, and palate. When a mucocele appears in the mouth floor, it is defined as a **ranula** (related to the Latin term for frog). It is also known as a **mucous retention cyst.**

Pathogenesis

Mucoceles are thought to arise from either a trauma or a rupture of the minor salivary gland ducts with extravasation

of mucus into the surrounding tissue. Sublingual glands and minor salivary glands are more susceptible to developing mucoceles owing to continuous mucous secretions in these glands, whereas the parotid and submandibular glands secrete on stimulation. The cause of ranulas is not as clear.

Clinical Findings

Mucous retention cysts generally present as pale, smooth, bluish-hued submucosal cysts. They are painless and may slowly enlarge.

Ranulas, involving the sublingual or submandibular ducts, present as round, fluctuant masses in the mouth floor. They are usually unilateral and may affect any age group with no gender preference. A **simple ranula** is a true cyst with an epithelial lining that occurs intraorally with elevation of the mouth floor. A **plunging ranula** extends below the mylohyoid muscle, beyond the sublingual space, and involves the sub-mandibular space. It may extend further inferiorly to present as a painless submandibular or cervical neck mass. Unlike a simple ranula, a plunging ranula does not have an epithelial lining and therefore is classified as a pseudocyst.

A physical exam is usually adequate for the diagnosis, but a CT scan can provide excellent views of the extent of the cyst.

Complications

Mucoceles and ranulas cause few complications. However, infections can occur.

Differential Diagnosis

The differential diagnoses include cystic hygroma, lymphangioma, thyroglossal duct cyst, and dermoid cyst. An important differential diagnosis for a mucous retention cyst is malignant mucoepidermoid carcinoma.

Treatment & Prognosis

A complete surgical intraoral excision of a mucous retention cyst is curative with few recurrences at the site. The treatment of a simple ranula consists of either simple excision of the cyst and possible removal of the associated gland, or marsupialization of the cyst wall. Recurrences are possible with the latter procedure. In the case of plunging ranulas, treatment requires excision either intraorally or combined with a cervical incision and extirpation of the associated gland. Recurrence can occur with inadequate excision.

Nico MM, Park JH, Lourenco SV. Mucocele in pediatric patients: analysis of 36 children. *Pediatr Dermatol* 2008 May–Jun; 25(3):308–311 [PMID: 18577033].

XEROSTOMIA

Xerostomia is defined as dry mouth. In addition to the discomfort from dry mouth, patients with xerostomia may also experience an altered sense of taste, dysphagia, and complications related to dental decay. Disorders of salivary flow in the parotid gland can cause this condition. In addition, many systemic conditions can result in dry mouth: Sjögren syndrome, stress, diabetes, chronic infection, and irradiation. Xerostomia also results as a side effect of a variety of medications.

The treatment of xerostomia is aimed at the underlying conditions; symptomatic treatment includes an increased intake of fluids, sialagogues, mouthwashes, and artificial saliva. In addition, there are currently medications prescribed to minimize xerostomia for patients undergoing radiation.

Cho MA, Ko JY, Kim YK et al. Salivary flow rate and clinical characteristics of patients with xerostomia according to its aetiology. *J Oral Rehabil* [Epub 2010 Mar; 37(3):185–193]. [PMID: 20002531].

PTYALISM

Ptyalism refers to the hyperproduction of saliva. It is associated with a number of medical conditions, including inflammation, cerebral palsy, and pregnancy. Medications may also produce ptyalism as a side effect.

If medications with drying agents are not effective, surgical treatment is indicated. Other treatment options include selective neurectomy of the chorda tympani nerve, excision of the salivary gland, and either ligation or transposition of the affected duct.

BENIGN NEOPLASTIC DISEASES

ESSENTIALS OF DIAGNOSIS

- 64–80% of primary salivary tumors occur in the parotid gland, 7–15% occur in the submandibular gland, and <1% occur in the sublingual glands.
- 54–80% of all tumors are benign.
- Peak incidence of salivary tumors occurs in the sixth to seventh decades.
- Painless, slowly enlarging solitary mass in the salivary gland.
- Deep parotid lobe tumors may present as a painless, asymmetric swelling of the soft palate.
- Fine-needle aspiration cytology and imaging aid in the diagnosis.
- Complete surgical excision is most often curative.

General Considerations

Approximately 80% of salivary gland tumors occur in the parotid gland. Of these tumors, approximately 75–80% are benign. There is no consistent correlation between the rate of tumor growth and whether a tumor is benign or malignant. Most benign tumors of the parotid gland are epithelial tumors.

In general, only 15% of diseases of the submandibular gland are neoplastic. Compared with parotid tumors, approximately 50–60% of submandibular tumors are benign.

Minor salivary gland tumors account for approximately 15% of all salivary gland tumors. It is estimated that only 35% of minor salivary gland tumors are benign, with pleomorphic adenoma being the most common neoplasm followed by basal cell adenoma.

Clinical Findings

Most benign parotid tumors present as slow-growing, painless masses often in the tail of the parotid gland. Tumors of the other salivary glands similarly present as painless masses. Fine-needle aspiration of salivary tumors, although not as sensitive or specific as in other tumors (eg, the thyroid), is extremely useful in differentiating between malignant and benign processes. The accuracy rate is approximately 85% in determining if a parotid tumor is benign or malignant; this rate is higher when determining whether or not a lesion originates from parotid tissue. CT scanning and MRI may help identify deep lobe tumors if clinically warranted.

Differential Diagnosis

The differential diagnoses of benign salivary gland tumors not only include each other but must also alert a clinician to their malignant counterparts. Various other benign neoplastic entities involving the salivary glands must be considered: papillary ductal adenomas, sebaceous adenomas, ancient schwannomas, congenital epithelial tumors, cavernous hemangiomas, and ectopic extraglandular tissues. Fine-needle aspiration is most useful in determining whether an asymptomatic mass in the region of the parotid gland or submandibular space is of glandular origin or not. Treatment options can be tailored based on these initial findings.

Complications

Complications of pleomorphic adenomas are rare and include malignant transformation into a carcinoma expleomorphic adenoma. There is rare malignant transformation of Warthin tumor, monomorphic adenomas, and the benign salivary tumors to be described. Little is known about the incidence of the malignant transformation of tumors found in the submandibular gland.

Complete excision ensures an excellent prognosis; however, recurrence occurs if there are positive margins. With the repeat excision of recurrences, the risk to the facial nerve expectedly rises. Recurrent tumors are frequently multinodular. Recurrence can be attributed to either inadequate margins, or in the case of Warthin tumor, to its multicentricity.

Treatment

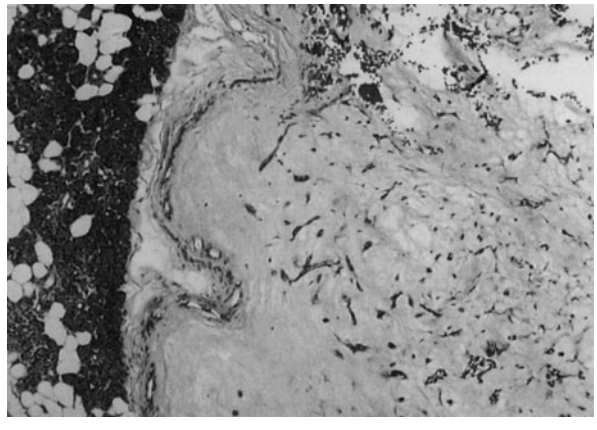
Complete surgical excision with uninvolved margins is the recommended treatment of benign tumors of the salivary glands. Usually, a superficial parotidectomy with preservation of the facial nerve is adequate unless there is deep lobe involvement. Parapharyngeal space tumors require resection through a form of transcervical approach. Enucleation alone is inadequate for tumors of the parotid gland; a complete submandibular excision, with preservation of the marginal mandibular, lingual, and hypoglossal nerves, is the treatment of choice. Radiation is not indicated in the treatment of benign salivary tumors.

Prognosis

With the complete removal of the tumor and excision of the affected gland, the prognosis is excellent. Malignant transformation and recurrences are rare.

PLEOMORPHIC ADENOMAS

Pleomorphic adenomas, or **benign mixed tumors**, are the most common neoplasms of the salivary glands (Figure 18–2). They represent approximately 60–70% of all parotid tumors and 90% of submandibular benign tumors. These neoplasms affect females more than males and are commonly seen in the third to sixth decades of life. When the deep parotid lobe is involved, a pleomorphic adenoma can present as a parapharyngeal space tumor with soft palate swelling. It presents as an isolated swelling or mass in the submandibu-



▲ **Figure 18–2.** Pleomorphic adenoma. (Image contributed by Christina Kong, MD, Standford University School of Medicine, Standford, CA.)

lar gland with little associated pain. There are no known etiologic factors.

Histologically, pleomorphic adenomas arise from the distal portions of the salivary ducts, including the intercalated ducts and acini. The mixture of epithelial, myoepithelial, and stromal elements is represented by the name, benign mixed tumor. Any of these individual components may predominate in the histology, but all three must be present to confirm the diagnosis. Both immunohistochemical stains specific for myoepithelial cells and epithelial cells can help to distinguish pleomorphic adenoma.

The differential diagnoses for pleomorphic adenomas should include malignant neoplasms: adenoid cystic carcinoma, polymorphous low-grade adenocarcinoma, deep-seated adnexal neoplasms, and mesenchymal neoplasms. Rare complications of pleomorphic adenoma include malignant transformation into a tumor known as carcinoma expleomorphic adenoma, or alternately, "benign" metastasizing mixed tumors. The word "benign" describes solely the histology, but not the pathologic behavior of this rare entity.

Although radiation is not indicated in the treatment of benign salivary tumors, it has been used occasionally to control recurrent pleomorphic adenomas. Complete surgical excision of the tumor with uninvolved margins is the recommended treatment. For example, a superficial parotidectomy with clear margins is the treatment of a pleomorphic adenoma located in the superficial lobe of the parotid gland. The prognosis for pleomorphic adenomas is excellent, with a 95% rate of nonrecurrence.

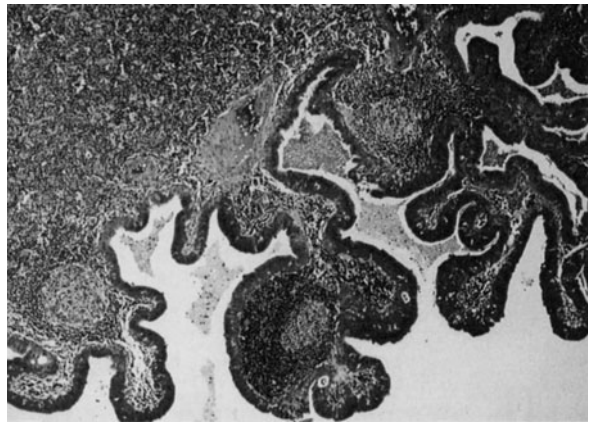
Lingam RK, Daghir A, Nigar E, et al. Pleomorphic adenoma (benign mixed tumour) of the salivary glands: its diverse clinical, radiological, and histopathological presentation. *Br J Oral Maxillofac Surg* 2009 Nov. 17 [Epub 2011 Jan; 49(1):14–20]. [PMID: 19926180].

WARTHIN TUMOR

Warthin tumor is also known as **papillary cystadenoma lymphomatosum** and is found almost exclusively in the parotid gland (Figure 18–3). It is characterized histologically by papillary structures composed of double layers of granular eosinophilic cells or oncocytes, cystic changes, and mature lymphocytic infiltration. It arises from the ectopic ductal epithelium. It represents approximately 5% of all salivary gland tumors and approximately 12% of benign tumors of the parotid gland. This tumor is more commonly seen in males in the fifth to seventh decades of life and there is an associated risk with smokers.

There is approximately 5.0–7.5% bilaterality and 14% multicentricity in Warthin tumor. CT scanning may demonstrate a well-defined mass in the posteroinferior segment of the superficial lobe of the parotid. If radiosialography is performed, increased activity is seen related to the presence of oncocytes and their increased mitochondrial content.

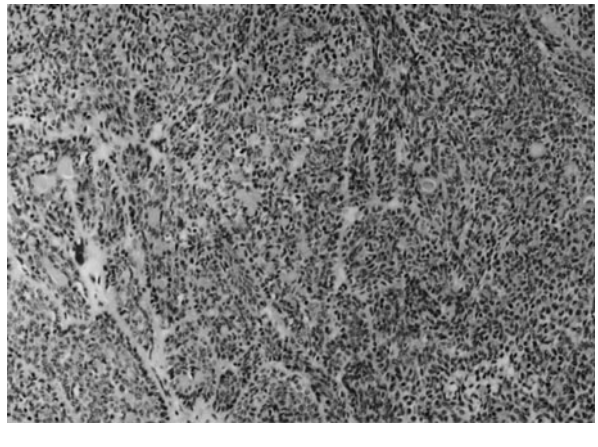
The diagnosis of Warthin tumor is easily arrived at based on histologic findings, with rare confusion with other tumors. The treatment requires complete excision of the affected portion of the gland with uninvolved margins.



▲ **Figure 18–3.** Warthin tumor. (Image contributed by Christina Kong, MD, Stanford University School of Medicine, Stanford, CA.)

MONOMORPHIC ADENOMAS

These slow-growing tumors represent less than 5% of all salivary gland tumors (Figure 18–4). Monomorphic adenomas differ from pleomorphic adenomas, in that they consist of only one morphologic cell type. Monomorphic adenomas are subclassified into a group of mostly epithelial and myoepithelial neoplasms that include basal cell adenomas, canalicular adenomas, oncocytomas or oxyphilic adenomas, and myoepitheliomas.



▲ **Figure 18–4.** Monomorphic adenoma. (Image contributed by Christina Kong, Stanford University School of Medicine, Stanford, CA.)

1. Basal Cell Adenomas

Basal cell adenomas account for 2% of all epithelial salivary gland neoplasms. Histologic types include tubular, trabecular, cylindroma, and solid; the latter is the most common variant. Basal cell adenomas occur equally between males and females and usually between the fourth and the ninth decades of life. The parotid gland is the most common site involved.

A basal cell adenoma must be differentiated from adenoid cystic carcinoma, basal cell adenocarcinoma, and ameloblastoma.

2. Canalicular Adenomas

The canalicular adenoma is a benign neoplasm that affects the minor salivary glands. This tumor used to be a subtype of the basal cell adenoma; however, it is now recognized as a separate entity based on histologic features. It must also be differentiated from adenocarcinoma. The canalicular adenoma tends to be multifocal and often occurs in the upper lip mucosa, especially in the elderly. Complete intraoral excision is curative, although the multifocality of the disease can predispose to recurrence if all foci are not addressed.

3. Oncocytomas

These benign tumors are composed of large polyhedron-shaped epithelial cells, known as oncocytes, packed with granular eosinophilic cytoplasm and mitochondria. The cytoarchitecture of these tumors is best visualized with electron microscopy.

Oncocytomas account for < 1% of all salivary gland neoplasms. There is no gender predilection and they occur in the sixth to eighth decades of life. There remains debate on the pathogenesis of these tumors and whether they are true neoplasms; oncocytomas may result from a hyperplastic process, a metaplastic process, or both.

The parotid gland is the most common site of an oncocytoma, followed by the submandibular gland. In these sites, this tumor presents as a painless, slow-growing mass that is often solid and occasionally cystic. The swelling of the parotid gland may be diffuse with approximately 7% bilaterality. Multiple tumors have also been reported. Owing to the high mitochondrial content of the cells, radiosialography can demonstrate high uptake of technetium-99m.

The oncocytoma is easily distinguished from Warthin tumor and pleomorphic adenoma. However, it must also be considered separately from the mucoepidermoid carcinoma, acinic cell adenocarcinoma, adenoid cystic carcinoma, clear cell carcinoma, and metastatic renal cell or thyroid carcinoma. Surgical excision with uninvolved margins is the recommended treatment; oncocytomas are radioresistant.

4. Myoepitheliomas

This subtype of monomorphic adenomas accounts for less than 1% of all salivary gland neoplasms. It consists almost exclusively of myoepithelial cells. There is no gender predilection; and myoepitheliomas are commonly seen in the third to sixth decades of life. The tumor occurs in the parotid gland 40% of the time.

Histologically, myoepitheliomas are well encapsulated. There are spindle cell and plasmacytoid cell types. The differential diagnoses include mixed tumor, schwannoma, leiomyoma, plasmacytoma, spindle cell carcinoma, and fibrous histiocytoma.

GRANULAR CELL TUMORS

The granular cell tumor is benign with malignant potential and is most commonly associated with the minor salivary glands. This tumor tends to occur in the oral cavity and is well circumscribed, mobile, and painless. Fine-needle aspiration can demonstrate a neoplastic process. A histopathologic examination shows polygonal cells with abundant eosinophilic granular cytoplasm and mildly pleomorphic nuclei that are round to oval-shaped. Because of its malignant potential, a combination of wide local excision and close observation is the most effective treatment.

Hughes JH, Volk EE, Seethala RR, LiVolsi VA, Baloch ZW. Relative accuracy of fine-needle aspiration and frozen section in the diagnosis of lesions of the parotid gland. *Head Neck* 2005;27(3):217 [PMID: 15672359].

Wilbur DC. Pitfalls in salivary gland fine-needle aspiration cytology. *Arch Pathol Lab Med* 2005;129(1):26 [PMID: 15628905].

Reddy V, Thangarajah T, Castellanos-Arango F, et al. Conservative management of Warthin tumour. *J Otolaryngol Head Neck Surg* 2008 Oct;37(50):744–749 [PMID: 19128687].

Zhou CX, Gao Y. Oncocytoma of the salivary glands: a clinicopathologic and immunohistochemical study. *Oral Oncol* 2009 Dec;45(12):e232—e238 [PMID: 19796983].

PARAPHARYNGEAL SPACE TUMORS

Parapharyngeal space tumors comprise 0.5% of all head and neck neoplasms. Most tumors found in the parapharyngeal space are benign. Between 40 and 50% of these tumors originate from the salivary glands. Of these, 80% are pleomorphic adenomas that arise from the deep lobe of the parotid gland. A more detailed discussion is presented in the chapter on parapharyngeal space neoplasms.

Mendelsohn AH, Bhuta S, Calcaterra TC, et al. Parapharyngeal space pleomorphic adenoma: A 30-year review. *Laryngoscope* 2009 Nov;119(11):2170–2174 [PMID: 19824044].

HEMANGIOMAS

General Considerations

Although not of glandular origin, hemangiomas are significant in the differential diagnosis of a parotid mass, especially in chil-

dren. These benign tumors are of endothelial cell origin and represent less than 5% of all salivary gland tumors. In children, the capillary hemangioma is the most common salivary gland tumor, accounting for more than 90% of parotid gland tumors in children less than 1 year of age. It affects females more than males and almost exclusively occurs in the parotid gland.

Clinical Findings

A hemangioma usually presents at birth as a unilateral, painless mass. It has a rapid, proliferative growth that often causes cosmetic deformity. Fine-needle aspiration is usually not necessary. CT scanning, MRI, or both may demonstrate the vascularity of the lesion. The differential diagnosis includes other vascular proliferative disorders such as lymphangioma and cavernous hemangioma.

Treatment

The possibility of spontaneous regression exists and therefore surgical excision may be delayed. However, if there is significant cosmetic or functional compromise, complete excision via parotidectomy with facial nerve preservation may be indicated. A caveat in children is the more superficial location of the facial nerve than that seen in adults, which is important to consider during intraoperative identification of the nerve. Malignant transformation has not been described.

Greene A, Rogers G, Mulliken J. Management of parotid hemangioma in 100 children. *Plast Reconstr Surg* 2004 Jan;113(1): 53–60 [PMID: 14707622].

Mehta D, Willging JP. Pediatric salivary gland lesions. *Sem Pediatr Surg* 2006 May;15(2):76–84 [PMID:16616310].

Malignant Diseases of the Salivary Glands

19

Adriane P. Concus, MD & Theresa N. Tran, MD

General Considerations

Malignant salivary gland neoplasms represent 3–4% of head and neck malignancies and <0.5% of all cancers diagnosed yearly in the United States, with an incidence of only 1–2 per 100,000 individuals. Unlike the more common mucosal head and neck cancers, which, in general, are attributed to excessive tobacco and alcohol use, specific carcinogenic factors for malignant salivary gland growths have not been as clearly identified. Viral infections, radiation, environmental exposure, and genetic factors have been hypothesized as causes. Malignant salivary gland tumors are classified by the World Health Organization as carcinomas, nonepithelial tumors, lymphomas, metastatic or secondary tumors, and unclassified tumors (Table 19–1).

Only 20–25% of parotid gland neoplasms, approximately 45–50% of submandibular gland neoplasms, and > 70% of sublingual and minor salivary gland neoplasms are malignant. However, because 75–80% of salivary gland neoplasms are located in the parotid gland, this gland is still the most common salivary gland to be affected with a malignant neoplasm; a ratio of 40:10:1 is cited for malignant tumors of the parotid, submandibular, and sublingual glands, respectively.

Table 19–2 shows the histologic types of malignant salivary gland disease in order of frequency. The disease site also is important for predicting the histology. Mucoepidermoid carcinoma is most common in the parotid gland. Approximately half of malignant submandibular gland neoplasms are adenoid cystic carcinomas. Minor salivary gland malignant neoplasms are most often adenoid cystic carcinomas and adenocarcinomas. Prognosis varies according to histologic type, stage, and primary site.

Anatomy

The salivary gland unit is depicted in Figure 19–1. The acinus is located at the distal end of a salivary unit. It consists of pyramidal saliva-forming cells arranged around a central lumen, with myoepithelial cells interposed between the basal side of these cells and the basement membrane. Acinar cells may be serous, mucinous, or seromucinous, which explains the different chemical compositions of the saliva of each gland.

Serous cells predominate in the parotid glands. The submandibular glands have mixed populations of serous and mucinous acinar cells. The sublingual glands have mixed populations of mucinous and seromucinous cells. The minor salivary glands have mostly seromucinous cells. The acinus empties into an intercalated duct, composed of cuboidal cells similarly lined by myoepithelial cells between the basal side and the basal lamina. Intercalated ducts empty into striated ducts composed of columnar cells with fine striations. Lastly, the striated ducts empty into excretory ducts, which are composed of two layers of epithelial cells ranging in shape from cuboidal to squamous. Undifferentiated reserve cells associated with the intercalated ducts differentiate into acinar cells, intercalated duct cells, striated duct cells, and myoepithelial cells. Reserve cells associated with the excretory ducts give rise to excretory duct columnar and squamous cells.

Histologically, the salivary glands are arranged into lobules separated by connective tissue septa and encased in a connective tissue capsule; the salivary unit ducts converge in a treelike fashion into a central draining duct. Salivary gland lobules are made up of the acini, intercalated ducts, and small striated ducts. Larger striated ducts and excretory ducts are located within the connective tissue septa.

The major salivary glands are the paired parotid, submandibular, and sublingual glands. In addition, 600–1000 minor salivary glands are distributed throughout the rest of the upper aerodigestive tract.

The parotid gland is located anteroinferior to the ear, overlying the mandibular ramus and masseter muscle, extending medially between the mandibular ramus and the temporal bone to occupy the parapharyngeal space. The facial nerve travels through the substance of the parotid gland, dividing the gland into superficial and deep lobes, though this distinction is a convenience of surgical dissection and does

Table 19–1. World Health Organization Classification of Salivary Gland Malignant Neoplasms.

Carcinomas
Mucoepidermoid carcinoma
Adenoid cystic carcinoma
Acinic cell carcinoma
Malignant mixed tumor
Carcinoma in pleomorphic adenoma
Carcinosarcoma
Polymorphous low-grade adenocarcinoma (terminal duct adenocarcinoma)
Epithelial-myoepithelial carcinoma
Salivary duct carcinoma
Basal cell carcinoma
Mucinous adenocarcinoma
Papillary cystadenocarcinoma
Adenocarcinoma, not otherwise specified (NOS)
Clear cell carcinoma
Sebaceous carcinoma and lymphadenocarcinoma
Oncocytic carcinoma
Malignant myoepithelioma (myoepithelial carcinoma)
Squamous cell carcinoma
Adenosquamous carcinoma
Lymphoepithelial carcinoma
Small cell carcinoma
Undifferentiated carcinoma
Other carcinomas
Other Tumors
Sarcoma
Malignant Lymphomas
Secondary Tumors
Melanoma
Squamous cell carcinoma
Renal cell carcinoma
Thyroid carcinoma
Unclassified Tumors

Data from Seifert G, Sobin LH: Histological typing of salivary gland tumours. In: *World Health Organization International Histological Classification of Tumours,* 2nd ed. New York: Springer-Verlag, 1991.

Table 19–2. Frequency of Salivary Gland Malignant Neoplasm by Histologic Type.

Histologic Type	Frequency of Occurrence (%)
Mucoepidermoid carcinoma	34
Adenoid cystic carcinoma	22
Adenocarcinoma	18
Malignant mixed tumor	13
Acinic cell carcinoma	7
Squamous cell carcinoma	4
Other	<3

Data from Spiro RH. Salivary neoplasms: overview of a 35-year experience with 2,807 patients. *Head Neck Surg* 1986;8:177.

not reflect an embryologic fusion plane or separate fascial layer. Malignant involvement of the facial nerve can result in facial weakness or paralysis and can provide an avenue for the intracranial extension of tumor. In addition, the facial nerve is at risk for injury during parotid surgery. The lymphatic drainage of the parotid gland is to both intraparotid and periparotid lymph nodes, and locally and regionally to the submandibular and deep jugular chain of nodes (levels I and II).

The submandibular glands are located in the submandibular triangle along with lymph nodes and branches of the facial artery and facial vein. The lingual, hypoglossal, and marginal mandibular nerves are all intimately associated with the submandibular gland. As with malignant disorders of the facial nerve and parotid gland, these nerves can be invaded by the cancer, resulting in paresis, paralysis, or numbness, as well as the intracranial extension of tumor. These nerves also are at risk for injury at the time of surgery. Submandibular gland lymphatics drain to the submandibular and deep jugular chain of nodes.

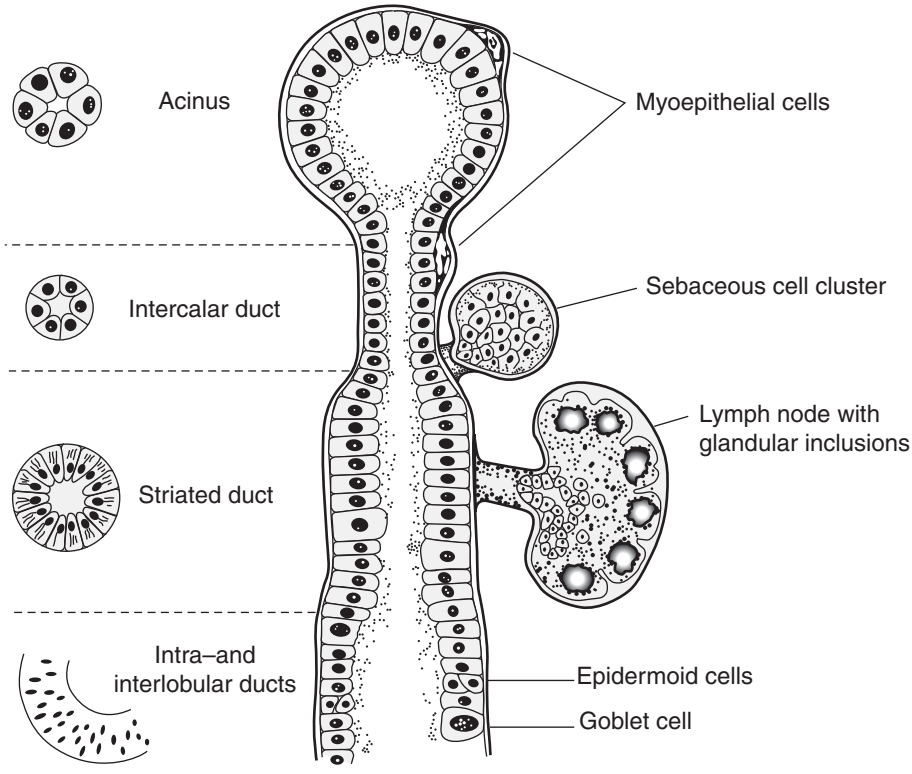
The sublingual glands are located deep in the anterior floor of mouth mucosa, adjacent to the submandibular glands. The sublingual gland lymphatics also drain to the submandibular and to the jugular chain of nodes.

Most of the minor salivary glands are located in the oral cavity and oropharynx, but minor salivary glands are distributed throughout the upper aerodigestive tract. The lymphatic drainage of the minor salivary glands is according to the lymphatic drainage of the anatomic location.

Pathogenesis

The **Reserve Cell Theory** (currently favored) of salivary gland neoplasia states that salivary neoplasms arise from reserve (or stem) cells of the salivary duct system. The type of neoplasm depends on the stage of differentiation of the reserve cell at the time at which the neoplastic transformation occurs; it also depends on the type of reserve cell. The intercalated duct reserve cells give rise to adenoid cystic and acinic cell carcinoma. The excretory duct reserve cells give rise to mucoepidermoid, squamous cell, and salivary duct carcinoma.

The **Multicellular Theory** of salivary gland neoplasia states that salivary neoplasms arise from differentiated cells along the salivary gland unit. For example, squamous cell carcinoma arises from the excretory duct epithelium and acinic cell carcinoma arises from the acinar cells.



▲ **Figure 19–1.** The salivary gland unit. (Adapted, with permission, from Thawley SE, Panje WR, Batsakis JG, Lindberg RD. *Comprehensive Management of Head and Neck Tumors.* Philadelphia: WB Saunders, 1999.)

Batsakis JG, Regezi JA, Luna MA et al. Histogenesis of salivary gland neoplasms: a postulate with prognostic implications. *J Laryngol Otol* 1989;103:939 [PMID: 2685148]. (Classic article proposing the Reserve (Stem) Cell Theory of salivary gland histogenesis.)

Saku T, Hayashi Y, Takahara O et al. Salivary gland tumors among atomic bomb survivors, 1950–1987. *Cancer* 1997;79(8): 1465 [PMID: 9118025]. (A look at Hiroshima and Nagasaki atomic bomb survivors and salivary gland neoplasms, supporting a role for ionizing radiation in salivary gland tumorigenesis.)

Staging

Table 19–3 lists the American Joint Committee on Cancer (AJCC) 2010 TNM (tumor, node, metastasis) Staging system used for malignant disorders of the major salivary glands. Malignant diseases of the minor salivary glands are staged according to the staging system for the primary site (oral cavity, pharynx, larynx, nasal cavity, and paranasal sinuses). T4 tumors are divided into moderately advanced (T4a) and very advanced (T4b) tumors, and, accordingly, Stage IV is divided into IVA, IVB, and IVC (distant metastases present).

American Joint Committee on Cancer. Greene FL, Page DL, Fleming ID, Fritz AG, Balch CM, Haller DG, eds. *AJCC Cancer Staging Manual*, 6th ed. New York: Springer-Verlag, 2002. (The definitive reference for the currently used American Joint Committee on Cancer staging system.)

Clinical Findings

A. Symptoms and Signs

Patients with malignant disease of the salivary glands most often present with an incidentally noted mass. Pain, facial nerve palsy (although lingual and hypoglossal nerves can be affected by submandibular and sublingual tumors), and cervical adenopathy portend locally advanced disease and a poor prognosis. In the parotid gland, the superficial lobe refers to the parotid tissue lateral to the facial nerve and encompasses about two thirds of the gland parenchyma; the deep lobe refers to that which is medial, although there is no embryologic fascial plane between these two locations. Parotid gland tumors involving the deep lobe can have parapharyngeal space extension and present as a symptomatic or asymptomatic (usual) oropharyngeal mass with no palpable external abnormality. In the submandibular triangle, it can be difficult to distinguish

Table 19–3. T (tumor), N (nodes), M (metastases) Staging for Major Salivary Gland (Parotid, Submandibular, Sublingual) Malignant Neoplasms, 2010 Revision.

Stage	T	N	M
I	T_1	N_0	M_0
II	T_2	N_0	M_0
III	T_3	N_0	M_0
	T_{1-3}	N_1	M_0
IVA	T_{1-3}	N_2	M_0
	T_{4a}	N_{0-2}	M_0
IVB	T_{4b}	Any N	M_0
	Any T	N_3	M_0
IVC	Any T	Any N	M_1
T_X	Primary tumor cannot be assessed		
T_0	No evidence of primary tumor		
T_1	Tumor ≤2 cm, no extraparenchymal extension		
T_2	Tumor >2 cm, ≤4 cm, no extraparenchymal extension		
T_3	Tumor >4 cm or extraparenchymal extension (or both)		
T_{4a}	Tumor invades skin, mandible, ear canal, facial nerve, or any of these structures		
T_{4b}	Tumor invades skull base or pterygoid plates, or encases carotid artery		
N_X	Regional lymph node cannot be assessed		
N_0	No cervical lymph node metastasis		
N_1	Single ipsilateral lymph node <3 cm		
N_{2a}	Single ipsilateral lymph node metastases >3 cm ≤6 cm		
N_{2b}	Multiple ipsilateral lymph node metastases, each ≤6 cm		
N_{2c}	Bilateral or contralateral lymph node metastases, each ≤6 cm		
N_3	Single or multiple lymph node metastases >6 cm		
M_X	Distant metastasis cannot be assessed		
M_0	No distant metastasis		
M_1	Distant metastasis present		

between a mass in the submandibular gland itself and an enlarged submandibular lymph node. Malignant disease of the minor salivary glands is often submucosal and can be located anywhere throughout the upper aerodigestive tract.

B. Laboratory Findings

Fine-needle aspiration (FNA) biopsy of major salivary gland and neck masses is easily performed in the office. For malignant salivary gland neoplasms, FNA is 80–90% sensitive. Because the usual recommendation is for surgical removal of a salivary gland with any neoplasm, the cost-effectiveness of routinely performing FNA for salivary neoplasms is a matter of current debate.

C. Imaging Studies

Computed tomography (CT) scanning and magnetic resonance imaging (MRI) are both effective modalities for imaging the size and the local and regional extension of malignant salivary gland growths, as well as highlighting potentially malignant cervical nodes. CT and MRI give more detailed information and are therefore preferred to ultrasound, which is also useful in identifying salivary gland masses as well as in distinguishing between solid and cystic masses. Positron emission tomography (PET) scanning is of use in evaluating metastatic or unknown primary site disease. Other nuclear medicine imaging that has been used for the salivary glands includes technetium radioisotope scanning, although this is more useful for benign Warthin tumors.

Batsakis JG, Sneige N, El-Naggar AK. Fine-needle aspiration of salivary glands: its utility and tissue effects. *Ann Otol Rhinol Laryngol* 1992;101:185 [PMID: 1739267]. (A look at the use of FNA biopsy in salivary gland neoplasms.)

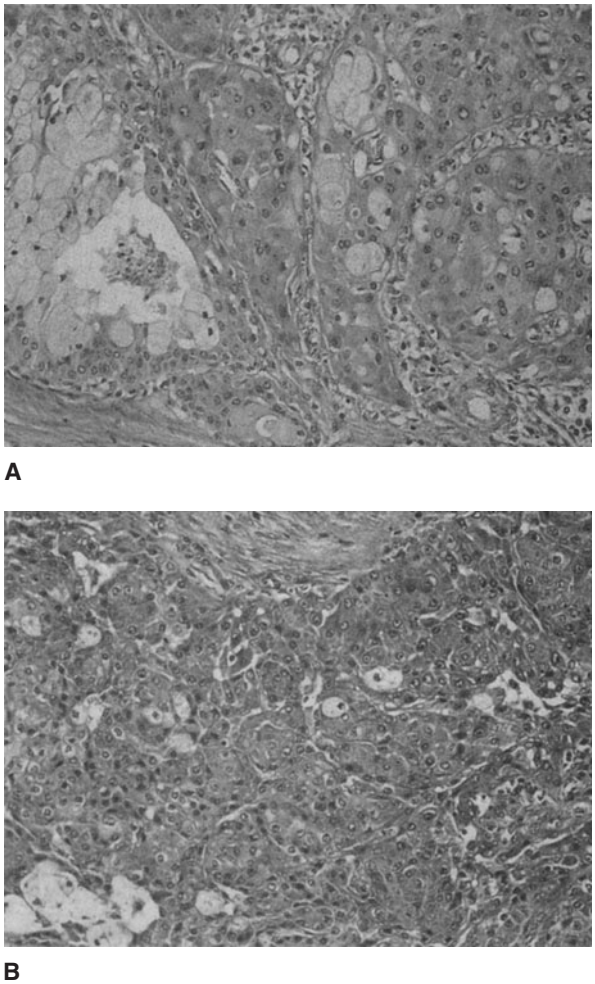
Histologic Types

The classification of malignant salivary gland neoplasms and the relative incidence by histologic type has been listed in Tables 19–1 and 19–2. Malignant salivary gland disorders are further divided into low-grade, intermediate-grade, and high-grade histology based on clinical behavior and prognosis (Table 19–4). Below are descriptions of the more common histologic types.

Table 19–4. Grade Classification of Salivary Gland Malignant Neoplasms.

Low Grade
Low-grade mucoepidermoid carcinoma
Low-grade adenocarcinoma
Low-grade squamous cell carcinoma
Acinic cell carcinoma
Polymorphous low-grade adenocarcinoma
Basal cell carcinoma
Intermediate Grade
Intermediate-grade mucoepidermoid carcinoma
Intermediate-grade adenocarcinoma
Intermediate-grade squamous cell carcinoma
Adenoid cystic carcinoma
Epithelial-myoepithelial carcinoma
Oncocytic carcinoma
Myoepithelial carcinoma
Carcinoma in pleomorphic adenoma
Salivary duct carcinoma
High Grade
High-grade mucoepidermoid carcinoma
High-grade adenocarcinoma
High-grade squamous cell carcinoma
Carcinosarcoma
Undifferentiated carcinoma

Data from Therkildsen MH, Christensen M, Andersen LJ et al. Salivary gland carcinomas prognostic factors. *Acta Oncol* 1998;37:701.



▲ **Figure 19–2.** Mucoepidermoid carcinoma. **(A)** Low grade, **(B)** intermediate grade, and **(C)** high grade. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

A. Mucoepidermoid Carcinoma

Mucoepidermoid carcinoma is the most common type of malignant salivary gland disorder. Eighty to ninety percent of mucoepidermoid carcinoma occurs in the parotid gland. Its prevalence is highest in the fifth decade of life, with a female preponderance as high as 4:1. Histologically, mucoepidermoid carcinomas are characterized by a mixed population of cells: mucin-producing cells, epithelial cells, and intermediate cells (Figure 19–2). The intermediate cells are believed to be the progenitor of the other two types of cells. No myoepithelial cells are present.

Mucoepidermoid carcinomas are classified as low, intermediate, and high grade based on clinical behavior and tumor differentiation. Clinical aggressiveness, local invasion, and lymph node metastases are all greater, and the prognosis is worst for high-grade tumors. Histologically, low-grade mucoepidermoid carcinomas are well circumscribed, with pushing margins and dilated cystic areas containing mucinous material. The cystic structures are lined by mucin-producing, intermediate, or epidermoid cells. As the grade escalates, the tumors become more infiltrative and poorly circumscribed. Cystic formations seen in low-grade tumors are lost. Nests of tumor become more solid and irregular with intermediate or epidermoid cells dominating. High-grade mucoepidermoid carcinomas are characterized by the invasion of adjacent normal structures, atypical mitoses, perineural invasion, and lymph node metastases. High-grade mucoepidermoid carcinoma is distinguished from squamous cell carcinoma by the presence of intracellular mucin.

The 5-year survival rate for low-grade mucoepidermoid carcinomas is 70%, whereas for high grade it is only 47%. The 15-year disease-free survival rate is approximately 50% for low-grade mucoepidermoid carcinoma and 25% for intermediate- and high-grade tumors.

B. Adenoid Cystic Carcinoma

Ten percent of salivary gland neoplasms are adenoid cystic carcinoma. More than two thirds of them arise from the minor salivary glands. Adenoid cystic carcinoma is the most common type of malignant disorder to arise in the submandibular, the sublingual, and the minor salivary glands. It occurs with equal frequency in men and women and most often presents as an otherwise asymptomatic mass.

Adenoid cystic carcinoma is usually partially or nonencapsulated and infiltrates the surrounding normal tissue. There is basaloid epithelium clustered in nests in a hyaline stroma. The most common histologic subtype (44%) is the cribriform type, characterized by a "Swiss cheese" pattern of vacuolated areas (Figure 19–3A). The prognosis for the cribriform subtype is intermediate. The tubular subtype (35%) carries the best prognosis and is characterized by cords and nests of malignant cells (Figure 19–3B). The solid subtype (21%) has the worst prognosis and is characterized by solid sheets of adenoid malignant cells (Figure 19–3C).

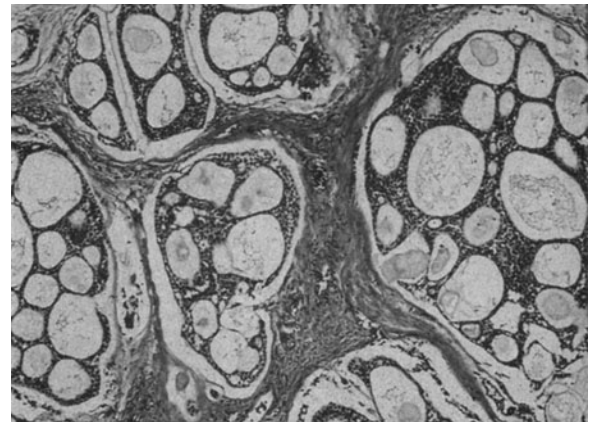
Adenoid cystic carcinomas are unique among salivary gland tumors because of their indolent and protracted clinical course. Perineural spread, including "skip lesions" or discontinuous areas of spread along a nerve, occurs commonly (up to 80% of cases). For this reason, adjuvant radiation that includes the anatomic course of the regional named nerves is often recommended. Lymphatic spread is uncommon, and consequently neck dissection or wide-field radiation to regional lymphatics is rarely recommended. Distant metastases can occur up to 20 years after the initial diagnosis; disease-specific survival continues to decline for more than 20 years after the initial treatment. Prognostic factors for adenoid cystic carcinoma include site of origin, TNM staging, local spread, nodal status, distant metastasis, and recurrence. The survival rate among patients with adenoid cystic carcinomas arising from the parotid gland is higher than that for patients with similar tumors arising from the minor salivary glands.

C. Acinic Cell Carcinoma

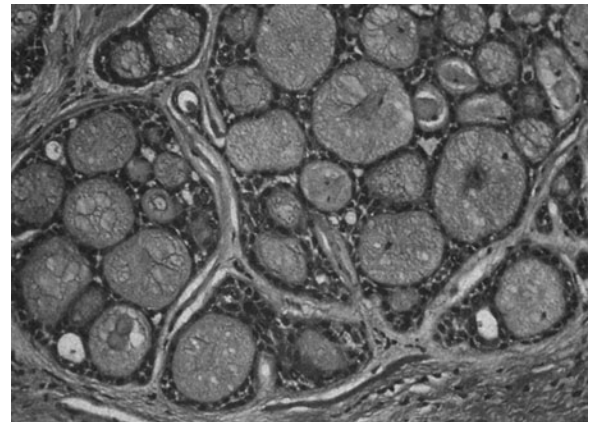
Acinic cell carcinoma represents 15% of malignant parotid gland neoplasms. Eighty to ninety percent occur in the parotid gland, and most of the remaining occur in the submandibular gland. Acinic cell carcinoma occurs most often in the fifth decade of life and in women more often than in men.

Acinic cell carcinomas are typically encased in a fibrous capsule. Histologically, there are two cell types: (1) serous acinar cells (explaining the predilection for the parotid gland) and (2) cells with clear cytoplasm (Figure 19–4). There are four histologic patterns: solid, microcystic, papillary, and follicular.

Acinic cell carcinomas are low-grade malignancies. The overall survival rate at 5, 10, and 15 years is 78%, 63%, and 44%, respectively.



A



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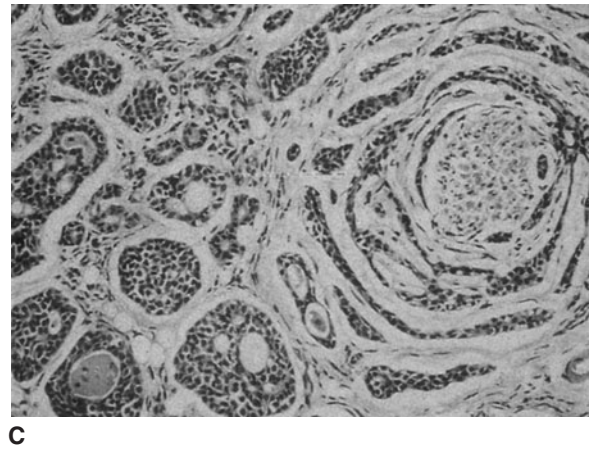
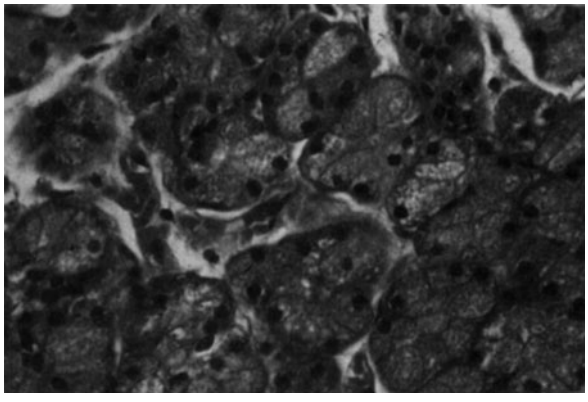


C

▲ **Figure 19–3.** Adenoid cystic carcinoma. **(A)** Cribriform pattern, **(B)** cribriform and tubular growth pattern, and **(C)** solid subtype. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)



▲ **Figure 19–4.** Acinic cell carcinoma. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

D. Malignant Mixed Tumors

Malignant mixed tumors represent 3–12% of malignant salivary gland disorders. They arise in benign mixed tumors (pleomorphic adenomas). Microscopically, there may be one small malignant growth within a benign mixed tumor, or the benign tumor may be essentially replaced by the malignant lesion with destructive infiltrative growth.

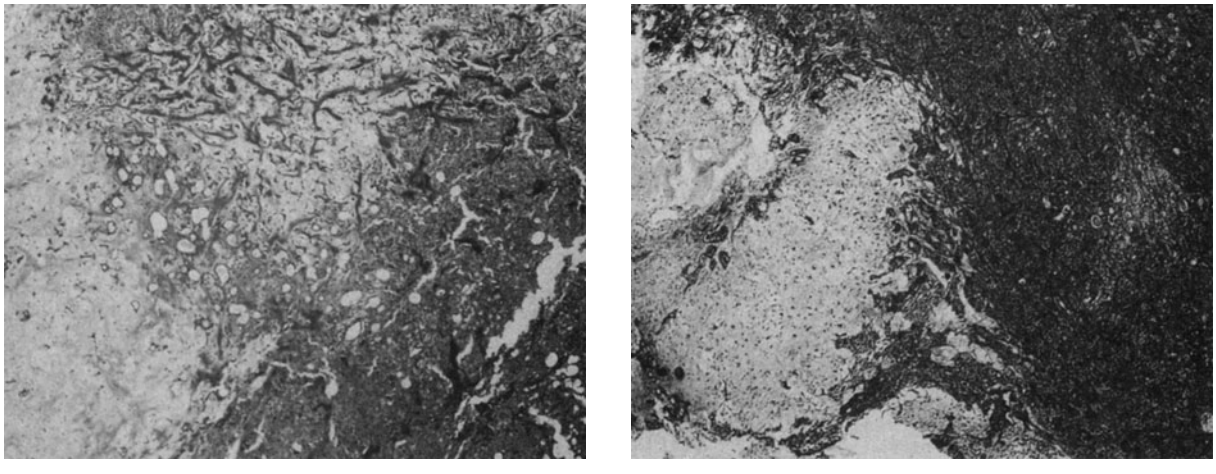
Carcinoma ex-pleomorphic adenoma is the most common malignant mixed tumor variant (Figure 19–5A); 75% occur in the parotid gland. Histologically, there is a mixture of epithelial and mesenchymal cells, but the distinguishing feature is that the malignant component is purely epithelial. The malignant part may have features of an adenocarcinoma, a squamous cell carcinoma, an undifferentiated carcinoma, or some other form of a malignant epithelial disorder. Carcinoma ex-pleomorphic adenomas are nodular or cystic with minimal encapsulation. Unlike pleomorphic adenomas, they typically have areas of necrosis and hemorrhage.

A true malignant mixed tumor, also called carcinosarcoma, is very rare (Figure 19–5B). It has epithelial and mesenchymal malignant elements both in the primary site and nodal metastases.

Malignant mixed tumors are classified as high grade. If treated before they become invasive, the prognosis is good. However, invasion and locoregional and distant metastases are common. Surgery with adjuvant radiation is the preferred treatment. Nonetheless, the 5-year survival rate is <10%.

E. Adenocarcinoma

Adenocarcinomas of the major salivary glands originate from excretory or striated ducts. In its most differentiated form, the glandular cytoarchitecture is maintained. The growth pattern can be solid or cystic, papillary or nonpapillary, with or without mucin production, and can range from low grade to high grade in histology and clinical course. With newer refinements in special staining and classification systems, many malignant disorders formerly categorized as adenocarcinomas have defined their own categories, including polymorphous low-grade adenocarcinoma, epithelial-myoepithelial carcinoma, and salivary duct carcinoma. Adenocarcinomas of the salivary glands not fitting into one of the more specific classifications are called *adenocarcinoma NOS* (not otherwise specified). Clinically, poor prognostic



A **B**

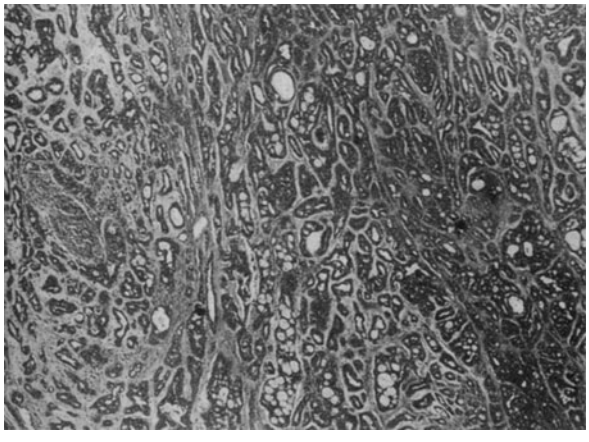
▲ **Figure 19–5.** Malignant mixed tumors. **(A)** Carcinoma ex-pleomorphic adenoma and **(B)** carcinosarcoma. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

indicators for adenocarcinomas include advanced stage, infiltrative growth pattern, and abnormal DNA content.

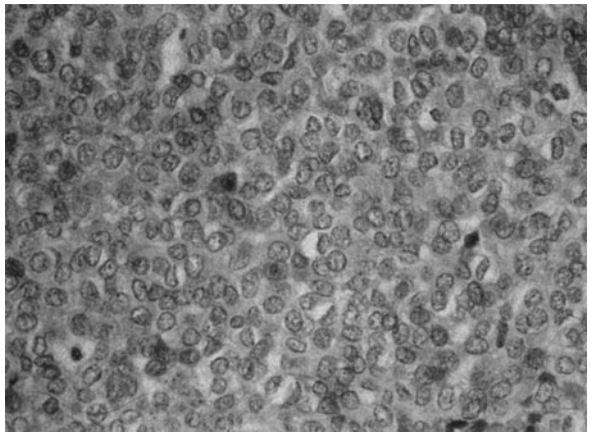
F. Polymorphous Low-Grade Adenocarcinoma

Polymorphous low-grade adenocarcinoma is also termed terminal duct carcinoma or lobular carcinoma and is the second most common malignant disorder of the minor salivary glands. Fifty percent of polymorphous low-grade adenocarcinomas occur in the palate. Women are affected more often than men, typically in the sixth decade.

Polymorphous low-grade adenocarcinoma most often presents as a painless, submucosal mass. There is cytologic uniformity of myoepithelial or luminal ductal cells within one tumor, but histologic diversity of the cells between tumors (Figure 19–6). Patterns of growth include tubular, papillary, glandular, and solid. Despite infiltrative growth and perineural invasion, the clinical course is typically indolent, with <10% having lymph node metastases.

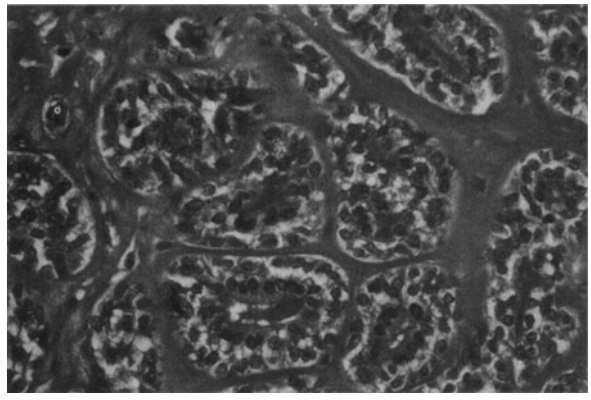


A



B

▲ **Figure 19–6.** Polymorphous low-grade adenocarcinoma. **(A)** Low power and **(B)** high power. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)



▲ **Figure 19–7.** Epithelial-myoepithelial carcinoma. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

G. Epithelial-Myoepithelial Cell Carcinoma

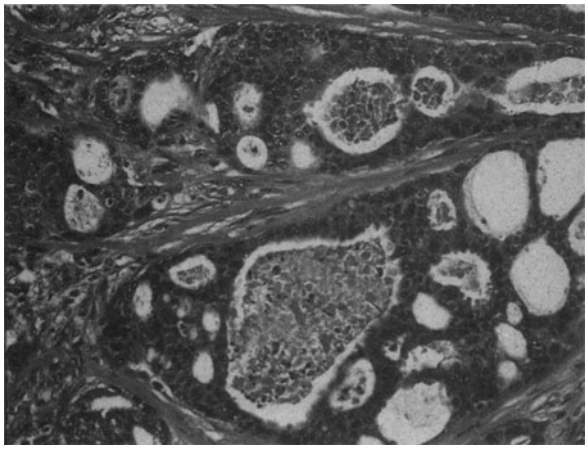
Epithelial-myoepithelial cell carcinoma represents less than 1% of salivary gland neoplasms. Most occur in the parotid gland. Histologically, there are malignant myoepithelial cells, with a minor (less than 5%) of ductal component (Figure 19–7). Cribriform, tubular, or solid patterns can be formed. These tumors may arise de novo, from a preexisting myoepithelioma, or as the carcinomatous component of a carcinoma ex-pleomorphic adenoma. Forty percent of patients experience local recurrence, 20% experience cervical metastases, and 40% die of disease.

H. Salivary Duct Adenocarcinoma

Salivary duct adenocarcinoma is named for its histologic resemblance to intraductal carcinoma of the breast (Figure 19–8). Unlike intraductal carcinoma of the breast, this disease occurs in men three times more frequently than in women. This malignant disorder arises from the excretory duct reserve cells and is a high-grade malignant disease process with a dismal prognosis. Thirty-five percent of patients have local recurrence; 62% develop distant metastases; 77% die of disease, with a mean survival of 3 years.

I. Clear Cell Carcinoma

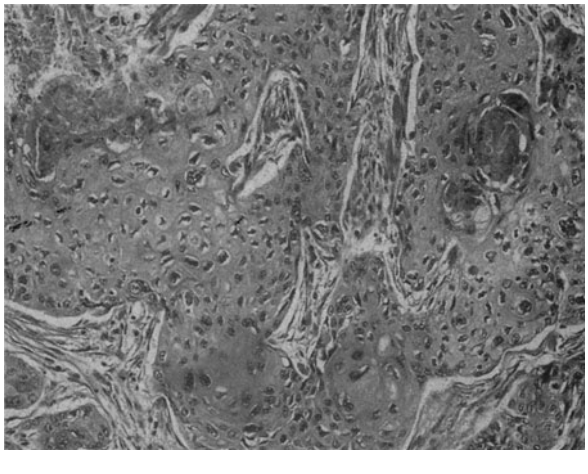
Clear cell carcinomas arise in the minor salivary glands, usually in the oral cavity. Histopathologically, trabeculae, cords, and nests of monomorphic clear cells are seen. They are glycogen-rich, but mucin-negative. This is a low-grade tumor.



▲ **Figure 19–8.** Salivary duct carcinoma. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

J. Squamous Cell Carcinoma

Squamous cell carcinoma (SCC) of the salivary gland is rare (Figure 19–9). Debate exists as to whether or not true primary SCC of the salivary glands exists. High-grade mucoepidermoid carcinoma must be excluded. The distinction is made with special immunohistochemical staining for mucin, which is positive in mucoepidermoid carcinoma but not in SCC. Metastases to the parotid gland or the direct extension of SCC from the overlying skin must also be considered. Most SCCs of the salivary glands present in advanced stage and >50% of the time have nodal metastases at diagnosis.



▲ **Figure 19–9.** Squamous cell carcinoma. (Reprinted, with permission, from Wenig BM. *Atlas of Head and Neck Pathology.* Philadelphia: WB Saunders, 1993.)

K. Lymphoma

Salivary gland lymphoma arises from intraglandular lymph nodes or from extranodal lymphoid tissue within the salivary glands. Patients are typically in their sixth or seventh decade. Ninety percent occur in the parotid gland. Five percent of extranodal lymphomas affect the salivary glands. The majority of salivary gland lymphomas are of B-cell lineage. Upon the diagnosis of a salivary gland lymphoma, a full-body evaluation for other involved sites is performed, as with a new diagnosis of lymphoma anywhere else in the body.

There is an association between Sjögren disease and salivary gland lymphoma, with the risk of developing a salivary gland lymphoma being 44 times higher in patients with Sjögren disease than in the general population. The prognosis for a lymphoma associated with Sjögren disease is worse than for salivary gland lymphoma not associated with this disease.

Some salivary gland lymphomas are immunohistochemically indistinguishable from low-grade lymphomas of the mucosa-associated lymphoid tissue (MALT) and are therefore termed salivary gland MALT lymphomas. Like the gastrointestinal tract MALT lymphomas, salivary gland MALT lymphoma is an indolent disease, and affected patients have a long survival.

L. Metastases to the Salivary Glands

Less than 10% of malignant salivary gland disorders are metastases from other sites. Most are lymphatic metastases to the parotid gland from skin cancers of the face, ear, or scalp. These are evenly divided between SCC and melanoma; the likelihood of metastasis depends on the stage/depth of the primary lesion. Hematogenous metastases to the salivary glands are rare, but have been reported from lung, kidney, breast, and thyroid cancers. The contiguous extension of cutaneous malignant disorders, as well as those of sarcomas arising from the facial soft tissues, is another mechanism for secondary malignant involvement of the salivary glands.

M. Malignant Salivary Gland Neoplasms in Children

Mucoepidermoid carcinoma is the most common malignant salivary gland neoplasm in children, followed by acinic cell carcinoma. Eighty-five percent of malignant salivary gland disorders in children occur in the parotid gland.

Khafif A et al. Adenoid cystic carcinoma of the salivary glands: a 20-year review with long-term follow-up. *Ear Nose Throat J* 2005;84(10):662,664 [PMID: 16382750]. (Review of an institution's experience and analysis of prognostic indicators in patients with adenoid cystic carcinoma.)

McHugh, JB et al. Update on selected salivary gland neoplasms. *Arch of Pathol Lab Med* 2009;133(11):1763–1774 [PMID: 19886710]. (Overview and update on four common salivary gland malignancies with focus on diagnostic features.)

Seifert G, Sobin LH. Histological typing of salivary gland tumours. In: *The World Health Organization Histological Classification of Tumours.* 2nd ed. New York: Springer-Verlag, 1991. (The WHO classification of salivary gland neoplasms.)

Westra WH. The surgical pathology of salivary gland neoplasms. *Otolaryngol Clin North Am* 1999;32(5):919 [PMID: 10477796]. (Review of the cellular and morphologic features of the most common salivary gland neoplasms.)

Treatment

A. Surgical Measures

Surgery with the complete removal of the tumor, including a cuff of histologically normal tissue for adequate margins, is the mainstay of treatment for both major and minor salivary gland malignancies.

1. Surgery for major salivary gland malignant neoplasms—For malignant parotid gland tumors, a total parotidectomy (or an extended parotidectomy if the tumor extends into surrounding structures) is recommended. The facial nerve is sacrificed if it is directly involved with the tumor (ie, encased in the tumor, unable to be dissected from tumor, paretic, or paralyzed preoperatively). In patients whose facial nerve is intact but the margins of resection are close to the nerve, postoperative adjuvant radiation should be considered because it has been shown to significantly improve local control. The typical surgical approach is through a Blair or modified Blair-type incision. For malignant disorders of the parotid gland with parapharyngeal space extension, surgery must include parapharyngeal space (or infratemporal fossa) dissection, sometimes requiring a submandibular or even a mandibulotomy–mandibulectomy approach. A lateral temporal bone resection may be required as well if the ear canal is involved.

For malignant disease of the submandibular and sublingual glands, formal supraomohyoid neck dissection is preferred over a simple gland excision. As with the facial nerve in parotidectomy, the lingual, hypoglossal, and marginal mandibular nerves are preserved unless there is evidence either preoperatively or intraoperatively of their direct involvement by the tumor.

2. Surgery for minor salivary gland malignant neoplasms—For malignant growths of the minor salivary glands, wide local excision is recommended. This approach may be extensive, even including a skull base resection, depending on the location, size, and extension of the tumor. Tumors involving the maxillary sinus and nasal cavity may require partial or total maxillectomy. If the ethmoid is involved with extrasinus extension, craniofacial resection, orbital exenteration, or both may be required for more extensive tumors. A transoral or combined transoral–transcervical approach is used for malignant neoplasms of the minor salivary glands that affect the oral cavity and oropharynx. A partial or total laryngectomy or even tracheal resection is required for minor salivary gland tumors involving the larynx or trachea.

Table 19–5. Incidence of Occult Lymph Node Involvement for Salivary Gland Malignant Neoplasms.

Salivary Gland Neoplasm	Incidence (%)
Squamous cell carcinoma	40
Adenocarcinoma	18
Mucoepidermoid carcinoma	14
Acinic cell carcinoma	4
Adenoid cystic carcinoma	4
Tumor <4 cm	4
Tumor >4 cm	>20

3. Neck dissection—Neck dissection is the recommended treatment of the neck for malignant salivary gland tumors (1) with clinically apparent cervical adenopathy (14% of cases), (2) for tumors >4 cm (in which the risk of occult metastases is >20%), or (3) for a high-grade histology (in which the risk of occult metastases is >40%) (Table 19–5). Elective neck dissection for adenoid cystic carcinoma generally is not recommended because the risk of occult nodal metastasis is low.

B. Nonsurgical Measures

1. Radiation therapy—Both conventional and neutron-beam radiation therapy have been advocated as single-modality treatments for T1 and T2 malignant salivary gland neoplasms. This approach is controversial, but may be considered if there are real contraindications to surgery.

Adjuvant radiation to the tumor resection bed improves local control for (1) T3 and T4 tumors; (2) tumors of high-grade histology (see Table 19–4); (3) positive nodes or perilymphatic invasion; (4) facial or other perineural involvement; (5) a close or positive surgical margin; (6) bone, cartilage, or muscle invasion; or (7) recurrent disease. The standard radiation therapy used is a unilateral mixed electron and photon technique. Postoperative radiation to the neck is recommended, as above, for major and certain minor salivary gland primary sites when there are positive neck nodes. Radiation is an acceptable alternative for a node-negative (ie, N0) neck with aggressive features (see indications for neck dissection). For minor salivary gland tumors, elective radiation of the N0 neck is advocated only for primary tumors of the tongue, floor of mouth, pharynx, and larynx. Conventional radiation has been shown to have prohibitively poor local control rates for inoperable disease.

Neutron-beam radiation has been shown to be more effective than conventional radiation against malignant salivary gland disorders; it results in a higher degree of tumor

destruction with fewer toxic effects to surrounding normal tissues. In particular, neutron-beam radiation protocols have been more successful than conventional radiation in treating adenoid cystic carcinoma. Neutron-beam therapy can achieve excellent locoregional control, higher than mixed beam and photons in advanced, recurrent, as well as incompletely resected salivary neoplasms. It is also the preferred treatment for inoperable disease. Fast neutron therapy is not widely available.

2. Chemotherapy—The role for chemotherapy in the treatment of malignant salivary gland disorders is limited to the palliative setting, such as in advanced-stage or metastatic disease not amenable to local therapies including surgery and/or radiation. Partial or complete responses have been achieved in up to 50% of patients, which typically last 5–8 months and may include significant pain control. Most of these patients have adenoid cystic carcinoma, mucoepidermoid carcinoma, or high-grade adenocarcinoma. Currently, paclitaxel is the agent used most frequently. Although chemotherapy alone does not improve survival rates, the integration of radiation and chemotherapy has been shown to increase local control and represents an improvement in the management of salivary gland malignancies.

3. Molecular targeted therapy—Recent studies suggest new molecular agents as potential alternatives to current chemotherapeutic agents in the treatment of salivary gland malignancies. They may be preferred over chemotherapy due to fewer side effects and potentially greater efficacy. Novel agents targeting specific receptors, such as epidermal growth factor receptor (EGFR) and Her-2/neu, have shown promising results in their future additions to the treatment regimens for salivary gland cancers.

C. Treatment of Recurrence and Metastatic Disease

Recurrent, malignant salivary gland tumors are treated with the same guidelines as for primary disease. Neutron-beam radiation can, in selected cases, be used when previous external beam radiation has already been administered. In patients with metastatic disease, a "wait-and-watch" policy is advocated, and systemic treatment is currently reserved for patients with symptomatic or progressive disease. The role of molecular targeted agents in these tumors remains investigational.

D. Complications of Treatment

The complications of the treatment of salivary gland tumors include complications of surgery and those of radiation therapy.

1. Complications related to surgery—Facial nerve (or other nerve) paralysis, hematoma, salivary fistula or sialocele, Frey syndrome, and cosmetic deformity are among the surgical complications.

2. Complications related to radiation therapy—Complications of radiation include acute mucositis, trismus and fibrosis, osteoradionecrosis, and impairment of vision. Since most radiation protocols for malignant salivary gland neoplasms involve unilateral treatment, xerostomia occurs less often than in the treatment of other upper aerodigestive tract tumors.

Cortesina G, Airoldi M, Palonta F. Current role of chemotherapy in exclusive and integrated treatment of malignant tumours of salivary glands. *Acta Otorhinolaryngol Ital* 2005;25(3):179 [PMID: 16450774]. (A look at the role of chemotherapy in the treatment of salivary gland malignancies.)

Douglas JG et al. Treatment of salivary gland neoplasms with fast neutron radiotherapy. *Arch Otolaryngol Head Neck Surg* 2003;129 (9):944 [PMID: 12975266]. (The University of Washington experience with and their evaluation of the efficacy of neutron-beam radiotherapy for adenoid cystic carcinoma.)

Huber PE et al. Radiotherapy for advanced adenoid cystic carcinoma: neutrons, photons or mixed beam? *Radiother Oncol* 2001;59(2):161 [PMID: 11325445]. (Comparison of the different radiotherapeutic treatments of advanced adenoid cystic carcinomas.)

Laurie SA, Licitra L. Systemic therapy in the palliative management of advanced salivary gland cancers. *J Clin Oncol* 2006;24 (17):2673 [PMID: 16763282]. (Review of the role of chemotherapy in advanced salivary gland malignancy of different histologies.)

Mehra R., Cohen, RB. New agents in the treatment for malignancies of the salivary and thyroid glands. *Hematol Oncol Clin North Am* 2008;22(6):1279 [PMID: 19010274]. (A look at the new drugs under investigation for salivary and thyroid malignancies and a review of epidemiology and pathogenesis of salivary gland and thyroid cancers.)

Prott FJ, Micke O, Haverkamp U et al. Results of fast neutron therapy of adenoid cystic carcinoma of the salivary glands. *Anticancer Res* 2000;20(5C):3743 [PMID: 11268448]. (The University of Munster experience with neutron-beam radiotherapy and adenoid cystic carcinoma.)

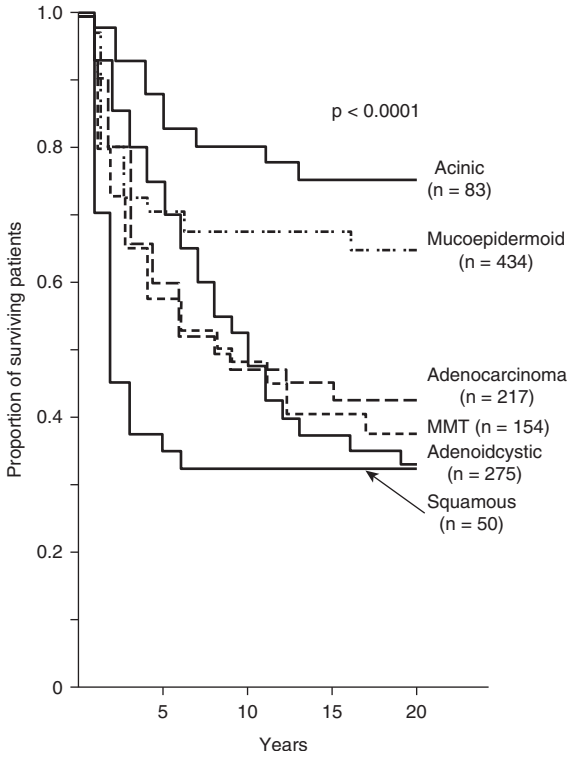
Spiro JD, Spiro RH. Cancer of the parotid gland: role of 7th nerve preservation. *World J Surg* 2003;27(7):863 [PMID: 14509520]. (A look at the management of the facial nerve in surgeries for parotid malignancies.)

Spiro RH. Management of malignant tumors of the salivary glands. *Oncol* 1998;12(5):671 [PMID: 9597678]. (Review of treatment guidelines for malignant neoplasms of the salivary glands.)

Vattemi, E et al. Systemic therapies for recurrent and/or metastatic salivary gland cancers. *Expert Rev Anticancer Ther* 2008;8(3):393 [PMID: 18366287]. (Review of systemic treatment for recurrent and metastatic salivary gland cancers.)

Prognosis

The indicators of a poor prognosis for malignant salivary gland tumors include pain, facial or other nerve involvement, high-grade histology, the invasion of skin and other surrounding tissues, the presence of cervical or distant



▲ **Figure 19–10.** Kaplan–Meier survival curve for malignant salivary gland disorders, subdivided by histologic type. (Adapted, with permission, from Spiro RH. Salivary neoplasms: overview of a 35-year experience with 2,807 patients. *Head Neck Surg* 1986;8:177.)

metastases, and recurrent disease. For major salivary gland tumors, distant metastases occur most often in adenoid cystic carcinoma and undifferentiated carcinoma. The lungs, liver, bone, and brain are the most common sites. Survival varies greatly with both histologic type and the initial stage. For example, malignant mixed tumors with distant metastases portend a very poor patient survival, whereas survival of more than 10 years has been reported for adenoid cystic carcinoma with distant metastases. For this reason, treatment of the primary adenoid cystic tumor and its metastatic sites is warranted. Figure 19–10 shows survival curves, subdivided by histologic type, for major and minor salivary gland tumors.

Carinci F, Farina A, Pelucchi S et al. Parotid gland carcinoma: 1987 and 1997 UICC T classifications compared for prognostic accuracy at 5 years. *Eur Arch Otorhinolaryngol* 2001;258(3):150 [PMID: 11374257]. (The 1997 T-staging found to be of greater prognostic value than the earlier 1987 T-staging system for malignant parotid lesions.)

Regis de Brito Santos I, Kowalski LP, Cavalcante de Araujo V et al. Multivariate analysis of risk factors for neck metastases in surgically treated parotid carcinomas. *Arch Otolaryngol Head Neck Surg* 2001;127(1):56 [PMID: 11177015]. (Identified risk factors for neck metastasis in parotid carcinoma include histologic type and T stage.)

We would like to acknowledge Mark D. DeLacure, MD for his contribution to this chapter in the previous editions of CDT.

Cleft Lip & Palate

20

William Y. Hoffman, MD, FACS, FAAP

In large series, the distribution of clefts is about 50% cleft lip and palate, 30% cleft palate only, and 20% cleft lip only. Cleft lip occurs most often on the left side; the distribution of left to right to bilateral cleft lip is approximately 6:3:1. Right-sided clefts are more commonly associated with syndromes. There is a slightly higher incidence in males.

Modern ultrasound can identify cleft lip by the absence of muscle fibers crossing the lip. Specific efforts must be made to obtain a frontal view to make a prenatal diagnosis. Newer ultrasounds have increasing accuracy. Although fetal surgery for clefts is not yet feasible in humans, prenatal diagnosis makes it possible to counsel parents earlier and prepare them for the care that their new child will require (Figure 20–1).

EMBRYOLOGY

It is important to remember the embryology of clefting; the primary palate includes the lip and premaxilla, whereas the secondary palate extends from the incisive foramen back. The lip and alveolus are formed by the fusion of the frontonasal process and the lateral maxillary processes; this fusion is reinforced by the migration of mesenchymal tissue derived from neuroectoderm (Figure 20–2). The stabilization of neuroectoderm by folate during the first trimester of pregnancy has been shown to reduce the incidence of clefting as well as that of other neural crest defects such as myelomeningocele.

ANATOMY

An understanding of the anatomic derangements is critical to proper repair. In the cleft lip, the orbicularis oris muscle is interrupted, and the remnants of the muscle adjacent to the cleft flow toward the upper portion of the cleft, at the base of the columella medially and at the alar base laterally. Incomplete clefts have variable amounts of muscle intact across the upper portion of the lip. In bilateral complete clefts, there is no muscle in the central portion (the prolabium).

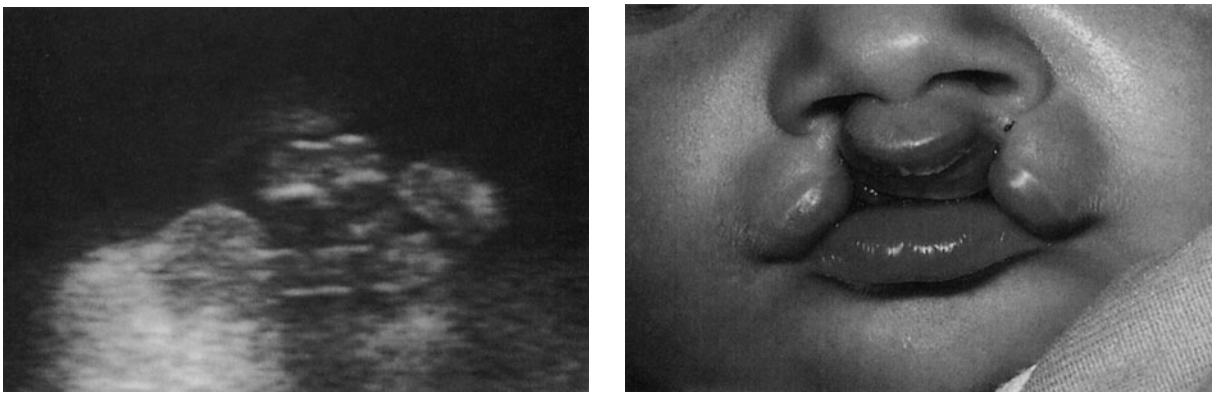
Normally, the levator palatini muscle forms a sling that elevates the soft palate and excludes the nasopharynx from the oropharynx during speech and swallowing. In the cleft palate, the levator muscle is oriented longitudinally, parallel with the cleft margin. This abnormal orientation of the muscle is even seen in submucous cleft palate, when the mucosa is intact (Figure 20–3). The most recent techniques of cleft palate repair incorporate reorientation of the levator muscle as part of the repair, which contributes to the improved speech results seen today.

The tensor palatini muscle is also abnormally oriented, more longitudinally than normal; this results in inadequate opening of the eustachian tube in children with cleft palate. It also explains the high incidence of serous otitis media seen in these children; almost all children with clefts require myringotomy and tube placement in early development. As they grow, the eustachian tube develops stronger cartilaginous support and the need for ventilating tubes is generally outgrown.

CLASSIFICATION

Clefts are generally classified as complete or incomplete. **Complete cleft lip** implies a separation of the lip that extends through the nasal sill and the alveolus into the palate. **Incomplete cleft lip** may present as a cleft of variable width with an intact bridge of skin below the nasal sill, known as a Simonart's band. At the other end of the spectrum is the **forme fruste** or **microform cleft lip,** which may be as little as a small notch in the vermilion (Figure 20–4).

Clefts may also be **unilateral** or **bilateral.** As with unilateral clefts, bilateral clefts may be complete or incomplete, and these variants may be different on the two sides. In a complete bilateral cleft, the central portion of the alveolus, the premaxilla, is attached only to the nasal septum and the central lip or prolabium is attached only to the premaxilla and the columella. These cases pose a particular problem because the premaxilla migrates anteriorly and



A B

▲ **Figure 20–1.** **(A)** Ultrasound of a child with bilateral cleft, incomplete on the left. **(B)** Photo of the same child postnatally before lip repair.

can be virtually horizontal in orientation. The premaxilla must be brought down into a closer relationship with the lateral segments in order to achieve a bilateral cleft lip repair (Figure 20–5).

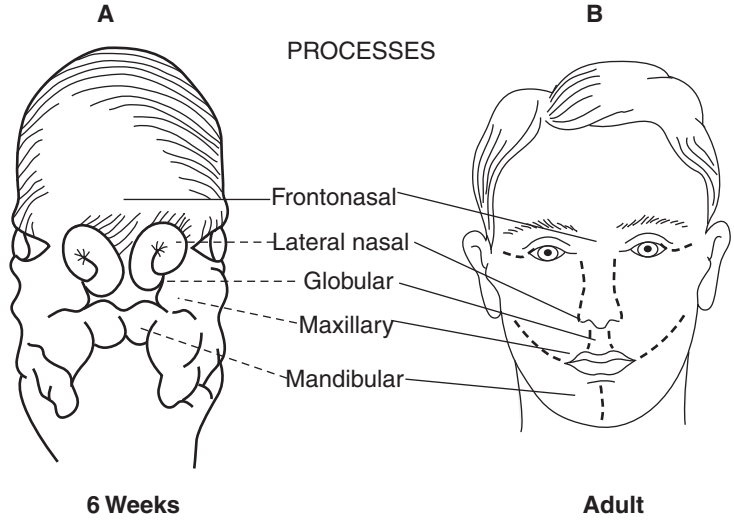
Complete cleft palate occurs in association with complete cleft lip, whereas **incomplete cleft palate** refers to a cleft of the secondary palate only. As with the lip, the presentation of incomplete clefts has a great deal of variability, from a wide cleft of the palate extending all the way forward to the incisive foramen, to a narrow cleft of the posterior portion of the soft palate. The **submucous cleft palate** represents a specific entity with separation of the levator palatini muscles but intact mucosa.

SYNDROMES

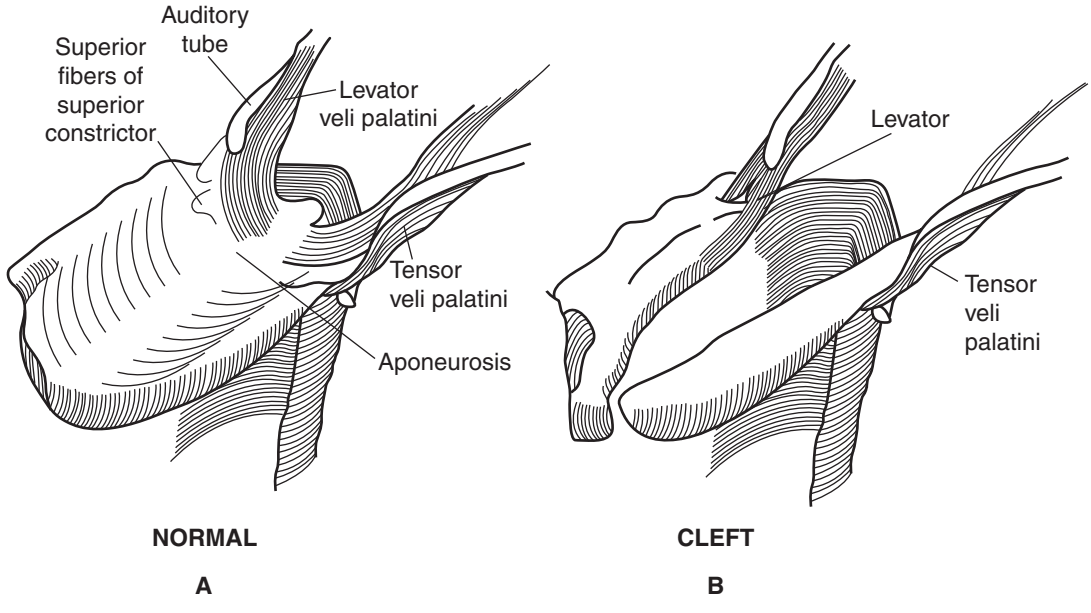
Literally hundreds of congenital syndromes include clefting as one manifestation of a genetic abnormality. Together, these make up <20% of all clefts; those not associated with a syndrome are generally referred to as "isolated" clefts.

1. Velocardiofacial Syndrome

Velocardiofacial syndrome, or **Shprintzen syndrome,** is associated with a deletion at the 22q locus. This is the same locus involved in the DiGeorge syndrome, and there may be overlap with this syndrome of B-cell dysfunction. As the name implies, affected children have clefts (usually of



▲ **Figure 20–2.** Diagram of a 6-week-old embryo. The frontonasal process will give rise to the central lip and premaxilla, the lateral nasal process will develop into the alae of the nose, and the maxillary processes will produce the lateral lip and maxillary segments.



▲ **Figure 20–3.** Anatomy of the cleft palate. **(A)** Normal anatomy; note the sling formed by the two sides of the levator palatini muscle. **(B)** Cleft palate; the levator muscle is oriented longitudinally, somewhat parallel with the cleft margin.

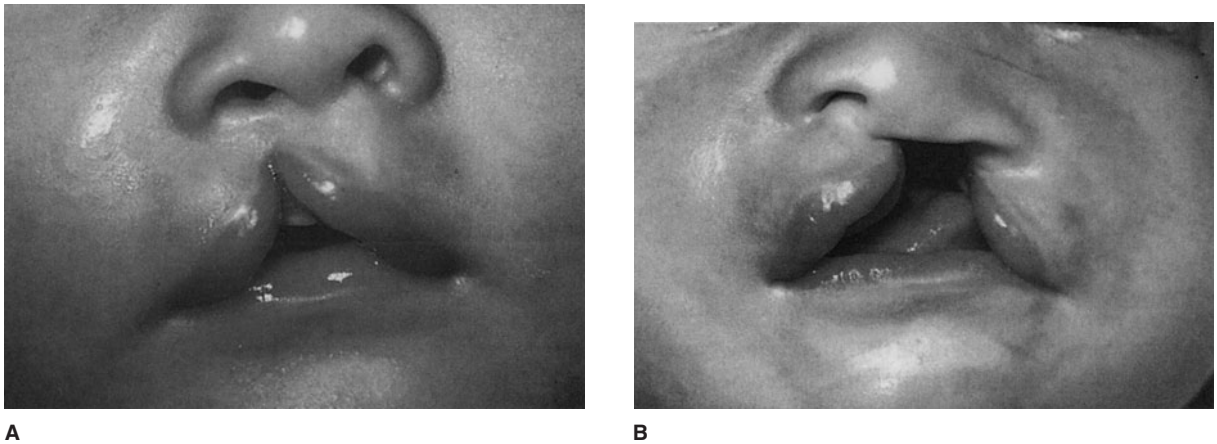
the palate only), cardiac anomalies, and characteristic facial appearance. There may be velopharyngeal insufficiency in the absence of any cleft. Children with velocardiofacial syndrome have a developmental delay that may contribute to problems with speech. It is possible to test for the genetic deletion with **fluorescent in situ hybridization** (ie, FISH testing).

2. Van der Woude Syndrome

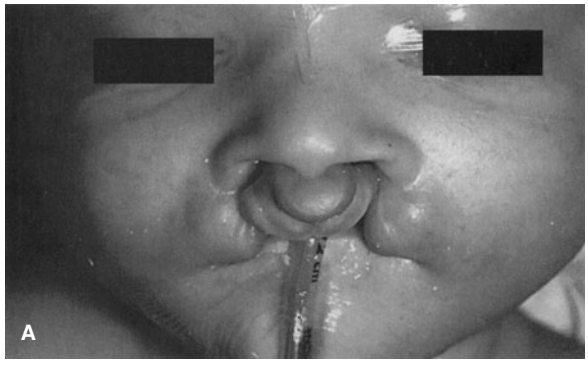
Van der Woude syndrome is an association of clefting with lower lip sinus tracts, known as **lip pits.** This syndrome is notable for autosomal dominant inheritance and for variable penetrance; even within a single family, affected children may have different presentations (Figure 20–6).

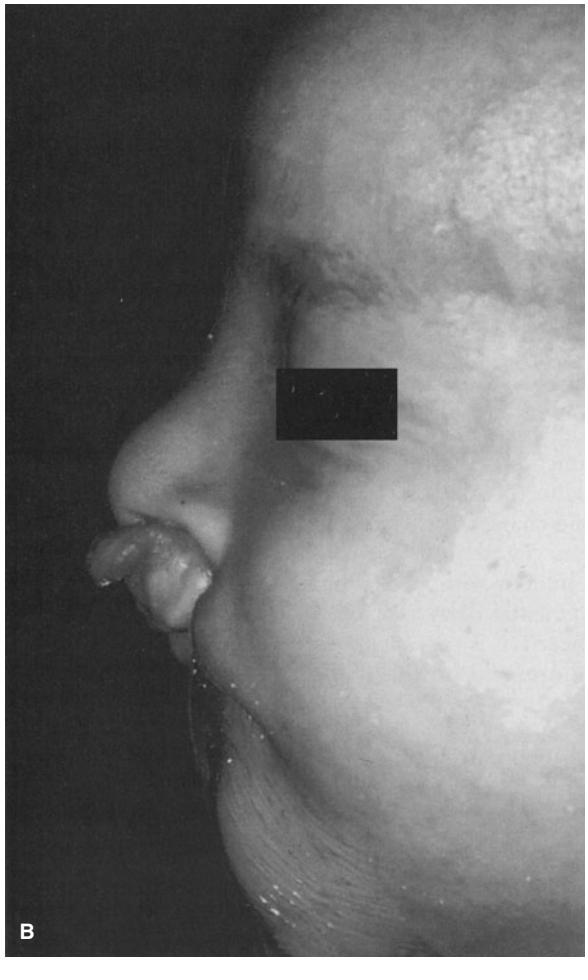
3. Stickler Syndrome

Stickler syndrome is an association between clefts and ocular abnormalities, including fairly severe myopia presenting at an early age, as well as retinal abnormalities. Generally, an examination by a pediatric ophthalmologist is recommended

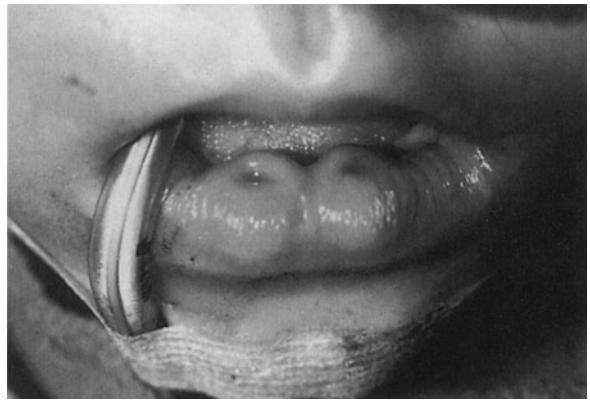


▲ **Figure 20–4.** Examples of unilateral cleft lip. **(A)** Incomplete cleft. **(B)** Complete unilateral cleft lip.





▲ **Figure 20–5.** Bilateral complete cleft lip. **(A)** Anteroposterior view. The central portion, the prolabium, is of fairly good size in this example. **(B)** Lateral view. Note the short columella and the anterior displacement of the prolabium and premaxilla due to the interruption of the orbicularis oris muscle.



▲ **Figure 20–6.** Van der Woude syndrome. This child has only a cleft palate, but the expression is variable and can include complete cleft lip and palate as well. The lip pits (sinus tracts of minor salivary glands) in this patient are particularly prominent.

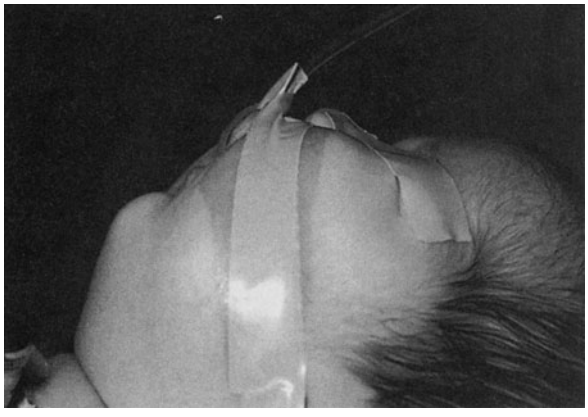
for children with clefts to make or rule out the diagnosis in the first year of life.

PIERRE ROBIN SEQUENCE

Pierre Robin syndrome is characterized by a triad of retrogenia, retrodisplacement of the tongue, and respiratory insufficiency. Most children with this syndrome also have clefts of the secondary palate, which are characteristically U-shaped clefts that are quite wide. The breathing difficulties seen in Pierre Robin sequence arise from posterior positioning of the tongue and upper posterior pharyngeal obstruction (Figure 20–7).

In most cases, the respiratory obstruction is seen immediately in the neonatal period. Turning the infant to the prone position may move the tongue forward and alleviate the obstruction. The placement of a nasogastric feeding tube permits better nutrition and also breaks the seal of the tongue against the posterior pharyngeal wall. Various types of oral airways have been used as temporizing measures to keep the tongue down and forward. Over time, the mandible grows forward in most cases and the problem improves.

If conservative measures fail in the neonatal period, surgical intervention is warranted. The goal of surgery is to avoid infant tracheostomy, which remains the final resort in these cases. In all cases **bronchoscopy** should be performed to rule out laryngomalacia or tracheomalacia, which would mandate tracheotomy. **Tongue-lip plication,** or **glossopexy,** is a simple procedure that requires an incision in the tongue just below the tip and in the wet vermilion of the lower lip; the two mucosal incisions are closed along with a retention suture that is tied over two buttons on the tongue and in the lower chin. This technique has been successful in avoiding tracheotomy in about 80% of



▲ **Figure 20–7.** Pierre Robin sequence. Note the extremely retruded chin in this child, who is being prepared for surgical tongue-lip adhesion.

cases in several large series. Recently, **mandibular distraction** has been used in infants to elongate the ramus and bring the tongue forward with the mandible. This is the preferred technique for treatment of PRS at a number of centers in the United States and elsewhere. The purported advantages are the high success rate, elimination of GERD, and the ability to repair the palate at an early age without airway problems. The long-term effects on mandibular growth are not known at this time.

SUBMUCOUS CLEFT PALATE

Submucous cleft palate represents a special subset of clefts that remains confusing in both diagnosis and treatment. The diagnosis is made by the findings of the classic triad of a bifid uvula, central thinning of the soft palate, and a palpable notch in the posterior border of the hard palate (normally the location of the posterior nasal spine). Anatomically, there is the same separation of the levator palatini muscle that is seen in overt clefts.

In large prospective studies, most patients with submucous cleft palate do not have speech problems (ie, nasal air loss). However, it is not uncommon to see patients with nasal speech who have an unrecognized submucous cleft. Patients with submucous clefts should be observed as speech develops; if nasal air loss occurs, surgical intervention should be considered. The **Furlow double-opposing Z-plasty** is an excellent method for repair in these cases (see Treatment section below).

Treatment

The care of children with a cleft lip and palate requires a comprehensive treatment plan from the initial diagnosis through the completion of reconstruction in adolescence. A child with a complete cleft lip and palate requires several operations as he or she develops. In general, the goal of treatment is to have as few operations as possible with the best possible outcome. Naturally, there are a variety of approaches, any of which may produce the same final result. A comparison of outcomes has been difficult because of treatment differences, as well as the fact that the experience and ability of the individual surgeon may also influence the outcome.

It is important to emphasize the team approach to cleft care, which has developed gradually over the past 50 years. Although surgeons, speech therapists, and orthodontists, among others, may offer specific treatment, a dedicated cleft team offers the best possibility of coordinating the care among various specialists. This approach can both minimize the number and length of the various interventions as well as ensure that they are done at optimal times. The American Cleft Palate-Craniofacial Association has developed an outline of the standards for team care of cleft patients.

A. Preoperative Considerations

Before any surgery, it is important for the patient to have a thorough team evaluation, including genetic and pediatric examinations, which can lead to other studies to diagnose or rule out specific syndromes.

Oral intake can be compromised in children with cleft palate because of their inability to suck effectively. It is important to instruct parents in the use of a cleft nurser. There are a variety of types, all of which require less effort than a normal bottle; even a cross-cut nipple on a regular bottle may work in these cases. Most of the bottles require some squeezing to supplement flow. Adequate oral intake is assessed by weight gain.

Preoperative manipulation of the alveolar segments in complete cleft lip and palate is often used to reduce the width of a cleft, facilitating a tension-free surgical closure. Orthodontic appliances such as molding plates can be used but require frequent (weekly) modification of the plates to continue moving the segments. When extensions of the molding plate are used for stretching the nasal ala this is called nasoalveolar molding, or NAM. This is labor-intensive for the orthodontist, but can give the most accurate positioning of the segments. The use of taping across the cleft is much simpler and is still quite effective, but less predictable. This process is most important in complete bilateral clefts, in which control of the premaxilla is essential to achieving any type of repair. Once the lip is repaired, the intact orbicularis oris muscle maintains and continues to mold the position of the alveolar shelves.

Lip adhesion is a procedure in which the cleft segments are surgically united via small flaps, essentially creating an incomplete cleft lip. A successful lip adhesion molds the alveolar segment. A secondary operation is performed after an interval to convert the adhesion to a formal lip repair. Though appealing, this procedure creates scar tissue in the lip, which may impede the final lip repair.

B. Cleft Lip Surgery

1. Timing of lip repair—The classic "rule of tens" is still a reasonable guideline for lip repair: 10 weeks of age, a weight of 10 pounds, and a hemoglobin of 10 have been considered prerequisites for lip repair. This is partly based on anesthetic safety, which is probably a little better with increased age. The timing of the lip repair must be individualized for the patient. A premature infant may benefit from a later repair because of the increased incidence of apnea after general anesthesia in the first 3 months or so after gestational age. Similarly, if presurgical manipulation of the alveolus or premaxilla is required, this should be completed before the lip repair is undertaken. An incomplete cleft lip has less urgency because the alveolar segments are held in place by the intact Simonart's band.

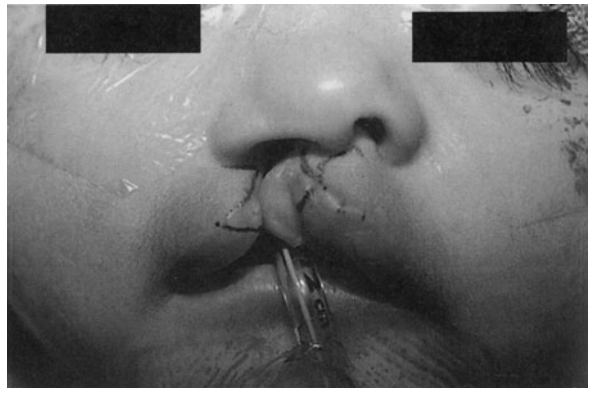
2. Goals of lip repair—The essence of lip repair is to create a symmetrical Cupid's bow and lip fullness, without losing normal contour of the lip and the philtrum. To create length on the cleft side, some tissue from the lateral lip element must be inserted into the medial segment. Breaking up the scar also reduces scar contraction, which can create secondary shortness of the repair. This was commonly seen with the original straight-line cleft repair.

The initial efforts to break up the scar and recruit lateral tissue were so-called quadrilateral repairs, with a stair-step closure that had the disadvantage of discarding a significant amount of tissue. The triangular lip repair essentially placed a modified Z-plasty above the vermilion border. Other repairs have a Z-plasty in the central portion of the lip. The rotation advancement repair moved the Z-plasty to the area below the nasal sill.

Many fine adjustments contribute to the ideal cleft lip repair. The symmetry of the nose, including the tip, as well as the alar base and the nasal sill are critical to the final appearance. The fullness of the mucosa should be equal on the two sides. The alignment of the junction of the wet and dry vermilion (the so-called "red line") can be a subtle but important difference between a good repair and an adequate one.

3. Rotation advancement cleft lip repair—The rotation advancement cleft lip repair, also referred to as a **Millard repair,** is probably the most commonly performed repair today. Almost no tissue is discarded; the medial lip element is rotated downward, even with a back cut, if necessary, and the lateral lip element is advanced into the defect under the nasal sill. Mucosal flaps are used to line the nose and the vestibule of the lip (Figure 20–8).

It is important to understand that the rotation advancement repair recruits length for the lateral advancement flap by following the vermilion border. Increasing the amount of rotation (and leaving a larger secondary defect) creates length on the medial side of the repair; this length cannot be duplicated on the lateral segment unless the incision is carried along the vermilion border. This is known as a "cut-as-you-go" technique because modifications can be made during the operation to obtain better symmetry.



▲ **Figure 20–8.** Rotation advancement (Millard) repair for unilateral cleft lip. The high point of the Cupid's bow on the central segment is brought down by the rotation; the secondary defect under the nose is filled by the lateral advancement flap.

The Millard repair has the advantage of creating good lip projection ("pout") by creating tension under the nasal sill rather than along the vermilion border. The most common problem is that the lip may be somewhat short after healing is complete. Placement of a tiny Z-plasty (1.0–1.5 mm) may improve this problem. Revision, if necessary, is much easier than revision after a triangular repair because of the linear nature of the lower portion of the repair.

4. Triangular cleft lip repair—The rotation advancement repair is by far the most frequently used in the United States; the triangular lip repair makes up the majority of the remainder. The triangular lip repair may also be referred to as the **Tennison–Randall cleft lip repair.**

The triangular cleft lip repair evolved from earlier quadrilateral repairs; they have in common a zigzag closure, which breaks up the forces of scar contracture. In the triangular repair, a nearly horizontal incision is made in the lower half of the medial cleft segment, and a triangular piece is fashioned in the lateral flap to fit in the resulting defect. This closure is essentially a modified Z-plasty placed relatively low on the lip. In some ways, the small Z-plasty discussed with the Millard repair is a modified triangular repair appended to the rotation advancement technique (Figure 20–9).

In all Z-plasties, length is borrowed at the expense of width. The placement of the triangle low on the lip results in an excellent lip length, but it has the disadvantage of creating a flat repair when viewed from the side. In contrast, the rotation advancement repair places the tightest part of the closure beneath the nasal sill, where the lip is normally the flattest, and creates a more natural pout, but at the expense of greater difficulty in obtaining adequate length.

▲ **Figure 20–9.** Triangular cleft lip repair. **(A)** Markings for triangular repair; shaded areas will be discarded. **(B)** Appearance during triangular repair. **(C)** Completed repair.

5. Bilateral cleft lip repair—Several factors contribute to the greater complexity of bilateral cleft lip repair.

A. Premaxilla—In complete bilateral cleft lip and palate, the premaxilla is usually quite protrusive and must be controlled preoperatively to achieve an adequate repair. Resection of the premaxilla was practiced previously, but this procedure results in severe maxillary retrusion, and an extremely complex reconstruction that can be accomplished only with prosthetics. The simplest method, **taping,** can be effective but requires a great deal of parental participation. As noted previously, **alveolar molding** with orthodontic plates is also used in a number of centers. This technique generally gives better alignment of the three segments of the maxilla before surgical intervention. Severe protrusion can be approached at the time of surgery with an **osteotomy of the vomer** to allow the premaxilla to be set back surgically, but this should be done only as a last resort because it is associated with maxillary hypoplasia.

B. Nasal deformity—The second major challenge in the bilateral cleft repair is the nasal deformity. The columella is extremely short and the nasal tip is flat, with bilateral alar base widening. Alveolar molding may be combined with **nasal molding** by adding small prongs anteriorly that are gradually elongated over several weeks; this can lengthen the columella nicely. Postoperative **nasal stents** can also be useful after lip repair.

Debate still exists over the management of the short columella. Traditionally, tissue has been obtained from the lip as forked flaps or nasal alae as **V-to-Y advancement flaps.** More recently, attention has been focused on obtaining length from the nose itself, since some of the loss of length is due to the separation of the nasal tip cartilages. Thus, V-to-Y incisions at the alar rim or vertical incisions over the tip have been proposed. As noted previously, preoperative orthodontic manipulation of the segments may be combined with nasal molding to lengthen the columella, which obviates any additional scars.

C. Blood supply maintenance—The third problem in the complete bilateral cleft is the maintenance of blood supply to the central cutaneous segment, the prolabium, as well as the bony premaxilla. The more extensive lengthening procedure done in a unilateral cleft cannot be applied to both sides of a bilateral cleft simultaneously without jeopardizing this blood supply, which can come only from the nasal septum. Thus, the bilateral cleft repair is often planned in stages to prevent any possible loss of tissue.

D. Symmetrical deformities—Symmetrical deformities are best approached with a symmetrical repair. It is essential to obtain complete closure of the orbicularis oris muscle at the time of the lip repair, bringing the two segments from each side together across the middle. The intact muscle contributes greatly to later growth of the lip, so the length of the lip is less critical (Figure 20–10).

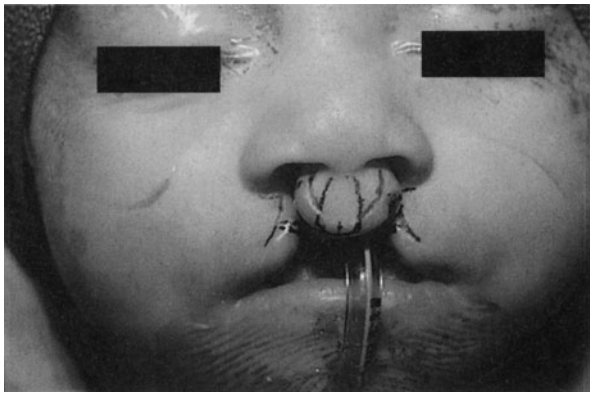
C. Primary Cleft Nasal Repair

The cleft nasal deformity in the unilateral cleft is multifactorial. There is the cleft itself, which in a complete unilateral situation extends up through the nasal sill and floor of the nose. This creates a widening of the alar base, which is further exaggerated by the decrease in bony support in the piriform aperture on the side of the cleft. The nasal septum is generally deviated toward the side of the cleft, further tipping the nasal pyramid toward the cleft side. There is decreased projection of the dome of the alar cartilage on the side of the cleft, either as a primary deformity or secondary to the above. The final result is a nasal appearance that can be the primary stigma of the cleft deformity after a well-performed cleft lip repair.

Previously, the prevailing wisdom was that any procedure performed on a cleft nasal deformity early in life would result in irreparable scarring and the loss of growth potential of the nose. Today, abundant evidence exists that early correction of a cleft nasal deformity at the time of cleft lip repair can produce lasting improvement that grows proportionately with the child.

The common denominator in early cleft nasal correction is undermining of the nasal tip skin over the entire alar cartilage on the cleft side and over the dome of the noncleft side, extending the dissection up onto the inferior dorsum of the nose. This is done entirely through the existing incisions for the lip repair, at the base of the columella and at the alar base. No intranasal incisions are required. Suspensory sutures are then placed to elevate the nasal dome and to anchor the lateral crus of the alar cartilage on the cleft side in an advanced position; these are tied over percutaneous bolsters. **Internal suturing techniques** have also been described. The sutures are generally removed after only a few days. This procedure can result in excellent symmetry of the nose in simpler cases and acceptable improvement in more severe cases (Figure 20–11).

More recently, **nasal molding extensions** have been added to alveolar molding plates to improve nasal contour before the lip repair. Other surgeons prefer to use postoperative nasal stents, available commercially in Silastic (ie, polymeric silicone), which can be gradually increased in size and used to help mold the nose over several weeks after the surgery for lip repair.



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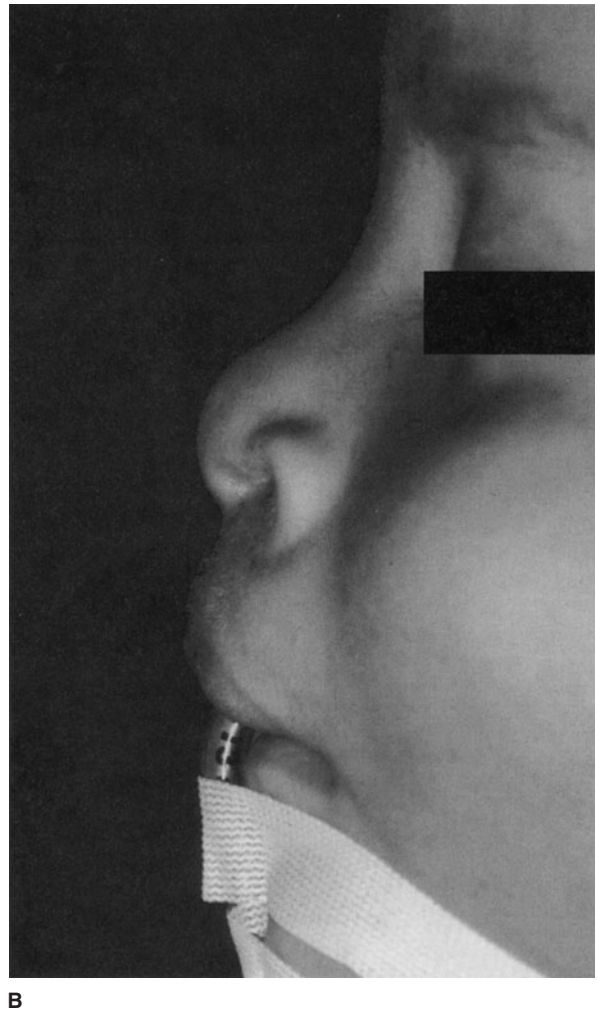

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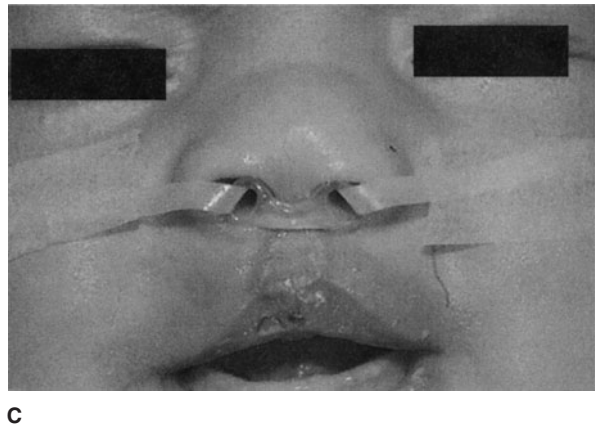

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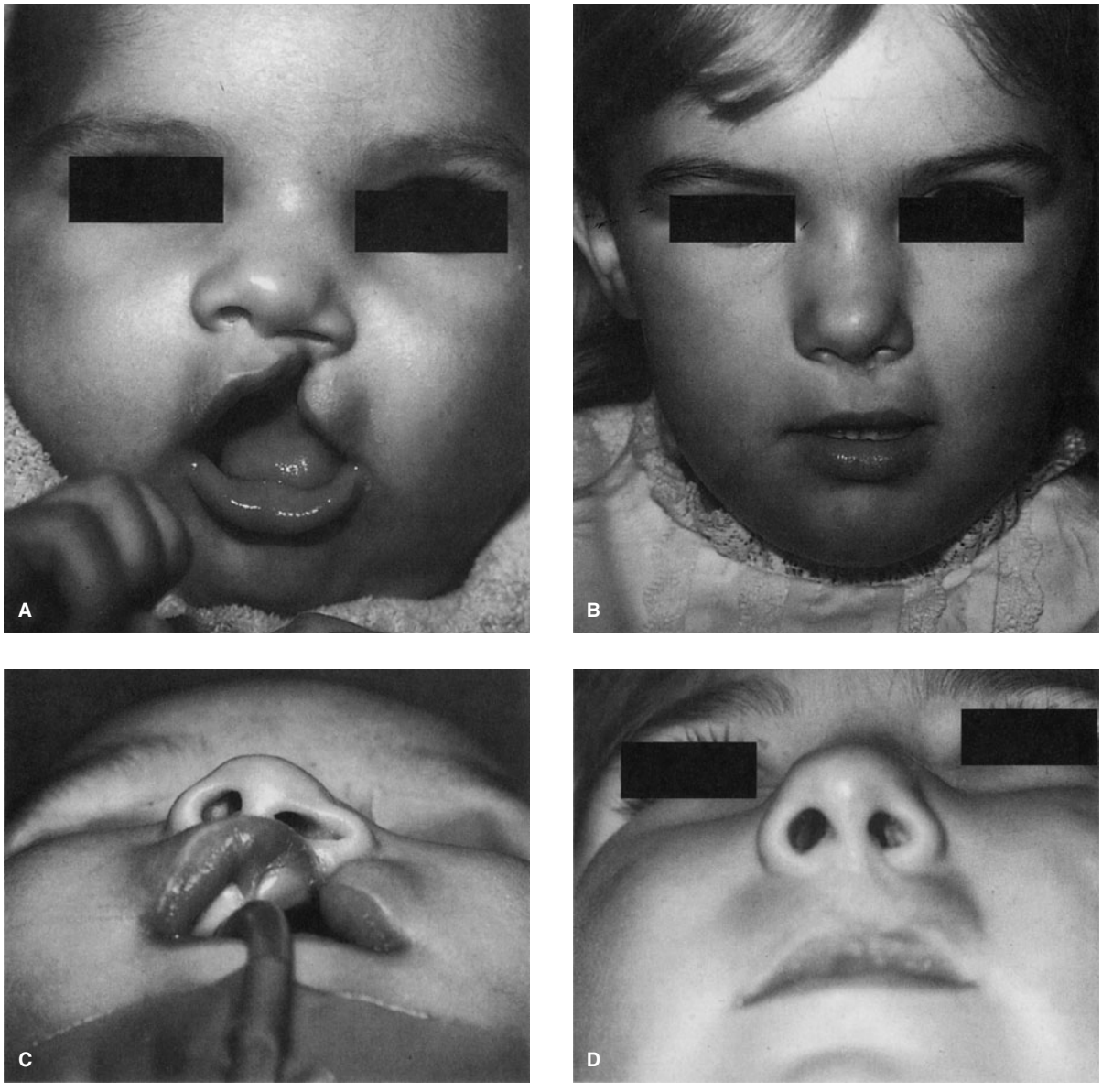
▲ **Figure 20–10.** **(A)** Markings for bilateral cleft lip repair. The forked flaps on each side of the prolabium will be placed under the nasal sills for later lengthening of the short columella. The mucosa is step-cut on the lateral segments to close in the midline under the prolabium, avoiding a whistle deformity. **(B)** Postoperative lateral view. The short columella is demonstrated. **(C)** Postoperative anteroposterior view. This child is wearing a Silastic stent in the nose to elongate the columella and round out the nostril.

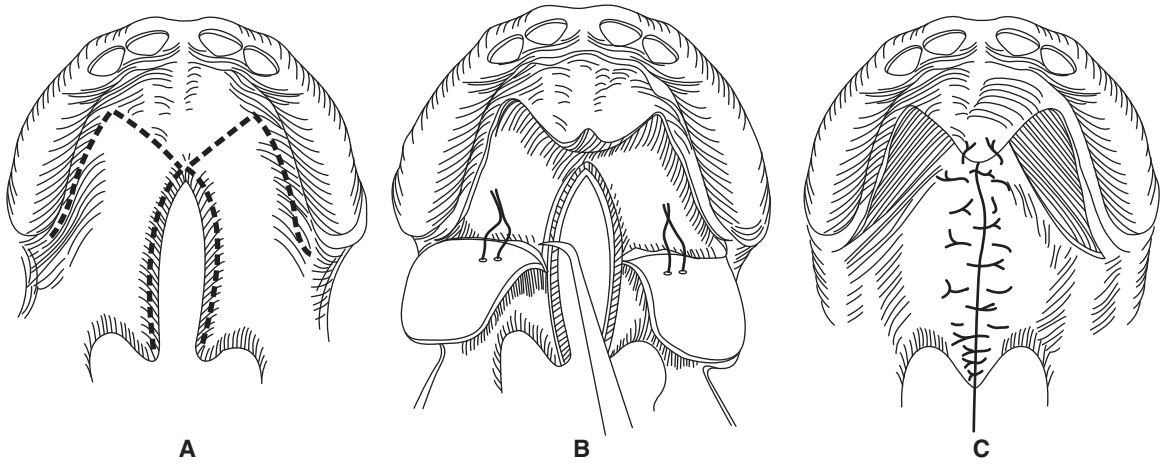


▲ **Figure 20–11.** Primary nasal correction. **(A)** and **(B)** Anteroposterior views before and after surgery, respectively. **(C)** and **(D)** Views before and after lip repair, respectively, with primary nasal correction (one operation at 3 months of age).

D. Cleft Palate Surgery

Cleft palate repair is primarily related to speech. Although there are obvious hygiene issues involved with the nasal regurgitation of food and fluids, most infants with cleft palates are able to gain weight appropriately and even to advance to solid food at about the same time as children without cleft palates. Intelligible speech, however, requires not only an intact palate but one with normal function.

1. Timing of palate repair—Again, the overriding concern is speech. The trend in timing of palate repair has been toward earlier repair, and there are data supporting palate repair earlier than a year of age. Both a decrease in compensatory articulations (habits that are developed to mimic a sound that cannot be produced because of the cleft) and a decreased need for secondary surgery for speech have been demonstrated with earlier repairs, even when compared to "later" repairs at 12–18 months of age.



▲ **Figure 20–12.** V-Y pushback palate repair. **(A)** Markings for incisions. **(B)** Mucoperiosteal flaps are developed from the oral surface based on the greater palatine vessels (shown) and on the nasal surface. **(C)** Completed repair. Note the bare areas on the anterior surface of the palate.

It is critical to think of palate repair in relation to the child's development of speech and language. The cleft does not affect speech development but, rather, the ability to produce specific sounds. In particular, sounds requiring positive intraoral pressure will be most affected. Early palate repair, then, is carried out in children who are displaying normal development in motor skills as well as in speech (babbling is the norm at about 7–9 months of age). In contrast, in children with syndromes that are associated with developmental delay, speech development may well be delayed as well and palate repair will be a little safer at a later stage, even at 18–24 months of age.

2. Techniques of palate repair—It is useful to conceptualize the different types of palate repair by separating techniques used for hard palate closure from those used for the soft palate. In both the hard and soft palates, the goal is a repair of both the nasal and oral mucosa, whereas in the soft palate, the functional repair of the levator muscle is an equally important component of the repair. Historically, the first palate repairs were of the soft palate only in patients with clefts of the secondary palate. Later, the introduction of mucoperiosteal flaps became the basis of most hard palate techniques.

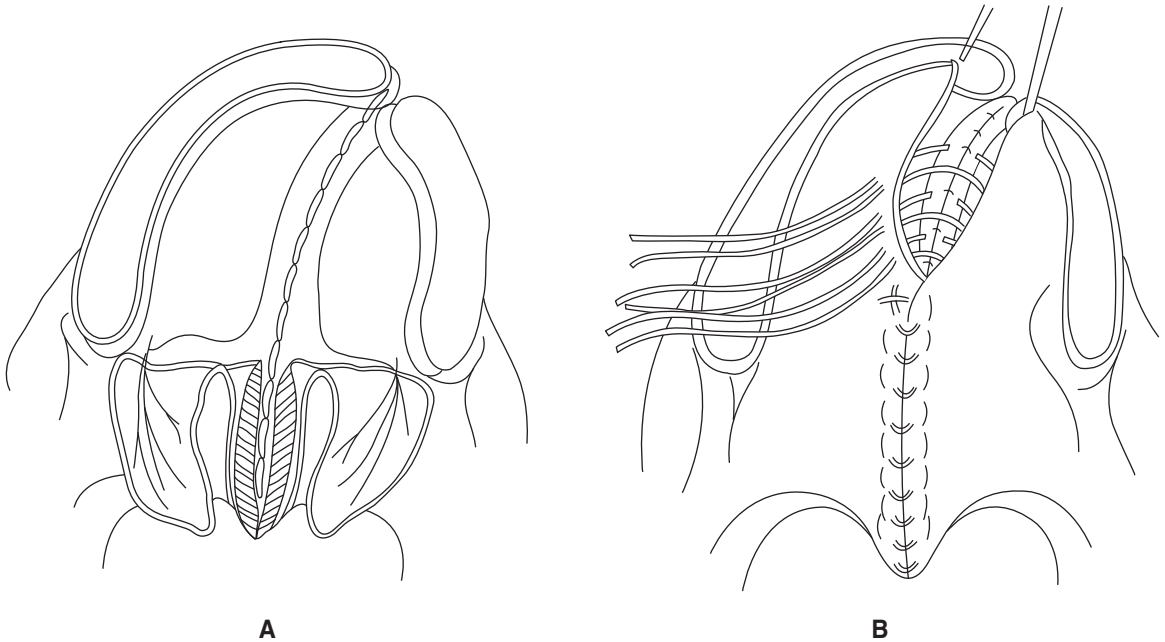
A. Von langenbeck repair—Two-stage palate repairs were originally described as a means of treating wide clefts; soft palate repair was done at the same time as lip repair, with the hard palate repaired later after the cleft width had diminished. In a way, this is analogous to lip adhesion; the surgeon is committed to a second operation and has additional scar to confront at the time of the second procedure. The use of two-stage palate repair has consistently been shown to produce poorer speech results when compared with most single-stage techniques, but is still used by some surgeons.

In this technique, relaxing incisions are made on each side, just behind the alveolar ridge. The hard palate is closed with bipedicle mucoperiosteal flaps (the primary blood supply is from the greater palatine vessels). It is necessary in all of these repairs to develop corresponding flaps on the nasal side. On the noncleft side, a superiorly based mucoperiosteal flap on the vomer is elevated to allow closure of the nasal mucosa. The open areas from the relaxing incisions are left to heal by secondary intention, which generally takes about 2 weeks.

B. V-Y pushback—In the V-Y pushback, also referred to as the **Veau–Wardill–Kilner repair,** open areas are left anteriorly to attempt to improve the length of the soft palate. Since the entire anterior border of the flap is elevated, it is imperative to preserve the greater palatine vessels for blood supply. The nasal incision is made behind the posterior border of the hard palate (Figure 20–12).

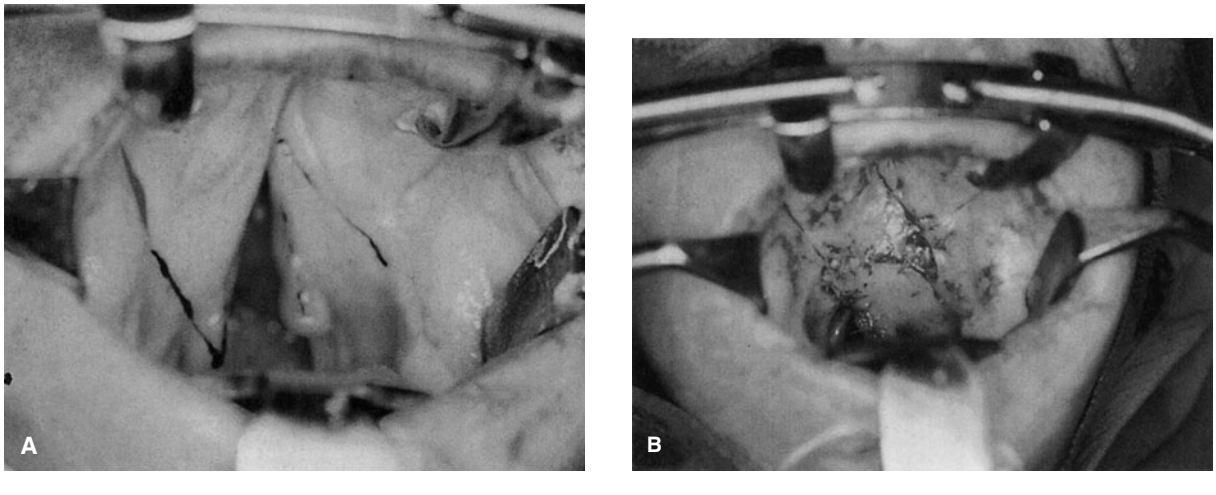
Although the pushback repair is excellent for improving length and can be used to great effect in combination with a pharyngeal flap, in complete clefts there is a substantial anterior area, which depends on nasal closure only. It is not surprising that this repair has a higher incidence of anterior fistulas, which can contribute to speech problems and are difficult to repair secondarily.

C. Two-flap palatoplasty—This technique uses more extensive bilateral flaps, which are based on the palatine vessels, and provides both greater security in the anterior closure and a decreased incidence of fistulas. Basically, this procedure extends the von Langenbeck technique by bringing the relaxing incisions behind the alveolar ridge forward to the cleft margin (Figure 20–13).



▲ **Figure 20–13.** Two-flap palatoplasty. **(A)** Mucoperiosteal flaps raised with intact greater palatine vessels. **(B)** Closure completed anteriorly up to the posterior alveolar margin.

D. Double-opposing Z-plasty—The use of opposing Z-plasty procedures on the oral and nasal side of the soft palate produces increased length but also realigns the levator palatini muscle in an overlapping fashion. The tensor tendon can be divided to release some of the tension on the repair. This may be a difficult technique to use in wider clefts, but it is an excellent choice in narrower clefts and submucous clefts (Figure 20–14).



▲ **Figure 20–14.** Furlow double-reversing Z-plasty. **(A)** Marking for Z-plasty. **(B)** Flaps transposed. Note that the nasal pattern (not seen) is the reverse pattern.

E. Levator muscle repair—The routine repair of the levator palatini muscle has only recently become a widely accepted technique in palate repair. The dissection of the muscle from both oral and nasal mucosa can be difficult, especially on the nasal side, and some physicians have even proposed using a microscope for the procedure.

A more aggressive approach to the levator muscle is achieved by dividing the tensor palatini tendon as it curves behind the hamulus so that the conjoined portion of the levator muscle is released. The muscle can then be placed well posteriorly and even overlapped to give additional tension to the closure. Excellent speech outcomes have been reported with this technique.

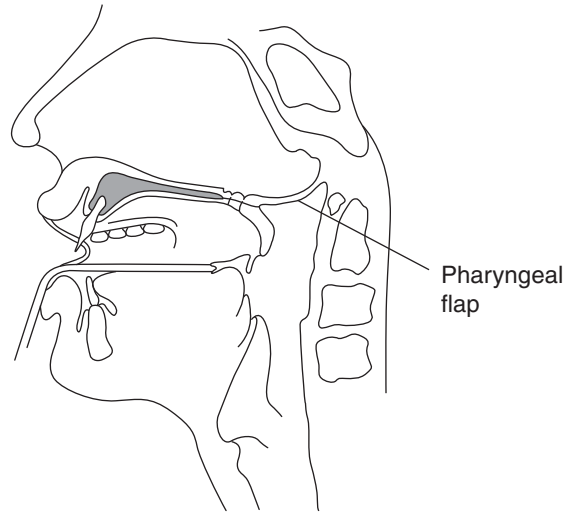
E. Velopharyngeal Insufficiency

Even with the best surgical technique, some patients have nasal air escape with speech after cleft palate repair. This can be due to scarring or shortening of the soft palate, inadequate movement of the levator muscle (which can be due to preexisting neurologic factors or surgical injury), or fistula formation with air loss through the hole rather than through the posterior pharynx. This is termed velopharyngeal insufficiency, or VPI.

1. Preoperative evaluation—Careful speech evaluation by a speech pathologist, usually a member of the cleft palate team, is the cornerstone of evaluation of VPI. Diagnostic methods include lateral cephalograms, nasal manometry, video fluoroscopy, or direct evaluation by nasoendoscopy. The temporary occlusion of a fistula by a piece of foil or a stoma adhesive in a cooperative patient can help to differentiate problems with the soft palate from those caused by a fistula. It is important to differentiate global VPI from "phoneme-specific" VPI, which occurs only with certain sounds, usually sibilants; the latter can be treated with speech therapy only, whereas the former generally requires surgical intervention.

2. Surgical measures—Surgery for VPI can be broadly divided into procedures that lengthen a functioning palate and those that partially obstruct the area of closure in the posterior pharynx. Lengthening procedures include the V-Y pushback or the Furlow Z-plasty, both described previously. Posterior procedures include the pharyngeal flap and the pharyngoplasty.

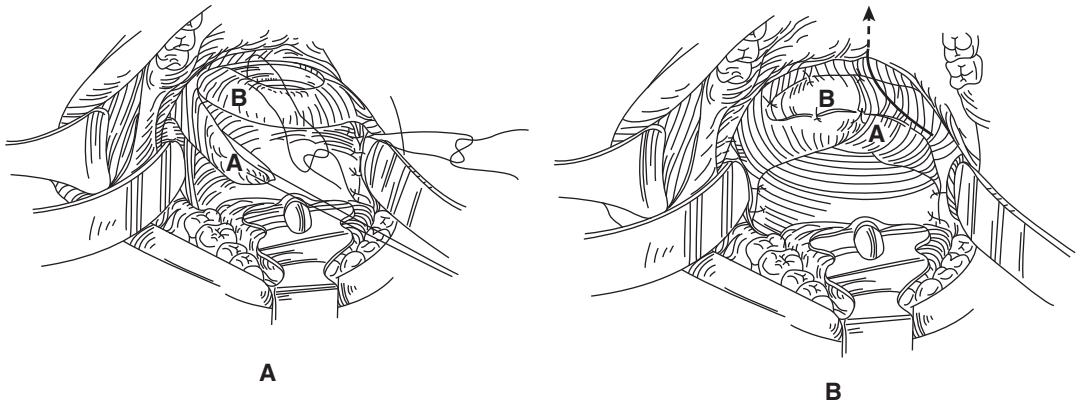
A. Pharyngeal flap—The pharyngeal flap consists of mucosa and muscular tissue taken from the posterior pharyngeal wall, generally with a superior base near the adenoid tissue (Figure 20–15). The flap can be placed into a defect in the nasal mucosa when combined with a pushback procedure, or sutured into the soft palate with a variety of techniques. All of these methods leave the flap partially obstructing the nasopharynx with air going through "ports" on either side. If the ports are too large, VPI will persist; if they are too small, nasal obstruction and hyponasal speech may result. In most large series, the success rate in treating VPI is 80–90%. A significant rate of sleep apnea, as high as 30–40%, has been reported with pharyngeal flaps.



▲ **Figure 20–15.** Pharyngeal flap. The flap is raised off the posterior pharyngeal wall and inset into the soft palate. Ports are left on each side of the flap for airflow.

B. Sphincter pharyngoplasty—The sphincter pharyngoplasty uses flaps made from the posterior tonsillar pillars, including the palatopharyngeus muscle, to create a theoretically innervated flap. These two flaps are sutured into a bare area created on the posterior pharyngeal wall just below the adenoids, creating a central port of decreased size and a larger area of prominence for contact with the velum. Success rates have been reported at approximately 90%, but with a smaller rate of sleep apnea (Figure 20–16).

3. Nonsurgical measures—Nonsurgical approaches to velopharyngeal insufficiency (VPI) can be considered when patients are poor candidates for surgery either because of general health or because of specific conditions in the palate, such as scarring. Nonsurgical treatment modalities include orthodontic appliances to cover any open fistulas anteriorly or a **speech bulb prosthesis** (also known as a **palatal lift appliance**), which is a prosthetic device with a large posterior extension to lift the soft palate superiorly and posteriorly. In a palate that is not repaired, a speech bulb may itself provide a point for contact of the posterior and lateral pharyngeal walls to provide closure during speech (Figure 20–17).



▲ **Figure 20–16.** Sphincter pharyngoplasty. **(A)** Myomucosal flaps are elevated from each posterior tonsillar pillar and a transverse incision made joining the two. **(B)** The overlapping flaps are sutured to each other and to the posterior pharyngeal wall, creating a central narrow port for airflow.

F. Secondary Surgical Procedures

As the child with a cleft grows, additional procedures are required. At a minimum, after lip and palate repair, bone grafting of the alveolar cleft and, later, septorhinoplasty, usually combined with any residual lip repair, are performed. It is important to reiterate the role that team care can play in this process; by having at least annual visits, the team can monitor the child's progress and recommend appropriate interventions at the optimum time.

1. Lip revision—The ultimate goal of cleft lip repair is to avoid secondary surgery, since each revision of a cleft lip scar creates new scar tissue and, of necessity, removes at least a small amount of adjacent normal tissue. Revision of the cleft repair is a common necessity, however; the most common problems are misalignment of the white roll or the junction of the wet and dry mucosa, inadequate length of the lip on the repaired side, and disparate fullness of the lip between the two sides. The last is easiest to correct because the new scar can be placed out of sight completely within the wet vermilion. Many techniques exist to correct the length of the lip repair, the most common being rerotation of an advancement-rotation repair (Figure 20–18).

The timing of revision is often coordinated with school ages, since entering a new school can be traumatic for the young child. Obvious problems are best corrected before kindergarten. A minor problem that is not causing any psychological concerns can often be addressed in conjunction with other procedures, such as bone grafting or rhinoplasty.

Bilateral cleft lip repairs are often staged, and columellar lengthening is best performed at age 4 or 5 before school starts. In some bilateral clefts with severe scarring, a **cross-lip flap** (also known as an **Abbe flap**) may be necessary; this simultaneously reduces the lower lip while adding bulk and length to the central portion of the upper lip (Figure 20–19).

2. Bone grafting—Bone grafting of the alveolar cleft is generally performed during mixed dentition, before eruption of the permanent cuspid. The procedure generally follows orthodontic maxillary expansion, if it is required; it is important to coordinate this procedure with the efforts of the treating orthodontist. The bone graft serves several functions: (1) stabilization of the maxilla, (2) support for the roots of the adjacent teeth, (3) closure of any residual anterior fistula, and (4) support for the alar base on the cleft side. As noted above, the lateral incisor is usually absent; the bone graft will support a dental implant for replacement of the missing incisor and aid in support for other prosthetic devices, such as a fixed bridge.

The bone graft is placed between the bony margins of the two (or three) alveolar segments after elevating the mucoperiosteal flaps to close the nasal floor and the anterior palate; the anterior opening is then closed by advancing a gingivoperiosteal flap from the lateral segment. Although cranial bone and rib have been advocated as donor sites, iliac crest cancellous bone remains the "gold standard" for this application.

Early bone grafting has also been proposed, with placement of a small rib graft in the alveolar space at the time of lip repair. This has generally been associated with increased rates of maxillary hypoplasia, although there may be significant technical variations that have an effect on long-term results.

As discussed previously, some centers are performing **gingivoperiosteoplasty,** which is the closure of the

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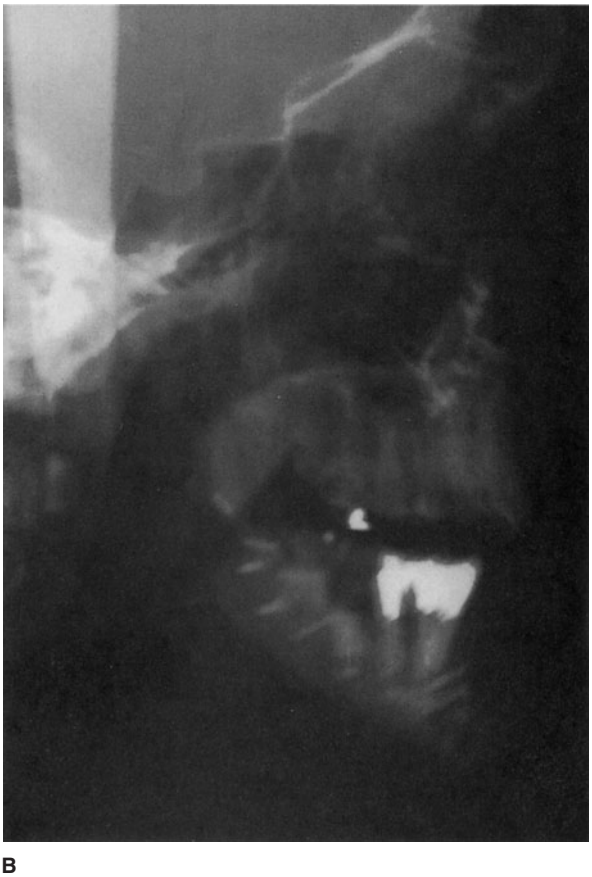

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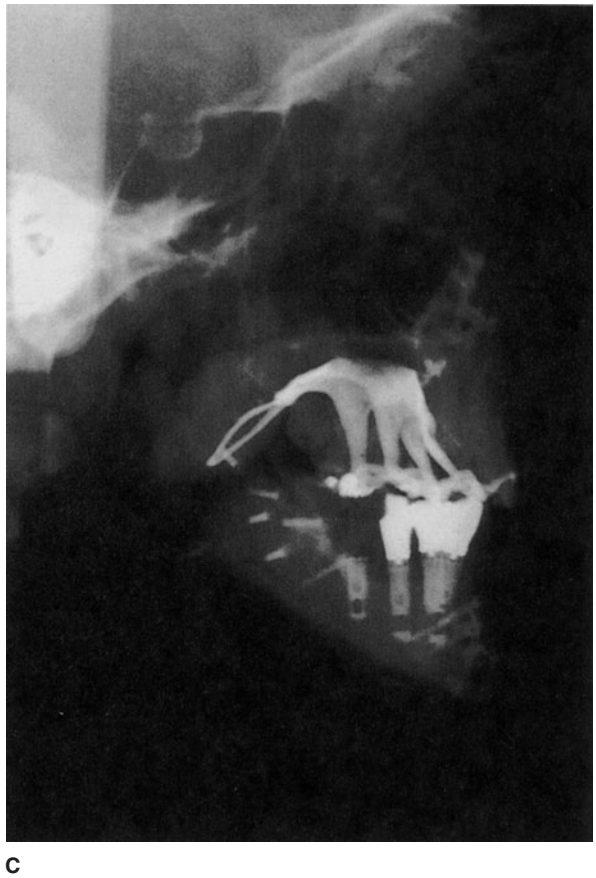
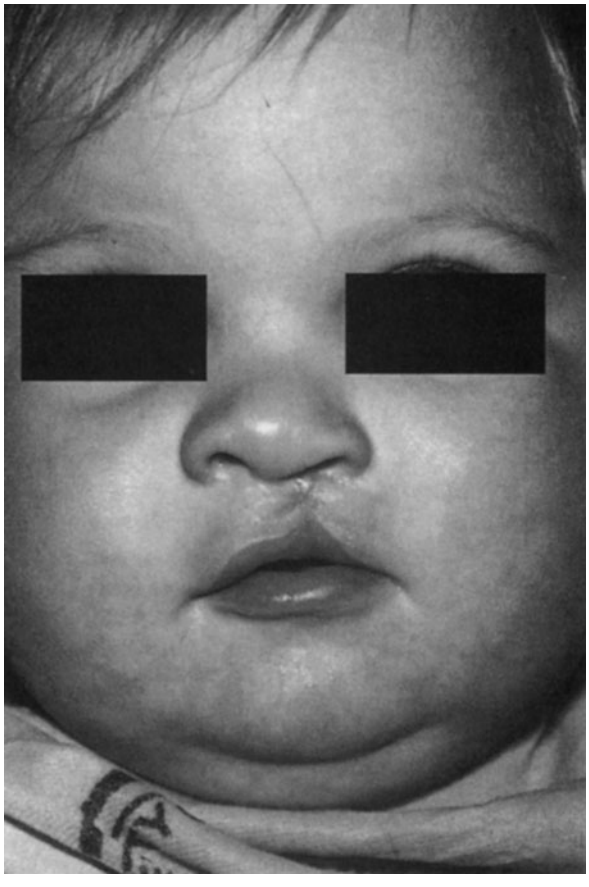


C

▲ **Figure 20–17.** **(A)** Speech bulb prosthesis. The large projection on the right side of the photo is gradually built up to elevate the soft palate. **(B)** Lateral cephalogram without the prosthesis. **(C)** Lateral cephalogram with prosthesis. The reduction in the posterior pharyngeal airspace can be seen clearly.



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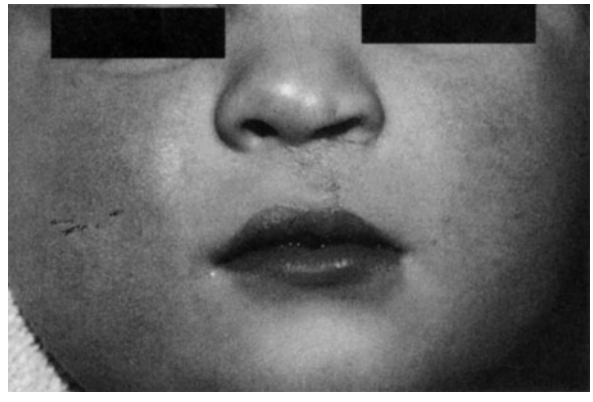

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▲ **Figure 20–18.** Revision of unilateral cleft lip repair. **(A)** A 1-year-old child several months after lip repair complicated by partial separation. **(B)** One year after revision, with complete redo of rotation advancement repair.

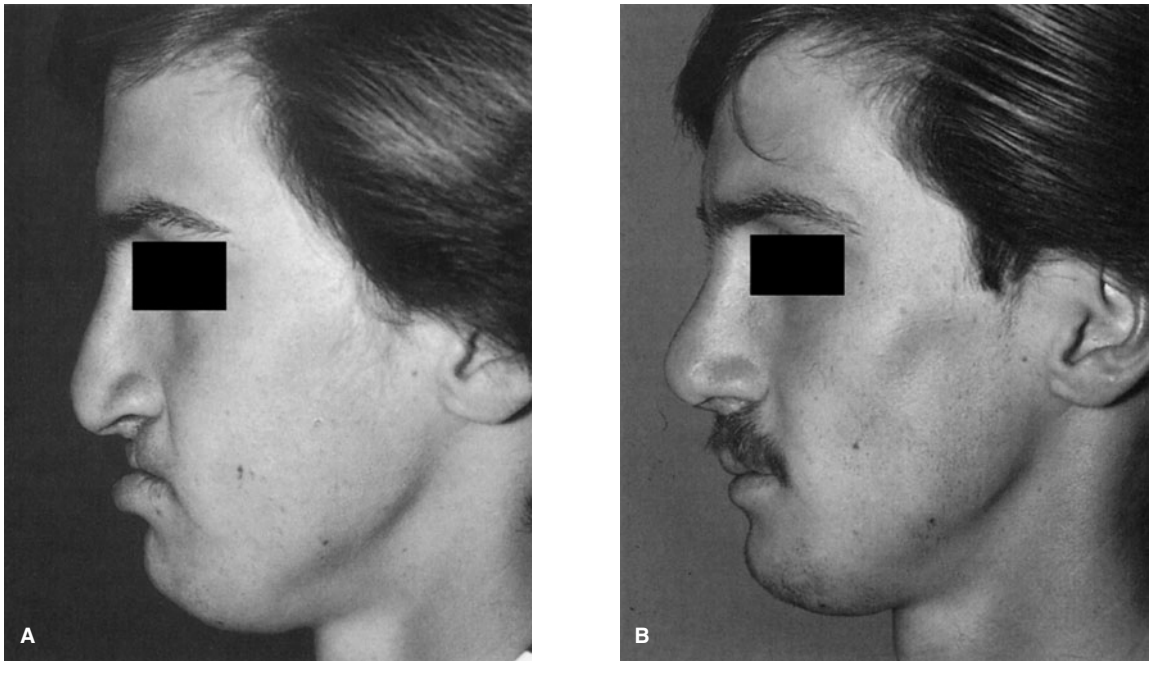
alveolar gap at the time of the primary lip repair. This can be accomplished only after careful alveolar positioning with a molding plate. Early results are promising at this stage, but it is too soon to evaluate the orthodontic and maxillary growth aspects of dentofacial development in these children.

3. Rhinoplasty—Both unilateral and bilateral clefts require rhinoplasty—usually in the early teens. If orthognathic surgery is required (see the following section), rhinoplasty is done subsequently. Every effort should be made at the time of lip repair to minimize the nasal deformity, but this has no effect on the severe septal deviation to the side of the cleft that is seen in most patients with a unilateral cleft.

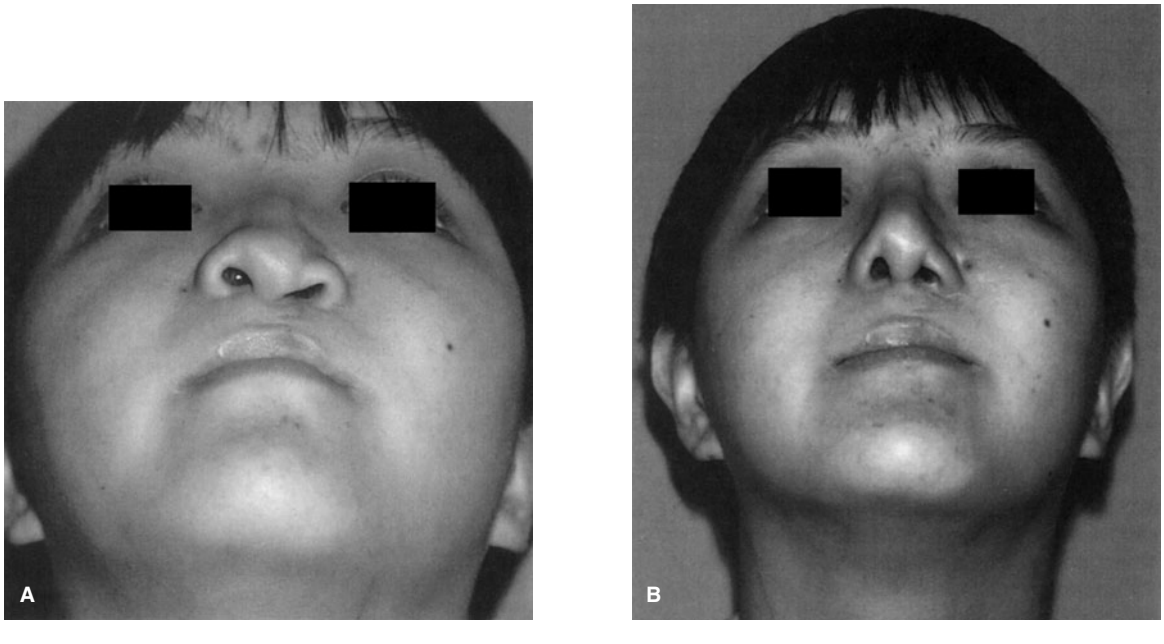
The septum is corrected with **septoplasty** or submucous resection of the septum; the latter is useful in that the removed cartilage can be used to reconstruct the nasal tip and provide graft material for a columellar strut and for the nasal tip.

Open rhinoplasty techniques are favored for cleft nasal reconstruction since they provide greater exposure for accurate correction. In unilateral clefts, the deficient cartilage on the side of the cleft can be rotated into a symmetrical position, sometimes augmented with tip grafting. In bilateral clefts, the two alar cartilages must be sutured together to achieve better tip narrowing and projection (Figure 20–20).

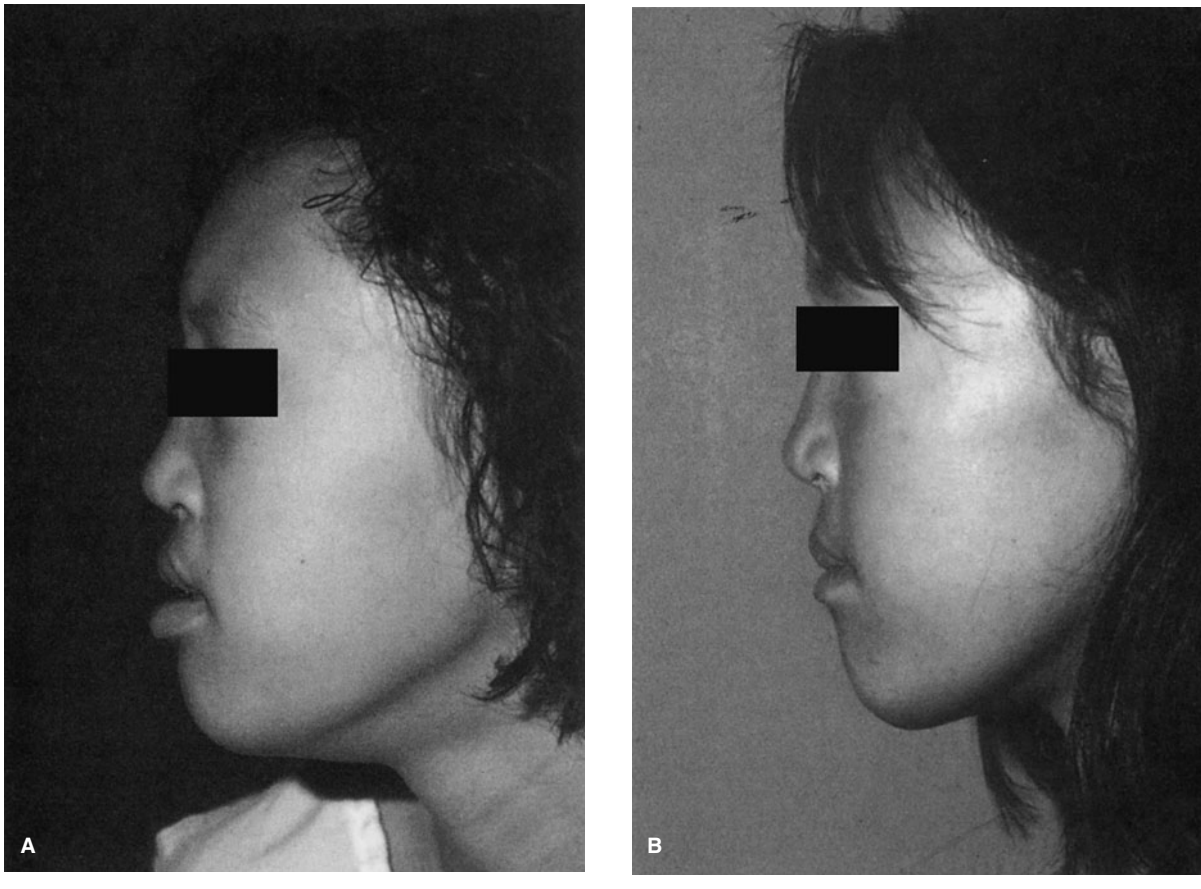
4. Orthognathic surgery—Approximately 10–15% of patients with clefts require **orthognathic surgery,** usually maxillary advancement. The decision regarding jaw surgery affects the orthodontic approach as well as the timing of bone grafting (this can be done at the time of maxillary surgery in some cases, rather than as a separate procedure). A large discrepancy between the two jaws may require the simultaneous setback of the mandible. Generally, these procedures are done near skeletal maturity, since the mandible is one of the last bones to stop growing—in early teens for



▲ **Figure 20–19.** A cleft lip reconstruction. The upper lip was reconstructed with an Abbe (cross-lip) flap, and a complete septorhinoplasty was completed. **(A)** Lateral view before surgery. **(B)** Lateral view after two operations. Note that the transfer of tissue from lower to upper lip has restored normal balance between the two.



▲ **Figure 20–20.** Late nasal reconstruction. **(A)** Preoperative view. Note severe slumping of alar cartilage on the cleft (left) side, inadequate nasal dorsum. **(B)** Postoperative view after rib cartilage grafting to the dorsum and columellar strut to support the nasal tip.



▲ **Figure 20–21.** Le Fort I maxillary advancement. **(A)** Profile prior to advancement. This patient had a cleft palate only. **(B)** Profile after maxillary Le Fort I procedure with rigid fixation.

girls, later for boys. It is important to monitor the patient's speech after maxillary advancement because the palate may come forward enough to produce nasal air escape where none was present previously (Figure 20–21).

American Cleft Palate Association. Parameters for evaluation and treatment of patients with cleft lip/palate or other craniofacial anomalies. *Cleft Palate Craniofac J* 1993;30:S1 [PMID: 8457579]. (Consensus paper from the American Cleft Palate Association that summarizes their recommendations for team care of patients with cleft lip and palate.)

Millard R. *Cleft Craft: The Evolution of Its Surgery.* Boston, MA: Little, Brown, 1976. (Classic text on cleft repairs. Even if dated, it is encyclopedic in scope, covering both history and technical aspects of cleft lip and palate surgery.)

Losee JE, Kirschner RE, editors. *Comprehensive Cleft Care.* New York: McGraw-Hill Medical, 2009. (This new text is extensive, well illustrated and affordable with chapters by most of the leaders in the field.)

21 Management of Adenotonsillar Disease

Maria V. Suurna, MD

ANATOMY AND PHYSIOLOGY

Waldeyer ring describes a circular structure of lymphoid tissue located in the nasopharynx and the oropharynx. It is formed by the two palatine tonsils, pharyngeal tonsils or adenoids, tubal or Gelach tonsils surrounding eustachian tube opening and lingual tonsils. The lymphoid tissue of Waldeyer tonsillar ring contains B-cell lymphocytes, T-cell lymphocytes, and a few mature plasma cells. This tissue is primarily involved in secretory immunity and regulates immunoglobulin production.

The cells are organized in lymphoid follicles similar to lymph nodes, but have specialized endothelium-covered channels that facilitate antigen uptake directly into the tissue. The independence of this system from lymphatic drainage is a unique advantage for antigen acquisition. The location of Waldeyer tonsillar ring and its design allow direct exposure of the immunologically active cells to foreign antigens entering the upper aerodigestive tract, which maximizes immunologic memory. These tissues are most active from the ages of 4–10 and tend to involute after puberty. After their involution, the secretory immune function of these tissues remains, but at a lower level.

The **palatine tonsils** are the largest component of the Waldeyer ring and are found in the lateral walls of the oropharynx. The tonsils are located within a tonsillar fossa formed by three pharyngeal muscles. The palatoglossus muscle forms the anterior tonsillar pillar, the palatopharyngeal muscle forms the posterior tonsillar pillar, and the base of the tonsillar fossa is formed by the pharyngeal constrictors, primarily the superior constrictor. The fibrous capsule of a tonsil is attached to the fascia of the pharyngeal muscles. The potential space between the tonsil and the pharyngeal muscles is a usual site of a peritonsillar abscess.

The glossopharyngeal nerve lies deep to the superior pharyngeal constrictor and supplies sensation to the tonsil through the tonsillar branch. The tympanic branch of glossopharyngeal nerve is responsible for a referred otalgia that is commonly present with tonsillar inflammation or following tonsillar surgery. The descending branches of the lesser palatine nerve are another sensory supply to the tonsil. The arterial blood supply is primarily based at the inferior pole, and the tonsillar branch of the dorsal lingual artery, the ascending branch of the palatine artery, and the tonsillar branch of the facial artery enter at this site. The superior pole receives its blood supply from the ascending pharyngeal artery and from the lesser palatine artery. Venous drainage occurs through a venous peritonsillar plexus that drains into the lingual and pharyngeal veins and feeds into the internal jugular vein. Lymphatic drainage is usually to the tonsillar lymph node behind the angle of the mandible, or to other jugulodigastric lymph nodes.

The tonsillar lymphoid tissue forms deep crypts that are lined with stratified antigen-processing squamous epithelium. These crypts maximize the exposure of tissue to surface antigens. They can also harbor debris and bacteria and become a source for infection, halitosis, and tonsilloliths.

The **adenoids** or pharyngeal tonsils and the lingual tonsils are not as well defined or specialized as the palatine tonsils. These structures consist of lymphoid tissue covered by a specialized, pseudostratified, ciliated columnar epithelium that forms redundant surface folds to maximize the surface area of the tissue. The adenoids are located over the surface of the superior and posterior wall of the nasopharynx, and have greatest growth in the first years of life.

Due to the confined space, adenoid hypertrophy can be a cause of upper airway obstruction in young children. By the age of 5, the adenoids start to regress and, with skull base growth, adenoid hypertrophy is rarely a problem thereafter. The blood supply to the adenoids includes numerous branches of the palate and pharynx. Venous drainage is to the pharyngeal plexus, and the lymphatics drain into the retropharyngeal and pharyngomaxillary lymph nodes.

INFECTIONS

The oropharynx and Waldeyer tonsillar ring are normally colonized by many species of aerobic and anaerobic bacteria, including staphylococcus, nonhemolytic streptococci, lactobacillus, bacteroides, and actinomyces. These organisms, and other pathogenic bacteria, viruses, fungi, and parasites, can cause infections of tonsillar and adenoid tissue. Oropharyngeal cultures obtained during the infection are not always useful in distinguishing the offending pathogen as they often yield multiple organisms, reflecting the normal flora of the oral mucosa.

ACUTE PHARYNGOTONSILLITIS

Acute pharyngotonsillitis may be caused by viral or bacterial infection, viral etiology being the most common. It is often difficult to distinguish between the two causes based on clinical exam. Patients present with fever, malaise, odynophagia, and lymphadenitis. On a physical exam tonsillar enlargement, erythema, and exudate may be present.

Viral Infections

Roughly half of cases of acute pharyngotonsillitis have a viral etiology. Patients commonly present with complaints of sore throat and dysphagia. Upon examination, there is often fever, tender cervical lymphadenopathy, tonsillar inflammation, and erythema with possible exudate. Common viral pathogens include adenovirus, rhinovirus, reovirus, respiratory syncytial virus (RSV), influenza, and parainfluenza viruses. Treatment for most viral infections is generally supportive. In some cases, patients develop a bacterial superinfection of tonsils that results in more severe symptoms. These patients benefit from systemic antibiotics.

Tonsillar infections with the Coxsackie virus result in herpangina, which presents as ulcerative vesicles over the tonsils, posterior pharynx, and palate. The disease commonly occurs in children under the age of 16. Such patients present with generalized symptoms of headache, high fever, anorexia, and odynophagia.

Epstein–Barr Virus (EBV) belongs to the herpes family of viruses and causes acute pharyngitis as a part of infectious mononucleosis. In developed nations and regions of high socioeconomic status, primary infection by EBV occurs during the second and the third decade of life. This is not the case in developing countries where more young children are affected by the disease. EBV is transmitted orally, and manifests as fever, generalized malaise, lymphadenopathy, hepatosplenomegaly, and pharyngitis. The tonsils are severely enlarged, sometimes to the point of compromising the airway, and are covered with an extensive grayish-white exudate. When the virus is acquired at a younger age, symptoms are often less severe.

EBV preferentially infects and transforms human B lymphocytes. The incubation period is about 2–6 weeks, during which EBV induces a proliferation of infected B cells. This is followed by a cellular immune response, characterized by the appearance of "atypical" cytotoxic T lymphocytes in the blood. In immunosuppressed patients with inherited or acquired immunodeficiency, such as AIDS, X-linked lymphoproliferative disorder, and post-transplant immunosuppression, this T-lymphocyte response is limited, and uncontrolled proliferation of B cells may result in hyperplasia of lymphoid tissues. EBV is also associated with Hodgkin and non-Hodgkin lymphomas, Burkett lymphoma, nasopharyngeal carcinoma, and other lymphoproliferative disorders.

Diagnosis of acute infectious mononucleosis usually can be made upon clinical observation of absolute lymphocytosis, atypical lymphocytes in the peripheral smear, heterophile antibodies, and EBV-specific antibodies. Increased fluid intake, rest, and analgesics comprise primary treatment. In the case of progressive airway obstruction due to obstructive tonsillar swelling, a short course of systemic steroids can also help. Rarely, a nasopharyngeal airway, nasotracheal intubation, tonsillectomy, or tracheotomy might be required to secure the airway.

An acute retroviral syndrome is a manifestation of primary infection with the human immunodeficiency virus (HIV). Following 1–5 week incubation period, symptoms develop that include fever, nonexudative pharyngitis, lymphadenopathy, and systemic symptoms such as arthralgia, myalgia, and lethargy.

Bacterial Infections

1. Acute Streptococcal Pharyngotonsillitis

Group A beta-hemolytic streptococcus (GABHS) is the most common cause of acute bacterial pharyngotonsillitis in children. "Strep throat" is a very common disease among adolescents and children, with an incidence that peaks during the winter and spring months, and tends to be uncommon in children less than 3 years of age. Transmission generally occurs through droplet spread and the incubation period is about 2–5 days. Symptoms usually include fever, sore throat, cervical lymphadenopathy, dysphagia, and odynophagia. Physical examination typically reveals tonsillar and pharyngeal erythema with purulent exudate.

Throat culture with a blood agar plate (BAP) is the standard method for establishing the diagnosis of pharyngitis caused by group A streptococcus in children. Office-based rapid antigen-detection tests (RADT) are also available. These tests have excellent specificity; however, the sensitivity of these tests is lower when compared to BAP leading to recommendation to confirm negative RADT results with BAP culture. The definitive tests to determine GABHS infection is measuring serum titers of antistreptolysin O (ASO). Certain individuals, "carriers," have positive throat cultures and remain asymptomatic.

Early diagnosis of GABHS pharyngitis and appropriate antimicrobial treatment is a standard of care to primarily prevent rheumatic fever. Although a number of drugs have shown promise in treating GABHS, a 10-day course of Penicillin V remains the treatment regimen of choice. Amoxicillin is commonly substituted for penicillin. Intramuscular benzathine penicillin G given as one dose is also an effective treatment and can be used when compliance with oral regimen is a concern. First-generation cephalosporins, macrolides, and climdamycin are alternatives for treatment of patients allergic to penicillin.

Complications of GABHS infection—Most GABHS pharyngotonsillitis is benign and self-limited; however, the potential for nonsuppurative and suppurative complications exists. The emphasis on rapid diagnosis and the widespread use of antibiotics have markedly decreased the incidence of nonsuppurative complications. In contrast, suppurative complications of acute bacterial tonsillitis are still commonly encountered.

A. Nonsuppurative complications—**Scarlet fever** occurs secondary to the endotoxin production by the bacteria during the episode of acute streptococcal pharyngotonsillitis. Clinical presentation includes erythematous rash, fever, lymphadenopathy, dysphagia, and erythematous tonsils and pharynx covered with a yellow membranous film. The tongue may become red, with desquamation of the papillae, often described as "strawberry tongue."

Acute **rheumatic fever** usually occurs 1–4 weeks following pharyngotonsillitis caused by GABHS. Streptococcal infection results in production of cross-reactive antibodies to heart muscle, leading to subsequent endocarditis, myocarditis, or pericarditis. Once heart tissue damage occurs, little can be done to reverse the process.

Poststreptococcal **glomerulonephritis** typically occurs as an acute nephritic syndrome about 1–2 weeks after a pharyngotonsillar infection or skin infection with a GABHS. The pathogenic mechanism of the disease involves injury to the glomerulus by deposition of the immune complexes as well as circulating autoantibodies.

A clinical entity known as pediatric autoimmune neuropsychiatric disorder associated with group A streptococcal infection (**PANDAS**) has been described. PANDAS is associated with the abrupt onset of severe exacerbations of obsessive–compulsive type behaviors or tics in children following GABHS infection. The pathophysiology of this condition is thought to be similar to Sydenham chorea, in which antineuronal antibodies cross-react with regions in the basal ganglia, producing behavioral and motor disturbances.

B. Suppurative complications—Suppurative complications of bacterial pharyngotonsillitis include peritonsillar abscess, parapharyngeal abscess, retropharyngeal abscess, and cervical lymphadenitis or abscess. **Peritonsillar abscess** forms as a result of the spread of infection from the superior pole of the tonsil into the potential space between the pharyngeal muscle bed and the tonsillar capsule. The abscess usually occurs unilaterally and patients present with severe pain, odynophagia, and dysphagia. Trismus is often present secondary to the inflammation of the pterygoid musculature. On examination there is unilateral swelling of the plate with the tonsil medially displaced and the uvula shifted to the opposite side. Needle aspiration and incision and drainage are usually performed to treat the abscess. In patients with recurrent tonsillitis and recurrent peritonsillar abscess, a tonsillectomy is often recommended. Most surgeons prefer to operate after the acute infection has resolved; however, a "Quincy tonsillectomy," which is a tonsillectomy in acutely infected patient, is occasionally performed.

Infection from the tonsil or from a peritonsillar abscess can spread through the superior constrictor muscle into a potential space between the superior constrictor muscle and the deep cervical fascia forming a **parapharyngeal space abscess**. The abscess leads to medial displacement of the tonsil and pharyngeal wall. The patients often present with trismus and a decrease in the neck's range of motion secondary to the inflammation of adjacent pterygoid and paraspinal muscles. If not treated, the abscess may spread down the carotid sheath and into the mediastinum.

A **retropharyngeal abscess** may result from a spread of peritonsillar abscess or from infection of the lymph nodes in the retropharyngeal space. It is more common in children and symptoms usually include fever, dysphagia, muffled speech, noisy breathing, neck stiffness, and cervical lymphadenopathy.

Pharyngotonsillitis can lead to the enlargement and infection of the corresponding draining lymph nodes. Patients may present with enlarged, warm, erythematous, tender lymph nodes that can then progress to suppuration and abscess formation.

2. Non–Group A Streptococcal Pharyngitis

Group C and G streptococci commonly colonize upper respiratory tract and have been responsible for food-borne and waterborne outbreaks of pharyngitis. The symptoms can be similar to group A streptococcal pharyngitis but are generally less severe. Non–group A streptococci have never been shown to cause acute rheumatic fever.

Pharyngeal **diphtheria** is now extremely rare due to the widespread use of childhood immunization. The infection is caused by *Corynebacterium diphtheriae* and primarily occurs in unimmunized individuals. In addition to the usual symptoms of acute pharyngitis, this disease is characterized by a grayish firmly adherent pseudomembrane that covers the tonsils and may extend to the nares, uvula, soft palate, and pharynx. The disease can spread to larynx and tracheobronchial tree potentially compromising the airway. Removal of the pseudomembrane reveals bleeding of underlying surface. Exotoxins produced by *C. diphtheriae* may produce cardiac toxicity and neurotoxicity. The diagnosis is confirmed by culture of the pseudomembrane in Loeffler's or tellurite selective medium. The treatment should be started immediately

with administration of diphtheria antitoxin and penicillin or erythromycin, even before confirmation with the culture.

Patients with exposure to sexually transmitted diseases can develop tonsillar infections with *Neisseria gonorrhoeae* or *Treponema pallidum*. Gonococcal infections may present as an exudative pharyngitis. Primary oral syphilis manifests as a painless chancre on the lips, buccal mucosa, or oropharynx. Patients with secondary syphilis may present with bilateral tonsillar hypertrophy and painful oropharyngeal and tonsillar ulcers.

The role of anaerobic bacteria in tonsillitis should also be considered. Anaerobic bacteria predominate in tonsillar and retropharyngeal abscesses. There is also evidence of synergy between anaerobes and GABHS in cases of pharyngotonsillitis.

Fungal Infections

Oropharyngeal **candidiasis** is caused by overgrowth of *Candida albicans* and often present in patients with a history of immunosuppression, radiation, or altered microflora following long-term broad-spectrum antibiotic use. On exam, there are white cottage-cheese-like plaques over the pharyngeal mucosa, which bleed if removed with a tongue depressor. Clinical diagnosis may be confirmed with potassium hydroxide staining revealing fungal hyphae. Initial therapy usually consists of oral hygiene and topical treatment. Some of the available agents include oral nystatin preparations, amphotericis lozenges, and clotirimazole torches.

RECURRENT ACUTE TONSILLITIS

Many patients experience episodes of acute tonsillitis with complete recovery between episodes. The tonsils, because of their location and numerous crypts and crevices, harbor bacteria. Aggressive medical therapy for acute tonsillitis may not prevent additional infections. Otolaryngologists and primary care providers have debated the role of surgery for these patients for many years. Most surgeons now agree that a tonsillectomy is indicated in patients with recurrent acute tonsillitis involving 6–7 episodes of acute tonsillitis in 1 year, 5 episodes per year for 2 consecutive years, or 3 episodes per year for 3 consecutive years.

CHRONIC TONSILLITIS

Chronic tonsillitis is diagnosed when a sore throat is present for at least 3 months and is associated with tonsillar inflammation, halitosis and persistent tender cervical adenopathy. Clinical examination is often unremarkable but may reveal decreased tonsillar crypts and a smooth tonsillar capsule.

Antibiotics effective against anaerobes and beta-lactamase producing organisms, such as clindamycin or amoxicillin clavulanate, can be used for treatment. In patients with chronic tonsillitis unresponsive to appropriate antimicrobial therapy that results in persistent foul taste, halitosis or recurrent tonsillitis associated with the GABHS carrier state, tonsillectomy would be indicated.

Tonsilloliths are microbial biofilms that form within tonsillar crypts and are associated with halitosis and chronic cryptic tonsillitis. Patients may present with a foreign body sensation in the throat and expressible, hard white masses on their tonsils. Complete or intracapsular tonsillectomy is a treatment option for chronic cryptic tonsillitis in adults.

CHRONIC ADENOTONSILLAR HYPERTOPHY

Tonsillar and adenoid tissue has many specialized immunologic compartments responsible for humoral and cellular immune response, such as crypt epithelium, lymphoid follicles, and extrafollicular regions. Tonsils and adenoids are the first lymphoid organs in the body to encounter ingested and inhaled pathogens.

Hypertrophy of the lymphoid tissue occurs in response to colonization with normal flora, exposure to pathogenic microorganisms, and reaction to environmental factors. Lymphoid tissue of the Waldeyer ring is very small in infants and it significantly increases in size by the time the child is 4 years of age in association with immunologic activity.

Nasal obstruction, rhinorrhea, and a hyponasal voice are the usual presenting symptoms of adenoid hypertrophy. Tonsillar enlargement can cause snoring, dysphagia, and either a hypernasal or a muffled voice. Chronic adenotonsillar hypertrophy is the most commonly associated with sleep-disordered breathing in children, with symptoms ranging from upper airway obstruction to obstructive sleep apnea syndrome (OSAS). Upper airway obstruction can manifest as loud snoring, chronic mouth breathing, and secondary enuresis.

A history of witnessed apneic episodes, hypersomnolence or hyperactivity, frequent nighttime awakenings, poor school performance, and a general failure to thrive are common manifestations of obstructive sleep apnea. Over time, more severe cases of OSAS can lead to pulmonary hypertension, cor pulmonale, and alveolar hypoventilation resulting in chronic CO_2 retention, which can be slow to resolve even after relieving the obstruction with adenotonsillectomy.

The diagnosis of adenotonsillar hypertrophy is based on clinical history and physical examination. Nasal endoscopy is helpful in diagnosing adenoid hypertrophy, adenoid infections, and velopharyngeal insufficiency (VPI), as well as ruling out other causes of nasal obstruction. Lateral neck soft tissue radiography can be helpful in evaluating hypertrophic adenoids. Because of the difficulties in performing sleep studies in young children, the use of polysomnography to document obstructive sleep apnea in these patients remains controversial. This test is usually reserved for patients without a clear history of airway obstruction or for patients with craniofacial anomalies and neurologic disorders.

TONSILLAR NEOPLASMS

Asymmetric tonsillar hypertrophy is a physical finding that should prompt a physician to include neoplasms in the differential diagnosis. A likelihood of a malignant process is increased when tonsillar asymmetry is associated with rapid enlargement, constitutional symptoms, atypical tonsillar appearance, ipsilateral cervical lymphadenopathy, and a history of previous malignant growths.

Unilateral tonsillar enlargement in asymptomatic children is rarely of neoplastic etiology. Most children with apparent tonsil asymmetry have either asymmetric effacement of the tonsils by the tonsillar pillars or benign asymmetry of the tonsils. However, tonsillar lymphoma should be considered when unilateral tonsillar enlargement is present in an immunocompromised child or when acute asymmetric tonsillitis is unresponsive to medical therapy.

When this finding is accompanied by a suspect clinical course or history, a tonsillectomy should be performed for biopsy. Lymphoma and squamous cell carcinoma are the most common primary tonsillar neoplasms, but other malignant tumors may also present. Many primary malignant neoplasms such as melanoma and renal cell, lung, breast, gastric, and colon carcinomas have been reported to metastasize to the tonsil.

Benign tumors of the tonsil are rare and they include lipomas, fibromas, and schwannomas. Parapharyngeal space tumors are important to consider as a diagnosis, since they may present with signs and symptoms mimicking an asymmetric tonsillar hypertrophy or a tonsillar abscess.

POST-TRANSPLANT LYMPHOPROLIPERATIVE DISORDER

Post-transplant lymphoproliferative disorder is a life-threatening disorder in immunosuppressed population. It results from uncontrolled B-cell proliferation secondary to EBV infection in transplant patients in whom the cytotoxic T-cell activity is suppressed to prevent organ rejection. Adenotonsillar hypertrophy is often the initial presentation in pediatric cases. The process can progress to involve multiple organ systems. Risk factors include organ transplantation at a young age, genetic predisposition, type of organ transplant, type and intensity of immunosuppression, and EBV status. Adenotonsillectomy provides tissue for histopathologic diagnosis and relieves upper airway obstruction. Treatment often includes reduction of immunosuppression, adjuvant therapy with acyclovir or gangciclovir to prevent EBV DNA replication, and interferon alpha.

INDICATION FOR TONSILLECTOMY AND ADENOIDECTOMY

Adenotonsillectomy is one of the most common operations performed on children. Recurrent streptococcal tonsillitis traditionally has been the most common reason for the procedure. However, the trend for surgical treatment has shifted in the past few decades to upper airway obstruction being the most common indication for tonsillectomy and adenoidectomy in children. There has been an increasing recognition of the impact of labored breathing as a result of obstructive sleep disorder on the development of children.

Adenotonsillar hypertrophy is the most frequent cause of obstructive sleep-disordered breathing and adenotonsillectomy was shown to be effective in improving associated symptoms and quality of life; thus, it is considered to be the frontline therapy in pediatric cases. However, the effectiveness of adenotonsillectomy decreases significantly in obese patients, children with multiple morbidities, and patients with severe preoperative sleep apnea.

Polysomnography is considered a gold standard for evaluation and diagnosis of pediatric obstructive sleep disorder. Due to high cost, limited access, difficulty in performing the study in pediatric population, and associated delay in treatment, polysomnography is rarely used preoperatively in otherwise healthy children. A history of snoring with or without witnessed apneas, restlessness, daytime somnolence, behavioral changes, poor cognitive performance, and adenotonsillar hypertrophy on physical exam are criteria used to recommend adenotonsillectomy. Polysomnography is recommended for children under the age of 3 with medical comorbidities, morbid obesity, craniofacial syndromes, neuromuscular disorders, and when physical exam findings do not correlate with the degree of airway obstruction.

The current indications for tonsillectomy are referenced in Table 21–1. In all cases, the potential benefits of tonsillectomy should be weighed against the significant

Table 21–1. Surgical Indications for Tonsillectomy and Adenoidectomy.

Infectious Disease
Recurrent, acute tonsillitis, with more than 6–7 episodes in 1 year, 5 episodes per year for 2 years, or 3 episodes per year for 3 years
Recurrent, acute tonsillitis, with recurrent febrile seizures, or cardiac valvular disease
Chronic tonsillitis, unresponsive to medical therapy or local measures
Peritonsillar abscess with history of tonsillar infections
Obstructive Disease
Heroic snoring with chronic mouth breathing
Obstructive sleep apnea or sleep disturbances
Adenotonsillar hypertrophy with dysphagia or speech abnormalities
Adenotonsillar hypertrophy with craniofacial growth or occlusive abnormalities
Mononucleosis with obstructive tonsillar hypertrophy, unresponsive to steroids
Other
Asymmetric growth or tonsillar lesion suspicious for neoplasm (without adenoidectomy)

Table 21–2. Surgical Indications for Adenoidectomy Alone.

Infectious Disease
Adenoid hypertrophy with eustachian tube dysfunction and persistent ear infection or middle ear effusion
Adenoid hypertrophy associated with chronic sinusitis, unresponsive to medical therapy
Obstructive Adenoid Hypertrophy
Heroic snoring with chronic mouth breathing
Obstructive sleep apnea or sleep disturbances
Craniofacial growth or occlusive abnormalities
Other
Adenoid mass or lesion or asymmetric enlargement

morbidity of the procedure and the potential postoperative complications. The adenoids are often involved in the primary process affecting the tonsils and should be included in any discussion of tonsillar disease management. Because adenoidectomy has minimal additional morbidity when compared with tonsillectomy, it is often performed simultaneously with tonsillar surgery if the surgeon feels it will benefit the patient. The indications for adenoidectomy without tonsillectomy are listed in Table 21–2.

Tonsillectomy and Adenoidectomy Surgical Techniques

Traditional tonsillectomy results in the total removal of the tonsils. The procedure involves an incision of the mucosa adjacent to the tonsil along the anterior pillar, identification of the tonsillar capsule, and subcapsular dissection of the tonsil free from the underlying muscle bed. Blood vessels extending from the muscle bed into the tonsillar capsule, particularly at the superior and inferior poles, are carefully cauterized or ligated.

Cold dissection surgical techniques utilizing the scalpel, guillotine, or snare have largely been replaced with techniques utilizing cautery to achieve better hemostasis and to reduce intraoperative blood loss. Electrocautery introduces increased thermal damage to the surrounding tissues that results in more postoperative pain and odynophagia, which yields decreased oral intake and an increased risk of dehydration.

Newer tonsillectomy techniques have been introduced in recent years with a goal to decrease the morbidity, bleeding and pain, as well as the operative time of the procedure. The intracapsular tonsillectomy technique involves reduction of tonsils while preserving the tonsillar capsule with a thin rim of tissue, thereby, lessening the disruption of underlying muscle, nerves, and blood vessels. Several studies have shown that patients undergoing intracapsular tonsillectomy with microdebrider or coblator had significantly less postoperative pain and an earlier return to regular diet and activity as compared to total removal of tonsil with electrocautery technique. Due to these advantages, it has been gaining popularity in treating patients with sleep-disordered breathing secondary to adenotonsillary hypertrophy. There are still questions regarding long-term complications including tonsillar regrowth and development of recurrent tonsillitis for which patient might need to undergo additional surgery.

A variety of surgical modalities is available for adenoidectomy. Traditional adenoidectomy was performed using adenotome or adenoid curette to sharply excise adenoid tissue. More recently, techniques allowing for more controlled removal of adenoid tissue utilizing microdebrider, suction electrocautery, and coblator have been used. Morbidity from this procedure is fairly low, with minimal pain and a low incidence of postoperative bleeding, halitosis, or neck pain.

COMPLICATIONS OF TONSILLECTOMY AND ADENOIDECTOMY

Adenotonsillectomy and its postoperative course have a potential for significant morbidity and complications. Intraoperative complications related to general anesthesia are low. Care should be taken to suction oropharyngeal secretions and blood to reduce the risk of laryngospasm and aspiration following extubation. With the use of electrocautery, airway fire is a potential risk and can be avoided by reducing the oxygen concentration of the inspired gas and by minimizing an air leak around the endotracheal tube. Dental injury, temporomandibular joint dislocation, accidental extubation, and cautery burns are other potential intraoperative complications.

Postoperative bleeding is the most common complication of adenotonsillectomy. It occurs in about 5% of the cases. It can occur as a primary event within 24 hours of surgery or more commonly as a secondary event, usually between postoperative days 5 and 10 as a result of premature separation of eschar. The internal carotid artery lies within 5–30 mm of the lateral tonsillar fossa and can be injured as a result of deep cautery, suturing, or dissection.

In the immediate postoperative period, the patient may experience nausea, vomiting, and oropharyngeal pain that may lead to dehydration. Airway obstruction may develop secondary to edema. Postobstructive pulmonary edema may develop after relief of a long-standing, compensated airway obstruction or following inspiratory effort against obstruction caused by laryngospasm. Velopharyngeal insufficiency can occur following adenoidectomy in patients with a cleft palate or undiagnosed submucous cleft. Atlantoaxial subluxation, or Grisel syndrome, can occur as a result of ligamentous laxity secondary to inflammatory process following adenoidectomy. About 15% of patients with Down syndrome have asymptomatic atlantoaxial instability and can develop atlantoaxial subluxation postoperatively. Nasopharyngeal and oropharyngeal stenosis are long-term complications,

albeit uncommon, resulting from excessive tissue removal, approximation of raw mucosal surfaces during healing process, and scar contracture and maturation.

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We would like to acknowledge Yelizaveta Shnayder, MD, Kelvin C. Lee, MD, and Joseph M. Bernstein, MD for their contribution to this chapter in the previous editions of CDT.

Parapharyngeal Space Neoplasms & Deep Neck Space Infections

22

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DEEP NECK SPACE INFECTIONS

ANATOMY OF FASCIAL NECK PLANES & SPACES

The spatial compartments within the neck are defined by fascial planes. An understanding of this complex anatomy aids the clinician in diagnosing the cause of an infection and its likely routes of spread. Commonly affected spatial compartments are the retropharyngeal, parapharyngeal, and submandibular spaces.

The fascia of the neck comprises the superficial and the deep layers. The deep layer of cervical fascia is further divided into three layers: superficial, middle, and deep. The superficial portion of the deep cervical fascia envelops the sternocleidomastoid and trapezius muscles. It extends superiorly to the hyoid bone where it surrounds the submandibular gland and the mandible. Inferiorly, it attaches to the clavicle and, medially, it forms the floor of the submandibular space as it covers the muscles of the floor of mouth. The middle layer of deep cervical fascia, also known as the visceral or pretracheal fascia, surrounds the infrahyoid strap muscles, the thyroid, the larynx, the trachea, and the esophagus. Below the hyoid, this layer continues inferiorly to fuse with the pericardium. Above the hyoid, this layer continues on the posterior pharyngeal wall as the buccopharyngeal fascia. Between the middle and deep layers of deep cervical fascia is the retropharyngeal space.

The deep layer of cervical fascia, also known as the prevertebral fascia, surrounds the prevertebral muscle. Anteriorly, the deep layer of cervical fascia divides to form a thin alar layer and a thicker prevertebral layer. Between these two layers is the "danger space," extending from the skull base to the diaphragm.

The submandibular space is bound in four ways: (1) anteriorly by the mandible, (2) superiorly by the mucosa of the floor of mouth, (3) inferiorly by the superficial layer of the deep cervical fascia, and (4) posteriorly by the parapharyngeal space. The mylohyoid muscle further divides this space into the submaxillary space (below the mylohyoid muscle) and sublingual space (above the mylohyoid muscle).

ESSENTIALS OF DIAGNOSIS

- Sore throat, dysphagia, odynophagia, and neck pain.
- Fever, trismus, and neck mass.
- CT scan with contrast, ring enhancement, scalloping of the abscess wall, or any combination of these findings.

General Considerations

Pharyngitis and dental infections are the most common causes of deep neck space infections. However, in a large portion of patients, the etiology is unknown. Other etiologies include salivary gland infections, trauma, intravenous drug use, and malignancy.

Deep space infections of the head and neck tend to follow the fascial planes of the neck. Controversy exists concerning the choices of empiric antimicrobial therapy, imaging modalities, and medical versus surgical treatment. The successful management of these potentially life-threatening infections depends on an understanding of the anatomy of the cervical fascial planes and spaces, bacteriology, and the potential complications that may arise.

Clinical Findings

A. Symptoms and Signs

The most common signs and symptoms are painful/tender neck mass and fever. Patients may also present with leukocytosis, as well as signs and symptoms affecting the aerodigestive tract, including odynophagia, dysphagia,

trismus, and dyspnea. On physical exam, a parapharyngeal space abscess pushes medially to the tonsil and the lateral pharyngeal wall. Alternately, posterior wall swelling may be noted with a retropharyngeal space abscess.

B. Laboratory Findings

Laboratory tests should include a complete blood count, a measure of electrolytes with creatinine, and blood cultures. Leukocytosis is common and an increased hematocrit count may be suggestive of dehydration. Renal function should be checked before administration of intravenous contrast during the CT scan. Blood cultures should be drawn and sent before administering the first dose of antibiotics, especially if the imaging is suggestive of cellulitis rather than abscess.

C. Imaging

Although the history and the physical exam generally are sufficient to suggest deep neck abscesses, a variety of imaging studies may be useful both to confirm clinical suspicion and to delineate the extent of the infection. In the past, lateral plain radiographs aided in diagnosing retropharyngeal abscess; however, CT scans with intravenous contrast have become the cornerstone of diagnosis. Features of ring enhancement around a hypodense center have yielded a sensitivity of 87–95% and a specificity of 60–92% in larger series. Furthermore, an irregular enhancing border around a hypodense region on a CT scan is associated with an increased specificity (94%) for purulence at the time of surgery. However, given that it is a late finding associated with the breakdown of the lymph node or abscess wall, its sensitivity is only 60%.

Ultrasound may be a more effective means of distinguishing an abscess from cellulitis. However, CT scans provide additional information about the extent of the infection, its relation to the great vessels, and, in the case of prevertebral and retropharyngeal space infections, CT scans can rule out mediastinal extension. This combination of information is important in determining the safest surgical approach to ensure complete drainage.

Although magnetic resonance imaging (MRI) gives overall better soft tissue detail, it has not been used extensively in the evaluation of deep neck abscesses. The clinician is often limited by its availability, but it is of obvious benefit in patients with renal dysfunction or contrast allergies.

Lazor JB, Cunningham MJ, Eavey RD, Weber AL. Comparison of computed tomography and surgical findings in deep neck infections. *Otolaryngol Head Neck Surg* 1994;111(6):746 [PMID: 7991254]. (Assesses the accuracy of CT scans in patients manifesting signs and symptoms of deep neck infection. The false-positive rate was 13.2% and the false-negative rate was 10.5%.)

Rustom IK, Sandoe JAT, Makura ZGG. Paediatric neck abscesses: microbiology and management. *J Laryngol Otol* 2008;122: 480–484 [PMID: 17559713]. (Evaluates the presenting symptoms, microbiology and treatment of pediatric patients with neck abscesses)

Wetmore RF, Mahboubi S, Soyupak SK. Computed tomography in the evaluation of pediatric neck infections. *Otolaryngol Head Surg* 1998;119:624 [PMID: 9852537]. (Evaluates the efficacy of CT scans in superficial and deep neck infections; there is a 92% correlation between surgical and CT scan findings for deep neck infection.)

Differential Diagnosis

The differential diagnosis of a patient with fever, sore throat, and neck mass includes a broad spectrum of disorders. The diagnoses include pharyngitis with lymphadenopathy, suppurative lymphadenopathy, infected branchial cleft cyst, and deep neck abscess. A CT scan with contrast may help distinguish these various entities. Patients who present without fever or tenderness but with evidence of centrally hypodense lymph nodes should alert the physician to consider other less common entities such as mycobacterial infection, undiagnosed metastatic thyroid malignancy, and squamous cell carcinoma.

Treatment

The airway should be assessed on initial evaluation. If compromised, plans should be made for an immediate local tracheotomy or a fiberoptic intubation. Although fine-needle aspiration (FNA) and intravenous antibiotics have demonstrated efficacy for superficial neck abscesses, the treatment of deep neck abscess is generally incision and drainage. Patients with equivocal radiographic findings (low or heterogeneous lesions without ring enhancement) may initially be treated with antibiotics alone. Table 22–1 lists the common organisms from deep neck infections. Because of the increased incidence of penicillin resistance, antibiotics should cover gram-positive and anaerobic bacteria. If there is no clinical improvement on intravenous antibiotics within 48–72 hours, a repeat CT scan may document the evolution to abscess, therefore dictating the need for surgical intervention.

Table 22–1. Common Organisms in Deep Neck Infections.

Staphylococcus	43–74%
Streptococcus	13–50%
Anaerobes	7–17%
Haemophilus	4–11%

The surgical approach taken depends on the cause and the anatomic involvement of the infection. For example, in the retropharynx, lymph nodes generally involute with age. Thus, an abscess in the retropharyngeal space of an adult typically results from either trauma or the secondary spread of infection from a separately infected space. This infection is usually free to track vertically along fascial planes. In contrast, most pediatric abscesses result from suppurative adenitis. Because these pediatric abscesses typically originate in a lymph node, they are usually well contained in an inflammatory rind. Most pediatric otolaryngologists advocate transoral drainage for a patient with an infection of a retropharyngeal space abscess medial to the great vessels when it represents a confined process with no evidence of spread along the fascial planes. Abscesses with extension lateral to the great vessels may require transcervical or combined approaches for adequate drainage; these approaches may also be necessary in treating deep neck abscesses in adult patients.

Boscolo-Rizzo P, Marchiori C, Zanetti F, Vaglia A, Da Mosto MC. Conservative management of deep neck abscesses in adults: the importance of CECT findings. *Otolaryngol Head Neck Surg* 2006;135(6):894–899 [PMID: 17141080]. (Evaluates the efficacy of antibiotic therapy without surgical management for deep neck space infections.)

Daramola OO, Flanagan CE, Maisel RH, Odland RM. Diagnosis and treatment of deep neck space abscesses. *Otolaryngol Head Neck Surg* 2009;141(1):123–130 [PMID: 19559971]. (Review of 106 cases of deep neck space infection with emphasis on etiology, treatment, and comorbidities associated with deep neck space infection.)

Gidley PW, Ghorayeb BY, Stiernberg CM. Contemporary management of deep neck space infections. *Otolaryngol Head Neck Surg* 1997;116(1):16 [PMID: 9018251]. (Evaluation and treatment of infections of cervical neck spaces with a discussion of complications of deep neck space infections.)

Kirse DJ, Roberson DW. Surgical management of retropharyngeal space infections in children. *Laryngoscope.* 2001;111(8):1413 [PMID: 11568578]. (Management of 73 retropharyngeal space tumors discussing the approach to and clinical significance of scalloping on a CT scan with contrast.)

Complications

With antibiotics, the incidence of complications of deep neck space infections has greatly diminished. Meningitis and cavernous sinus thrombosis have been reported as rare complications of these infections.

A. Internal Jugular Vein Thrombophlebitis

The most common vascular complication is Lemierre syndrome (internal jugular vein thrombophlebitis). Sepsis and septic emboli frequently ensue and affect the lungs, the musculoskeletal system, and, occasionally, the liver. The treatment generally consists of β-lactamase-resistant antibiotics with good anaerobic coverage. The role of anticoagulation is controversial. The most common offending organism is *Fusobacterium necrophorum.* Surgical intervention is indicated when there is a lack of improvement after 48–72 hours of intravenous antibiotics.

B. Mediastinitis

Mediastinitis can occur from an infection spreading along the retropharyngeal, "danger," or prevertebral spaces. Patients may have increasing chest pain; a chest radiograph or CT scan may show a widened mediastinum. Adequate drainage may require thoracotomy.

C. Carotid Artery Rupture

Carotid artery rupture should be suspected with recurrent small hemorrhages, hematoma of the surrounding tissues, a protracted clinical course, and shock. Radiographic imaging, which allows for an earlier accurate diagnosis and appropriate intervention, has made this a rare sequela.

William A, Nagy M, Wingate J, Bailey L, Wax M et al. Lemierre syndrome: a complication of acute pharyngitis. *Int J Pediatr Otorhinolaryngol* 1998;45(1):51 [PMID: 9804020]. (Case presentation and review of clinical presentation, diagnosis, and management.)

ANATOMY OF THE PARAPHARYNGEAL SPACE

The parapharyngeal space forms an inverted pyramid with its base at the skull and its apex at the greater cornu of the hyoid bone. The fascial margins of the parapharyngeal space are complex, comprising different layers of the deep cervical fascia. As it curves around the lateral side of the pharyngeal mucosal space, the middle layer of the deep cervical fascia forms the medial fascial margin. The lateral fascial margin is formed by the medial slip of the superficial layer of the deep cervical fascia as it curves around the deep border of the masticator and parotid spaces. Posteriorly, the parapharyngeal space fascia is made up of the anterior part of the carotid sheath, formed by the fusion of all three layers of the deep cervical fascia.

Extending from the medial pterygoid plate to the styloid process, the tensor veli palatini and its fascia divide the parapharyngeal space into pre- and poststyloid spaces. The poststyloid compartment contains cranial nerves IX–XII: the glossopharyngeal nerve (CN IX), the vagus nerve (CN X), the accessory or spinal nerve (CN XI), and the hypoglossal nerve (CN XII), as well as the carotid artery, the jugular vein, the cervical sympathetic chain, and glomus bodies. The prestyloid compartment, bound anteriorly by both the medial pterygoid muscle and the mandible, contains fat, minor or ectopic salivary glands, the internal maxillary artery, and the branches of V3 (ie, the mandibular branch of the trigeminal nerve). Understanding these fascial

compartments and spaces facilitates the accurate interpretation of images and preoperative diagnosis.

PARAPHARYNGEAL SPACE NEOPLASMS

ESSENTIALS OF DIAGNOSIS

- Neck mass, snoring, possible sleep apnea, and mild dysphagia.
- Medial displacement of oropharyngeal wall without erythema.
- Prestyloid or poststyloid mass as determined by computed tomography (CT) scanning or magnetic resonance imaging (MRI).
- Cytologic findings diagnostic of benign or malignant tumor.

General Considerations

A wide spectrum of benign and malignant neoplasms may be encountered in the parapharyngeal space. These masses include primary neoplasms, masses extending from adjacent regions, and metastatic tumors. Modern imaging has advanced the understanding of this complex anatomic area, aiding in the diagnosis and management of tumors within the parapharyngeal space. Several large series of retrospective and single institution studies have contributed to the rational management of these tumors.

Clinical Findings

A. Symptoms and Signs

Parapharyngeal space tumors may present with a number of symptoms; the most common are neck mass, pain, and dysphagia (Table 22–2). Mass effect may result in symptoms of pressure, characterized by dysphagia, dysarthria, and airway obstruction that may manifest as sleep apnea or snoring. Trismus suggests infiltration into the pterygoid muscles or a mechanical obstruction of the coronoid process. Otologic symptoms most commonly relate to eustachian tube dysfunction, resulting from compression of the cartilaginous portion of the eustachian tube by a tumor. Pulsatile tinnitus, hearing loss, and otalgia have also been noted.

The need for a thorough head and neck evaluation cannot be overemphasized. A surprising number of asymptomatic benign tumors are detected on a routine clinical examination or on an imaging study performed for unrelated symptoms. Displacement of the medial wall of the oropharynx and tonsil is usually the first sign of a parapharyngeal space lesion. Alternately, the mass may be found posterior or inferior to the angle of the mandible, as one would see with a mass in the neck or in the parotid gland. A careful cervical and bimanual intraoral evaluation allows the clinician to formulate an impression of the extent of tumor.

Table 22–2. Symptoms of Parapharyngeal Space Neoplasms.

Neck mass	46%
Pain	20%
Dysphagia	13%
Pharyngeal mass	9%
Hoarseness	7%
Foreign body sensation	6%
Parotid mass	4%
Otalgia	4%
Trismus	2%

Data from Carrau RL et al. Management of tumors arising in the parapharyngeal space. *Laryngoscope* 1990;100:583.

Because cranial nerves IX–XII pass through the poststyloid compartment, each nerve may be affected. The tumor may arise from a nerve, or it may cause compression of the adjacent neural structures. Patients with schwannoma or paraganglioma of the vagus nerve may present with vocal cord paralysis. Tumors of the skull base and jugular foramen may produce neuropathy of the glossopharyngeal nerve (CN IX), the vagus nerve (CN X), or the accessory nerve (CN XI), presenting as (1) a reduction or absence of the gag reflex, (2) vocal cord paralysis, and (3) trapezius weakness with shoulder drop, respectively.

B. Laboratory Findings

If imaging studies suggest a paraganglioma, urine screening for vanillylmandelic acid (VMA), metanephrine, and normetanephrine should be performed. It is important to ask specifically for a history of hypertension, hypertensive episodes, facial flushing, or tachyarrhythmia.

C. Imaging Studies

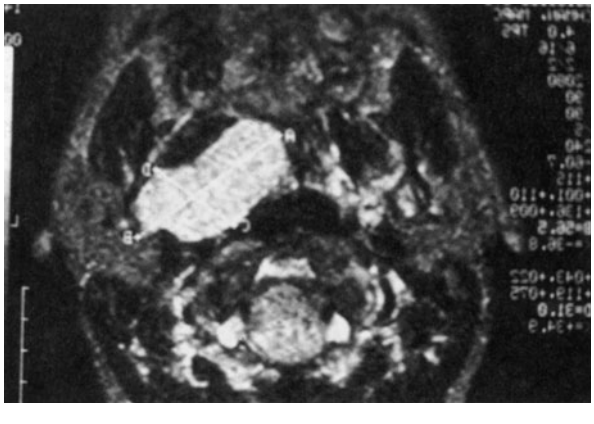
MRI or CT imaging allows localization of the tumor within one of the fascial compartments, relying on the relationship of the neoplasm both to surrounding fat planes and to structures such as the styloid process or skull base foramina (Table 22–3). The fatty triangle of the parapharyngeal space is easily identified on routine axial CT scans and MRI. Only when a mass is very large is the parapharyngeal space fat completely obscured. Tumors in the poststyloid parapharyngeal space, presumed to be nerve sheath lesions or paragangliomas, displace the parapharyngeal fat anteriorly and laterally. Tumors of the prestyloid space are most commonly salivary gland neoplasms. The preservation of the fat plane between the mass and the deep lobe of the parotid gland strongly suggests a neoplasm with an extraparotid

Table 22–3. Imaging Characteristics of Prestyloid Versus Poststyloid Masses.

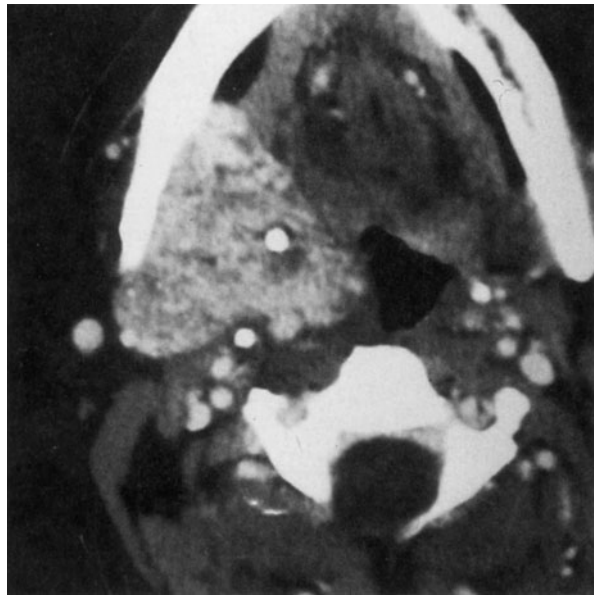
Prestyloid Space
Intraparotid mass
Fat planes between tumor and parotid gland lost
Parapharyngeal fat displaced anteriorly and laterally
Carotid artery displaced posteriorly
Extraparotid mass
Fat planes between tumor and parotid gland preserved
Parapharyngeal fat displaced anteriorly and laterally
Carotid artery displaced posteriorly
Poststyloid Space
Schwannoma
Fat planes between tumor and parotid gland preserved
Parapharyngeal fat displaced anteriorly and laterally
Carotid artery displaced anteriorly and/or medially[a]
Smooth enlargement of involved skull base foramen
Paraganglioma
Fat planes between tumor and parotid gland preserved
Parapharyngeal fat displaced anteriorly and laterally
Carotid artery displaced anteriorly and/or medially[b]
Ragged, irregular enlargement of involved skull base foramen

[a]Sympathetic chain schwannomas may displace the carotid artery posteriorly *or* anteriorly.
[b]Carotid body paragangliomas typically splay the internal and external carotid arteries.

origin, whereas the loss of a fat line between the mass and the parotid gland suggests a tumor that arises from the deep lobe of the parotid gland (Figures 22–1 and 22–2). Tumors originating from the deep lobe of the parotid gland may occasionally pass through the stylomandibular tunnel and have a dumbbell-like appearance.



▲ **Figure 22–1.** MRI of pleomorphic adenoma. Note continuity of tumor with deep parotid gland. (Photo contributed by Dr. Mark Urken.)



▲ **Figure 22–2.** Venous malformation of parapharyngeal space. (Photo contributed by Dr. Mark Urken.)

Radiographic visualization of carotid artery displacement is highly correlated with tumor groupings. Salivary gland tumors tend to displace the carotid artery in a posterior direction, whereas neuromas and glomus tumors distort the carotid sheath compartment in an anterior direction. The advantages of CT scans include lower cost, evidence of osseous invasion, and the demonstration of calcification within tumors. In contrast, MRI provides better soft tissue visualization of neural and vascular structures. By analyzing the inherent signal characteristics in combination with the surrounding fat plane distortion and the internal carotid artery displacement on MRI, the most common parapharyngeal masses may be distinguished.

Angiography should be considered if the initial CT scan or MRI suggests a vascular tumor or if carotid artery involvement is suspected. The precise blood vessels supplying the tumor can be determined and occluded before surgery. A carotid occlusion study may be necessary to determine whether a patient can tolerate the loss of the carotid artery.

D. Fine-Needle Aspiration Biopsy

Fine-needle aspiration (FNA) biopsy may contribute to the preoperative evaluation of parapharyngeal space tumors. Aspiration may be undertaken transcutaneously with tumors that are palpable in the neck or transorally with tumors that displace the pharyngeal wall significantly. CT-guided FNA may be appropriate in deeply seated parapharyngeal masses. FNA may be especially useful when clinical and radiographic

findings suggest a malignant neoplasm, affording the surgeon an opportunity to better counsel the patient and family preoperatively.

FNA results that do not correlate with other clinical findings suggest that a sampling error may have occurred. In addition, FNA is best avoided when a paraganglioma is suspected because of the potential for bleeding.

Cramer H, Lampe H, Downing P. Intraoral and transoral fine-needle aspiration. *Acta Cytol* 1995;39:340 [PMID: 7543234]. (Eight out of nine parapharyngeal space masses correctly diagnosed with FNA, with one third representing a malignant growth.)

Stambuk HE, Patel SG. Imaging of the parapharyngeal space. *Otolaryngol Clin North Am* 2008;41(1):77–101 [PMID: 18261527]. (Excellent review of the spatial anatomy and imaging characteristics of parapharyngeal space tumors.)

Differential Diagnosis

Tumors of the parapharyngeal space include primary neoplasms, tumors with direct extension from adjacent regions, and metastatic tumors (Tables 22–4 and 22–5).

A. Salivary Gland Neoplasms

Salivary gland neoplasms account for most of the parapharyngeal space tumors. Pleomorphic adenoma is the most common salivary gland neoplasm arising in the parapharyngeal space. It can arise from any portion of the parotid gland or from extraparotid salivary tissue. Other benign salivary gland tumors have been reported in the parapharyngeal space, including Warthin tumors, oncocytomas, and benign lymphoepithelial lesions. These tumors are commonly found in the prestyloid compartment. Rarely, mucoepidermoid carcinomas, malignant mixed tumors, adenoid cystic carcinomas, or adenocarcinomas may be encountered.

Table 22–4. Benign Parapharyngeal Space Neoplasms.

Salivary Gland
Benign lymphoepithelial disease
Monomorphic adenoma
Oncocytoma
Pleomorphic adenoma
Warthin tumor
Neurogenic
Ganglioneuroma
Neurilemoma
Neurofibroma
Paraganglioma
Miscellaneous
Arteriovenous malformation
Branchial cleft cyst
Lipoma
Meningioma

Data from Olsen KD. Tumors and surgery of the parapharyngeal space. *Laryngoscope* 1994;104(63):1.

Table 22–5. Malignant Parapharyngeal Space Neoplasms.

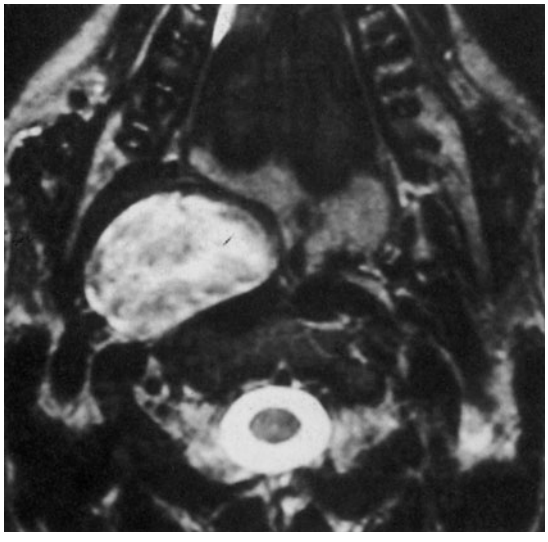
Salivary Gland
Acinic cell carcinoma
Adenocarcinoma
Adenoid cystic carcinoma
Mucoepidermoid carcinoma
Neurogenic
Malignant paraganglioma
Neurofibrosarcoma
Miscellaneous
Chondrosarcoma
Fibrosarcoma
Liposarcoma
Lymphoma
Metastatic disease

Data from Olsen KD. Tumors and surgery of the parapharyngeal space. *Laryngoscope* 1994;104(63):1.

B. Neurogenic Neoplasms

1. Schwannomas—Benign schwannomas or neurilemomas are the most common neurogenic neoplasm of the parapharyngeal space. The tumors typically present as slow-growing neck masses arising from any nerve with a Schwann cell sheath, including cranial nerves V3, IX, X, XI, and XII; the sympathetic nerve trunk; and the upper cervical nerves. Neurologic deficits do not always correlate with the nerve from which the neoplasm arises, and many patients are asymptomatic. The treatment of schwannomas is enucleation or tumor removal with preservation of the involved nerve. However, the large size of many of these tumors often precludes nerve preservation (Figure 22–3).

2. Paragangliomas—Chemodectomas or paragangliomas of the head and neck are rare and comprise 0.6% of head and neck tumors. They are usually slow growing and 2–3 times more common in women than in men. Paragangliomas involving the parapharyngeal space originate from either vagal or carotid bodies. Paraganglia develop from neuroectodermal tissue and are thought to function as part of the autonomic nervous system that monitors changes in the levels of pH, oxygen, and carbon dioxide. Ten percent of patients have a family history of these tumors, representing an inherited familial form. Multicentric neoplasms occur in 10–20% of sporadic cases and in up to 80% of familial cases. Thus, these patients should undergo routine preoperative screening for urinary catecholamines as well as abdominal and carotid



▲ **Figure 22–3.** Schwannoma of cervical sympathetic chain. (Photo contributed by Dr. Mark Urken.)

scanning to rule out clinically unrecognized tumors. In addition, a metastatic workup is warranted when imaging or clinical exam yields suspicious lesions; the therapeutic plan should address possible metastasis.

Overall, less than 10% of paragangliomas are malignant. Approximately 6% of carotid body tumors and 16–17% of vagal paragangliomas may be malignant. It is generally accepted that a paraganglioma is malignant only when metastasis to nonneuroendocrine tissue is demonstrated. Most commonly, paragangliomas spread regionally to the cervical lymph nodes or distantly to the lung, the liver, or the skin.

The most common presenting symptom of a vagal paraganglioma is a mass in the neck, often associated with hoarseness. The most common presenting symptom of a carotid paraganglioma is a mass located at the carotid bifurcation that is horizontally mobile, but vertically immobile.

Surgical removal of paragangliomas is the treatment of choice. Angiography with preoperative embolization minimizes bleeding as well as injury to the adjacent cranial nerves. Timing of surgical intervention is controversial. The patient and the surgeon must consider that these tumors are often benign and slow growing. Surgical resection may convert an asymptomatic patient to a patient with significant impairments of speech and deglutition. Observation may be warranted unless there is an increased suspicion for malignancy. For example, in cases of vagal paresis, surgical intervention may be delayed until the vagus nerve is completely nonfunctional. Patients fare better when given time to accommodate to a slowly progressive loss rather than to an acute iatrogenic paralysis.

Radiation therapy is another therapeutic option. To avoid debilitating bilateral paralyses to cranial nerves X and XII in multicentric tumors (eg, bilateral vagal or carotid paragangliomas), careful consideration should be given to which tumor should be resected initially and whether radiation therapy should be used in the management of one of these tumors. Radiation therapy can prevent further growth in many patients; however, late tumor progression can occur. Radiation does not reduce paraganglioma volume by the destruction of tissue; rather it induces fibrosis and decreases the fine vasculature of the tumor. In addition, poor surgical candidates (based on comorbidities, tumor size, tumor recurrence, or any combination of these factors) may elect radiation therapy for local control or symptomatic relief.

Hamza A, Fagan JJ, Weissman JL, Myers EN. Neurilemomas of the parapharyngeal space. *Arch Otolaryngol* 1997;123:622 [PMID: 9193224]. (Reviews the surgical management of neurilemomas of the parapharyngeal space in 26 patients.)

Lee JH, Barich F, Karnell LH et al. National cancer database report on malignant paragangliomas of the head and neck. *Cancer* 2002;94:730 [PMID: 11857306]. (A review of 59 cases of patients with malignant paraganglioma, including their symptoms. Presents a treatment algorithm.)

Pensak ML, Gluckman JL, Shumrick KA. Parapharyngeal space tumors: an algorithm for evaluation and management. *Laryngoscope* 1994;104:1170 [PMID: 8072368]. (A review of 123 patients, including their symptoms. Presents a treatment algorithm.)

Zhi K, Ren W, Zhou H, Wen Y, Zhang Y. Management of parapharyngeal-space tumors. *J Oral Maxillofac Surg* 2009;67(6):1239–1244 [PMID: 19446210]. (A review of 162 patients, including their presentation, tumor classification, and treatment.)

Surgical Treatment

Surgery is the mainstay of treatment. Intraoral biopsy and excision are generally contraindicated for all tumors.

A. Transcervical Approach

The transcervical approach is used for excising poststyloid space neoplasms. After flap elevation and identification of the ramus mandibularis, direct access to the poststyloid space is gained without dissecting the submandibular triangle. This approach has the distinct advantage of excellent cosmesis.

B. Transcervical–Submandibular Approach

The prestyloid parapharyngeal space may be satisfactorily approached through this method. A transverse incision is made in the most superior major skin fold, and then the superior portion of the cervical skin flap is elevated. The mandibular branch of the facial nerve must be identified and preserved. Retraction of the posterior belly of the digastric muscle permits the division and ligation of the facial artery, allowing the submandibular gland to be retracted anteriorly. The submandibular gland may be

removed and the digastric tendon divided if additional exposure is required.

C. Transparotid–Submandibular Approach

The excision of tumors arising from the deep lobe of the parotid gland and extending into the parapharyngeal space requires a transparotid–submandibular approach, including dissection of the facial nerve. A superficial parotidectomy is performed and then the deep lobe of the parotid gland is dissected free from the facial nerve. The mandibular branch of the facial nerve must be identified and preserved. Retraction of the posterior belly of the digastric muscle permits the division and ligation of the facial artery, allowing the submandibular gland to be retracted anteriorly. Lysis of the stylomandibular ligament enhances exposure; the neoplasm is then mobilized from the wound in a three-dimensional fashion.

D. Transmandibular Approach

The lateral mandibulotomy approach, commonly called the transmandibular approach, is best used for a pharyngeal malignant neoplasm that extends to the parapharyngeal space. This approach provides exposure and vessel control for vascular tumors extending to the skull base.

E. Other Approaches

Infratemporal fossa dissection and craniofacial approaches are reserved for malignant tumors, tumors involving the skull base, or tumors with intracranial extension.

Kanzaki S, Nameki H. Standardised method of selecting surgical approaches to benign parapharyngeal space tumours, based on pre-operative images. *J Laryngol Otol* 2008;122(6):628–634 [PMID: 17655777]. (Reviews imaging characteristics and surgical treatment of 22 patients with parapharyngeal space tumors, outlines a standardized method of selecting surgical approaches base on location of tumor.)

Malone JP, Agrawal A, Schuller DE. Safety and efficacy of transcervical resection of parapharyngeal space neoplasms. *Ann Otol Rhinol Laryngol* 2001;110:1093 [PMID: 11768696]. (33 patients undergoing the transcervical approach for parapharyngeal space neoplasms with excellent local control.)

Table 22–6. Complications of Parapharyngeal Space Surgery.

Hematoma
Seroma
Airway obstruction
Infection
Tumor recurrence
First bite pain
Frey syndrome
Cerebrospinal fluid leak
Meningitis
Nerve injury (greater auricular, facial, glossopharyngeal, vagus, spinal accessory, hypoglossal, cervical, or sympathetic)
Vessel injury (stroke, hemorrhage, or death)

Data from Olsen KD. Tumors and surgery of the parapharyngeal space. *Laryngoscope* 1994;104(63):1.

Complications

Paragangliomas account for most of the surgical morbidity (Table 22–6). There is a significant incidence of permanent deficits when operating on these neoplasms. A rehabilitation plan should be outlined with the patient and with family members who will aid in the support of the patient. The rehabilitation of speech and deglutition is facilitated if the patient understands (1) the function of cranial nerves IX, X, and XII and (2) the deficits that result with the functional loss of each nerve. The rehabilitation of a vagal paraganglioma may consist initially of augmentation by vocal fold injection with subsequent medialization laryngoplasty. Persistent velopharyngeal insufficiency may require palatoplasty.

Benign neurilemomas, soft tissue tumors, and salivary gland neoplasms are typically associated with less morbidity and rare recurrence compared with paragangliomas.

Olsen KD. Tumors and surgery of the parapharyngeal space. *Laryngoscope* 1994;104(63):1 [PMID: 8189998]. (An excellent review of the anatomy, presentation, and treatment of tumors affecting the parapharyngeal space.)

We would like to acknowledge Demetrio J. Aguila III, MD for his contribution to this chapter in the previous editions of CDT.

Benign & Malignant Lesions of The Oral Cavity, Oropharynx & Nasopharynx

23

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BENIGN & MALIGNANT LESIONS OF THE ORAL CAVITY & OROPHARYNX

ESSENTIALS OF DIAGNOSIS

- Nonhealing ulcer, painful or bleeding lesion.
- Lump in oral cavity or oropharynx.
- Neck mass.
- Dysphagia, dysphonia, or otalgia.
- Weight loss.
- Mass on imaging in primary site or neck.
- Positive biopsy of lesion.

General Considerations

The oral cavity is bounded anteriorly by the vermilion border of the lip, superiorly by the hard-soft palate junction, laterally by the tonsillar pillars, and inferiorly by the circumvallate papillae of the tongue. Cancer of the oral cavity is classified by subsite: lip, oral tongue (anterior two thirds), buccal mucosa, floor of mouth, hard palate, upper and lower gingiva (alveolar ridges), and retromolar trigone. There is an estimated annual incidence of 23,110 new oral cavity cancers in the United States with approximately 5370 deaths per year. Men are affected 2–4 times more often than women for all racial and ethnic groups. The incidence of oral cancer increases with age, with median age at diagnosis of 62, although there is a trend of increasing incidence of tongue cancer among young people.

Tobacco use (both chewing and smoking), alcohol, and betel nut chewing are well-established causes of oral cavity cancer, and their carcinogenic effects are often synergistic. Other etiologic factors include poor oral hygiene and immunosuppression. The majority (90%) of cases of lip cancer are related to chronic sun exposure.

The oropharynx is posterior to the oral cavity and is bounded by the soft palate superiorly and hyoid inferiorly. Oropharyngeal subsites include the base of tongue (posterior third), palatine tonsil, soft palate, and posterior pharyngeal wall. These lesions are often silent in early stages and, consequently, frequently present at advanced stage. Cancer of the oropharynx occurs in an estimated 7570 patients in the United States each year, resulting in approximately 1340 deaths. Males are afflicted 3–5 times more frequently than females. Oropharyngeal cancer is frequently related to tobacco and alcohol use, although 30–50% of cases may be related to human papilloma virus (especially HPV-16), particularly in tonsil cancer.

Staging

Staging for both lip and oral cavity cancer is determined according to the 2010 American Joint Committee on Cancer (AJCC) TNM (tumor, node, metastasis) staging system (Table 23–1). AJCC staging for oropharyngeal cancer is shown in Table 23–2.

Pathogenesis

The oral cavity and the oropharynx are lined by squamous epithelium. Therefore, the most common cancer arising from these regions is squamous cell carcinoma (SCC). Non-SCC histologies account for less than 10% of malignant lesions of the oral cavity. Minor salivary glands found throughout the oral cavity and oropharynx can give rise to adenocarcinoma, adenoid cystic carcinoma, mucoepidermoid carcinoma, and polymorphous low-grade carcinoma. Lymphoma is the second most common tumor of the tonsillar fossa. Other malignant tumors include sarcoma and mucosal melanoma.

Cancers of the oral cavity are often heralded by precancerous lesions. Leukoplakia and erythroplakia are white and red areas, respectively, which are abnormal but not necessarily neoplastic. These lesions may be entirely benign, precancerous, or frankly invasive, although this can only

Table 23–1. 2010 AJCC Staging: Lip and Oral Cavity.

Primary Tumor (T)			
T_X:	Primary tumor cannot be assessed		
T_0:	No evidence of primary tumor		
T_{is}:	Carcinoma in situ		
T_1:	Tumor ≤2 cm in greatest dimension		
T_2:	Tumor >2 cm, but not >4 cm, in greatest dimension		
T_3:	Tumor >4 cm in greatest dimension		
T_{4a}:	Moderately advanced local disease: • (Lip) Tumor invades through cortical bone, inferior alveolar nerve, floor of mouth, or skin of face (ie, chin or nose)[a] • (Oral cavity) Tumor invades adjacent structures only (eg, through cortical bone [mandible or maxilla], into deep [extrinsic] muscle of tongue [genioglossus, hyoglossus, palatoglossus, and styloglossus], maxillary sinus, or skin of face)		
T_{4b}:	Very advanced local disease: Tumor involves masticator space, pterygoid plates, or skull base and/or encases internal carotid artery		
Regional Lymph Nodes (N)			
N_X:	Regional lymph nodes cannot be assessed		
N_0:	No regional lymph node metastasis		
N_1:	Metastasis in a single ipsilateral lymph node ≤3 cm in greatest dimension		
N_2:	Metastasis in a single ipsilateral lymph node >3 cm, but not >6 cm, in greatest dimension; or in multiple ipsilateral lymph nodes, none >6 cm in greatest dimension; or in bilateral or contralateral lymph nodes, none >6 cm in greatest dimension		
N_{2a}:	Metastasis in a single ipsilateral lymph node >3 cm, but not >6 cm, in greatest dimension		
N_{2b}:	Metastasis in multiple ipsilateral lymph nodes, none >6 cm in greatest dimension		
N_{2c}:	Metastasis in bilateral or contralateral lymph nodes, none >6 cm in greatest dimension		
N_3:	Metastasis in a lymph node >6 cm in greatest dimension		
Distant Metastasis (M)			
M_0:	No distant metastasis		
M_1:	Distant metastasis		
Stage Grouping:			
0:	T_{is}	N_0	M_0
I:	T_1	N_0	M_0
II:	T_2	N_0	M_0
III:	T_3	N_0	M_0
	T_1	N_1	M_0
	T_2	N_1	M_0
	T_3	N_1	M_0
IVA:	T_{4a}	N_0	M_0
	T_{4a}	N_1	M_0
	T_1	N_2	M_0
	T_2	N_2	M_0
	T_3	N_2	M_0
	T_{4a}	N_2	M_0
IVB:	Any T	N_3	M_0
	T_{4b}	Any N	M_0
IVC:	Any T	Any N	M_1

[a]Superficial erosion alone of bone/tooth socket by gingival primary is not sufficient to classify as T4.

be determined after biopsy with histologic evaluation. Precancerous lesions range from dysplasia to carcinoma in situ and describe abnormal-appearing cells that have not invaded normal underlying epithelial tissues. Dysplasia is classified as mild, moderate, or severe according to its tendency to progress to cancer. Dysplasia, in mild forms, can regress if the carcinogenic agent is removed. Leukoplakia is usually a benign condition that is unlikely to progress into cancer (5%). Erythroplakia is more likely to be malignant at the time of the initial biopsy (51%).

The incidence of lymph node involvement from cancers of the oral cavity is related to the depth of invasion, site, size, and histologic grade of the primary tumor. Tumors of thickness greater than 1.5–2 mm are more likely to present with nodal metastases. Cancers of the oral tongue and floor of mouth have a higher incidence of nodal metastases than do cancers

Table 23–2. 2010 AJCC Staging: Oropharynx.

Primary Tumor (T)			
T_x:	Primary tumor cannot be assessed		
T_0:	No evidence of primary tumor		
T_{is}:	Carcinoma in situ		
T_1:	Tumor ≤2 cm in greatest dimension		
T_2:	Tumor >2 cm, but not >4 cm in greatest dimension		
T_3:	Tumor >4 cm in greatest dimension or extension to lingual surface of epiglottis		
T_{4a}:	Moderately advanced local disease: Tumor invades the larynx, extrinsic muscle of tongue, medial pterygoid, hard palate, or mandible[a]		
T_{4b}:	Very advanced local disease: Tumor invades lateral pterygoid muscle, pterygoid plates, lateral nasopharynx, or skull base or encases carotid artery		
Regional Lymph Nodes (N)			
N_x:	Regional lymph nodes cannot be assessed		
N_0:	No regional lymph node metastasis		
N_1:	Metastasis in a single ipsilateral lymph node ≤3 cm in greatest dimension		
N_2:	Metastasis in a single ipsilateral lymph nodes, >3 cm, but not >6 cm in greatest dimension; or in multiple ipsilateral lymph nodes, none >6 cm in greatest dimension; or in bilateral or contralateral lymph nodes, none >6 cm in greatest dimension		
N_{2a}:	Metastasis in a single ipsilateral lymph node >3 cm, but not >6 cm, in greatest dimension		
N_{2b}:	Metastasis in multiple ipsilateral lymph nodes, none >6 cm in greatest dimension		
N_{2c}:	Metastasis in bilateral or contralateral lymph nodes, none >6 cm in greatest dimension		
N_3:	Metastasis in a lymph node >6 cm in greatest dimension		
Distant Metastasis (M)			
M_0:	No distant metastasis		
M_1:	Distant metastasis		
Stage Grouping			
0:	T_{is}	N_0	M_0
I:	T_1	N_0	M_0
II:	T_2	N_0	M_0
III:	T_3	N_0	M_0
	T_1	N_1	M_0
	T_2	N_1	M_0
	T_3	N_1	M_0
IVA:	T_{4a}	N_0	M_0
	T_{4b}	N_1	M_0
	T_1	N_2	M_0
	T_2	N_2	M_0
	T_3	N_2	M_0
	T_{4a}	N_2	M_0
IVB:	T_{4b}	Any N	M_0
	Any T	N_3	M_0
IVC:	Any T	Any N	M_1

[a]Mucosal extension to lingual surface of epiglottis from primary tumors of the base of tongue and vallecula does not constitute invasion of the larynx.

of the lip, hard palate, and buccal mucosa. Cancers of the lip most commonly involve the lower lip and rarely proceed to lymphatic spread (<10%). In the case of nodal spread from lip cancer, it is typically the submental and submandibular nodes (level I) that are involved. Lateral tongue, floor of mouth, and buccal cancers drain to the ipsilateral submandibular nodal basin as well as to the upper (level II) and middle (level III) jugulodigastric nodes. Midline tumors may drain bilaterally.

Oropharyngeal tumors are frequently associated with nodal metastases at the time of diagnosis. The extensive lymphatics in this region drain primarily to the jugulodigastric basin (levels II to IV). It is important to note, however, that the retropharyngeal and parapharyngeal nodes are also at risk with oropharyngeal cancers.

Lung, liver, and bone are common metastatic sites for SCC of the oral cavity and oropharynx.

Prevention

Tobacco use, especially when combined with heavy alcohol intake, which has a multiplicative effect, accounts for 80% of oral cavity and oropharynx cancers in the United States. Stopping the use of tobacco products and decreasing alcohol intake can greatly reduce the risk of oral cancer and improve treatment outcomes. Cancer of the lip can be avoided by limiting sun exposure through the use of sunscreen or a wide-brimmed hat. Pipe smokers are particularly prone to cancer of the lower lip, and cessation of pipe smoking reduces this risk significantly. There is evidence that isotretinoin, a synthetic retinoid, may help prevent malignant progression of leukoplakia.

Clinical Findings

A. Symptoms and Signs

Benign and malignant lesions of the oral cavity and oropharynx present in a wide variety of forms. Although the oral cavity is a visually and palpably accessible site, the symptoms associated with malignant lesions are often vague or painless. They most commonly present with nonhealing ulcer, bleeding, pain, or ill-fitting denture. Locally advanced lesions may present with dysarthria, dysphagia, neck mass, and/or referred otalgia due to cranial nerve involvement.

Malignant lesions of the oropharynx are often asymptomatic until they reach a locally advanced stage. The most frequent complaints at presentation include vague discomfort, irritation and/or neck mass, although presenting symptoms vary by subsite. For example, the base of tongue has few pain fibers and consequently patients often present with an asymptomatic neck mass. Other possible symptoms include foreign body sensation in the throat, referred otalgia, dysphagia and/or dysarthria. Tonsillar lesions commonly present with pain, odynophagia, dysphagia, trismus and/or ipsilateral referred otalgia.

B. Laboratory Findings

A standard laboratory evaluation should include a complete blood cell count and blood chemistry profile, including liver and renal function tests. HPV testing of biopsy specimens can be considered in patients with oropharyngeal tumors, especially in patients with tonsillar lesions with no history of smoking.

C. Imaging Studies

A computed tomography (CT) scan, magnetic resonance imaging (MRI), or both types of imaging of the head and neck should be performed to evaluate the primary lesion and lymph node metastases. An MRI is preferred for the evaluation of soft tissue or base of skull involvement; a CT scan is better to evaluate cortical bone involvement. A chest X-ray should be performed to rule out metastases. Positron emission tomography (PET), especially when combined with CT (PET-CT), is increasingly used to assess the extent of primary tumor invasion, evaluate for regional and distant metastases, and detect synchronous second primary tumors.

D. Special Tests and Examinations

All lesions should first be evaluated by a complete history and head and neck examination, followed by flexible fiberoptic endoscopy as needed. Additional tests that may be performed include (1) examination under anesthesia, including palpation, direct laryngoscopy, and biopsy; (2) tumor mapping with toluidine blue dye and acetic acid, (3) a preradiation dental evaluation and audiology exam, and (4) Panorex films of the mandible to rule out mandibular invasion.

Differential Diagnosis

When evaluating a patient with any of the above symptoms, the differential diagnosis for a malignant lesion should also include bacterial or viral infection, trauma, leukoplakia or erythroplakia, eosinophilic granuloma, fibroma, giant cell tumor, pyogenic granuloma, papilloma, and verruciform xanthoma.

Treatment

Squamous cell cancers of the oral cavity are primarily treated surgically, while those of the oropharynx are primarily treated with definitive radiotherapy (RT). In general, early-stage lesions are treated by surgery or radiation alone, whereas locally advanced disease necessitates a multimodal approach: surgery and postoperative radiotherapy (PORT) ± chemotherapy in the oral cavity and definitive RT with concurrent chemotherapy in the oropharynx.

Surgery remains the primary treatment for cancers of the oral cavity due to the surgically accessible nature of the oral cavity, as well as the satisfactory functional outcomes that can be achieved. Moreover, treatment of oral cavity cancers with definitive radiation is made challenging by the mobility of structures within the oral cavity, the surrounding maxillodental structures that interfere with ionizing radiation. Tumors of the oral cavity also have a tendency toward well-differentiated histology that renders them relatively radioresistant.

For early-stage lesions, surgery can be performed through a transoral approach and closed primarily or with a split thickness skin graft with excellent functional outcome. More extensive lesions necessitate a larger surgical approach, often via mandibulotomy and requiring regional flap or free tissue transfer coverage, although minimally invasive (transoral laser and transoral robotic) techniques are increasingly being used. For locally advanced lesions deemed unresectable, definitive chemoradiotherapy is the treatment of choice.

PORT is recommended for resected patients with a high risk of locoregional recurrence. High risk is defined by close/positive margins or extracapsular lymph node extension.

Additional factors involved in risk-stratification include advanced T-stage, perineural or lymphovascular invasion, level IV nodal involvement and multiple positive lymph nodes. In the postoperative setting, a dose of 6000–6300 cGy is delivered to the tumor bed and areas of nodal involvement without remaining gross disease. Areas at high risk for recurrence, especially those with micro- or macroscopically positive margins, can be boosted to 6600–7000 cGy. Regions at risk for micrometastases but without pathologic or radiologic evidence of involvement, including the low neck and supraclavicular fossa, are treated with a prophylactic dose of 5000–5400 cGy. A pooled analysis of two randomized trials showed that the addition of concurrent cisplatin to PORT improves locoregional control and disease-free survival in patients with positive margins and extracapsular nodal extension; one of these studies also showed an improvement in overall survival.

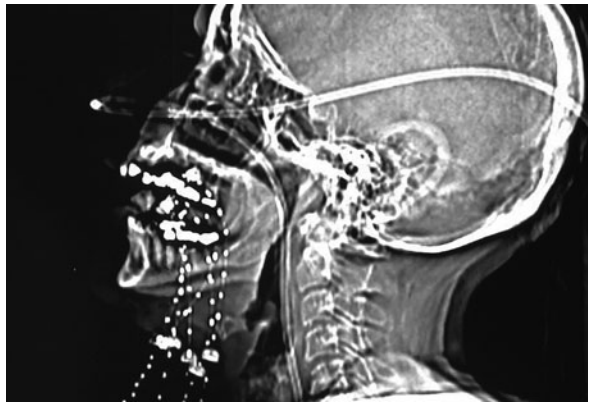
Primary RT is the preferred treatment for most squamous cell cancers of the oropharynx. In early stage lesions, RT and surgery can both provide high rates of local control, but RT is associated with better functional outcomes. Locally advanced disease is most often treated with definitive RT and concurrent chemotherapy. Several randomized trials, as well as a recent meta-analysis, have provided evidence that the addition of concurrent platinum-based chemotherapy to definitive RT offers a survival advantage in locally advanced disease.

Radiation has traditionally been delivered to the head and neck through conventional external beam radiation therapy (EBRT), brachytherapy (the implantation of temporary radioactive sources within the tumor; Figure 23–1), or a combination of these two modalities. Current external beam modalities involve three-dimensional dose delivery using 3D conformal radiation therapy (3DCRT) or intensity-modulated radiation therapy (IMRT). IMRT is a sophisticated technique that modulates the intensity of the radiation dose delivered within each field, permitting optimal coverage of tumor regions while sparing the surrounding normal tissue (Figure 23–2). Consequently, when compared to previous RT techniques, IMRT has been shown to reduce the incidence and severity of late toxicities (ie, xerostomia), in addition to allowing for improved locoregional control in many cases.

Definitive RT involves higher doses than postoperative treatment due to the presence of gross disease. Because of its ability to minimize toxicity to surrounding normal tissue, IMRT has enabled the delivery of higher doses to target volumes than was possible with previous RT techniques. Areas of known gross or macroscopic disease require doses of 7000 cGy. Nodal areas at high risk receive 6000–6600 cGy, and those at low risk receive 5000–5400 cGy.

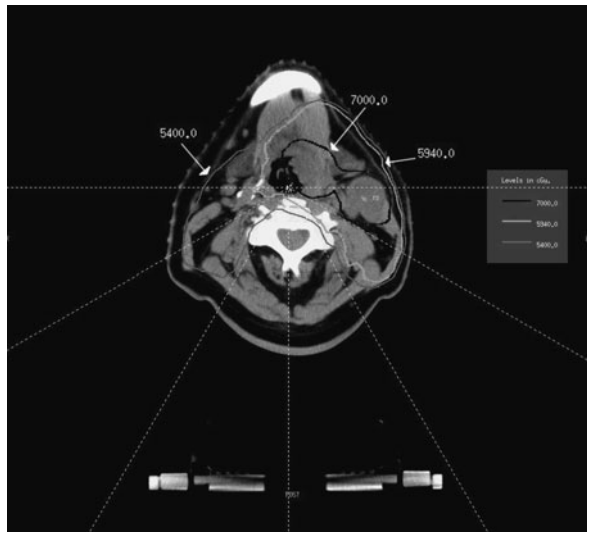
A. Lip

Surgery is the preferred modality for primary treatment of the lip. Small tumors can be treated with primary excision with excellent functional and cosmetic results. Primary excision is also preferred for T3 or T4 lesions, often requiring a reconstructive flap from the uninvolved opposing lip (eg, Abbe–Estlander technique) to maintain cosmesis and function. Postoperative RT (PORT) +/− chemotherapy is indicated in resected patients with high-risk features.



▲ **Figure 23–1.** Simulation film of brachytherapy implant for oral tongue cancer.

For T1 or T2 lesions, the incidence of lymph node metastasis is less than 10%. Due to the low incidence of regional metastasis, the regional lymph nodes are not usually treated for early-stage cancers of the lip. Locally advanced disease and high-grade lesions warrant neck dissection +/− PORT/chemotherapy.



▲ **Figure 23–2.** An IMRT dose distribution for a T2N2 base of tongue tumor. Dotted lines represent treatment fields.

B. Oral Tongue

For early T1 and T2 tumors that are deemed surgically resectable without significant functional morbidity, transoral partial glossectomy is the treatment of choice for management of the primary lesion. Advanced T3 and T4 disease with deep muscle invasion is often associated with lymph node metastases and is typically treated with transmandibular or transcervical total glossectomy. Depending on the extent of disease, ipsilateral or bilateral neck dissection is indicated at the time of primary resection. PORT +/− chemotherapy is indicated in patients with high-risk features.

Definitive RT for oral tongue lesions is reserved for patients with unresectable tumors or other contraindications to surgery.

C. Floor of Mouth

Small T1 or T2 tumors are highly curable, with transoral resection being the preferred modality. Larger infiltrative T3 or T4 lesions are best treated by radical surgery—often a composite resection incorporating the tongue, extrinsic musculature, and mandibular bone.

Early metastasis to the regional lymph nodes is common for carcinomas of the floor of mouth. Selective nodal dissection is warranted for T1 or T2 lesions with thickness >4 mm. Ipsilateral comprehensive neck dissection is indicated for advanced lesions, while bilateral neck dissections are warranted for lesions approaching the midline.

As with other sites of the head and neck, PORT +/− chemotherapy is indicated for high-risk features.

Primary RT (EBRT +/− brachytherapy) is reserved for patients with unresectable tumors or other contraindications to surgery. Lesions in close proximity to the mandible should not be treated with brachytherapy owing to the risk of osteonecrosis.

D. Buccal Mucosa

Smaller lesions may be treated with transoral excision alone with good local control, while larger lesions may require a cheek flap approach. T3 and T4 lesions with deep muscle invasion are usually treated with radical surgery, involving resection of the skin of the external cheek or bone of the adjacent maxilla or mandible.

For small lesions with clinically negative nodes, the neck can be observed, although an elective supraomohyoid (levels I–III) neck dissection is often recommended. Ipsilateral +/− contralateral neck dissection is indicated in T3 and T4 disease. For both the primary region and the neck, PORT +/− chemotherapy is indicated for high-risk features.

Primary RT is reserved for selected T2 lesions as well as those approaching the commissure so as to maximize cosmetic and functional outcome. In these cases, radiation can be delivered via external beam or brachytherapy, depending on the clinical situation.

E. Alveolar Ridge and Retromolar Trigone

As with other smaller lesions of the oral cavity, T1 lesions with minimal cortical invasion may be treated with primary transoral excision. Although lesions without periosteal invasion may be resected subperiosteally with preservation of the mandible, marginal mandibulectomy is indicated for tumors invading the periosteum, and bony involvement necessitates segmental mandibulectomy.

Depending on the presence of nodal involvement, either supraomohyoid or comprehensive neck dissection is indicated.

PORT +/− chemotherapy is indicated for high-risk features.

F. Hard Palate

Small lesions without periosteal involvement can be excised by transoral wide local excision, while periosteal or bony involvement requires an infrastructure maxillectomy followed by prosthetic rehabilitation. Advanced lesions require radical surgery with total palatectomy.

Elective treatment of the neck is often omitted due to the low rate of nodal metastases in early stage disease. If the primary disease extends beyond the hard palate, a supraomohyoid neck dissection is indicated.

PORT +/− chemotherapy is indicated for high-risk features.

G. Base of Tongue

Definitive RT, with or without chemotherapy, is the treatment of choice for most base of tongue tumors. Although comparable locoregional control can be achieved with surgery, RT is associated with better functional outcomes.

Early stage disease is usually treated with definitive RT consisting of either EBRT alone (preferably IMRT) or EBRT plus a brachytherapy boost. In the latter technique, a lower dose of EBRT is followed by a brachytherapy boost to the primary tumor, and a neck dissection is usually performed. Both techniques have proven track records with local control rates approaching, and in some cases exceeding 90%.

Chemoradiotherapy is the treatment of choice for locally advanced disease. Many series, both retrospective and prospective, have shown excellent locoregional control with acceptable acute and late toxicity in patients treated with IMRT or 3DCRT plus concurrent chemotherapy.

H. Tonsil, Soft Palate, and Pharyngeal Wall

As in the base of tongue, definitive RT with or without chemotherapy is the treatment of choice for tumors of the tonsil and soft palate.

Early stage disease may be treated with definitive RT alone. Lateralized early stage tumors of the tonsil may be treated with ipsilateral radiation fields to minimize irradiation to the contralateral side. Selected patients with small,

well-localized lesions may be treated with function-preserving surgery and elective neck dissection.

Definitive radiation with concurrent chemotherapy is the optimal treatment for locally advanced lesions. Many series have shown locoregional control rates of greater than 90% for patients treated with IMRT. Moreover, the improved dose conformality afforded by IMRT has resulted in reduced late adverse effects.

Tonsillar lesions are frequently associated with HPV infection. Patients with HPV positive tonsillar tumors have been shown to have superior treatment outcomes.

Complications

A. Surgical Complications

The complications of surgery include infection; hemorrhage; weight loss; facial swelling; difficulty with speech, phonation, and swallowing; and loss of speech or swallowing capability. The rate of surgical complications, including fistula formation and wound breakdown, is increased in irradiated tissue.

B. Radiation-Related Complications

The complications of radiation are divided into acute and chronic toxicities. Acute toxicities include fatigue, weight loss, mucositis, dysguesia, odynophagia, skin desquamation, and laryngeal edema. Chronic toxicities include dysphagia, xerostomia, trismus, hypothyroidism, hearing loss, and skin and soft tissue fibrosis/atrophy. Rare, but severe, late complications of radiation include osteoradionecrosis and carotid artery rupture. With the advent of IMRT, the rate of xerostomia has significantly decreased, resulting in improvement in patient quality of life.

Prognosis

The Surveillance, Epidemiology and End Results (SEER) Cancer Statistics review for the years 1999 to 2005 reports 5-year relative survival of oropharynx and oral cavity cancer of 62.5%. Local control and survival rates vary by individual subsite and are inversely related to degree of nodal involvement, tumor size and the presence of distant metastases. There is considerable evidence that survival is higher in patients with HPV-positive oropharyngeal tumors. Recent reports of oropharyngeal cancer treated with IMRT and concurrent chemotherapy have noted 3-year locoregional control rates ranging from 87% to 93%. Locoregional control rates for oral cavity cancer are lower; recent reports of patients treated with surgery and postoperative IMRT have noted 2-year locoregional control rates ranging from 78% to 82%.

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WEB SITES

The Cancer Group Institute (Background epidemiological information on oral cavity and oropharyngeal cancers): http://www.cancergroup.com

The National Cancer Institute (Treatment and prevention of oral cavity and oropharyngeal cancers): http://www.cancer.gov

(Surveillance Epidemiology and End Results – database of US cancer statistics): http://www.seer.cancer.gov/

Web MD Corporation (A review of lip and oral cavity cancer, presenting symptoms, staging, and treatment): http://www.webmd.lycos.com

The American Cancer Society (Overview of benign and malignant lesions of the oral cavity and oropharynx): http://www.cancer.org

BENIGN & MALIGNANT LESIONS OF THE NASOPHARYNX

ESSENTIALS OF DIAGNOSIS

- Positive biopsy.
- Mass on CT or MRI.
- Neck mass.
- Epistaxis or nasal discharge.
- Refractory otitis media.
- Ear pain or hearing loss.

General Considerations

The nasopharynx is a roughly cuboidal muscular tube located behind the nose in the upper part of the pharynx.

The borders of the nasopharynx include the posterior nasal cavity anteriorly, the sphenoid superiorly, the first and second vertebrae posteriorly, and the soft palate inferiorly. The lateral walls include the eustachian tube, the torus tubarius, and the fossa of Rosenmüller. The most common site of origin for nasopharyngeal carcinoma is the fossa of Rosenmüller.

Lymphatics from the nasopharynx run in an anteroposterior direction toward the base of the skull, where cranial nerves IX (the glossopharyngeal nerve) and XII (the hypoglossal nerve) lie. Other lymphatic pathways include deep drainage to the posterior cervical and jugulodigastric nodes. Lymphadenopathy is very common—about 80%—at presentation. Distant metastases, most frequently to the bone, correlate strongly with lymph node involvement (eg, N0 patients have a 17% incidence of metastases, whereas N3 patients have a 73% incidence).

Histologic subtypes include keratinizing SCC, nonkeratinizing carcinomas, and basaloid carcinomas. Nonkeratinizing carcinomas are further divided into undifferentiated and differentiated subtypes, while keratinizing SCCs are divided into well-, moderately-, and poorly differentiated subtypes. Nonkeratinizing undifferentiated tumors are the most common subtype in endemic areas and are considered to have the best prognosis due to their high chemo- and radiosensitivity. Rare types of nasopharynx cancer include lymphoma, sarcoma, adenoid cystic carcinoma, plasmacytoma, melanoma, and rhabdomyosarcoma.

Each year there are approximately 2200 new cases of nasopharyngeal carcinoma in the United States. There is predominance in males, with a 2.5:1.0 male-to-female ratio, and it is prevalent in individuals from southern China.

Staging

Staging for nasopharyngeal cancer is different from that for the oral cavity and the oropharynx (Table 23–2).

Pathogenesis

There is a suggestion of a genetic predisposition as first-generation Chinese Americans retain a higher incidence rate than Caucasian Americans. Genetic associations with nasopharyngeal carcinoma include HLA-BW46 and HLA-B17. Other causes include viral infection with the Epstein–Barr virus (EBV); dietary factors, including salt-cured fish; and environmental factors such as sawdust and smoke inhalation. As in other head and neck cancers, smoking is associated with a higher incidence, particularly in Caucasian males (Table 23–3).

Prevention

Smoking cessation and dietary modification to reduce salt-cured fish intake are factors that may be modified to reduce the risk of nasopharyngeal carcinoma.

Clinical Findings

A. Symptoms and Signs

The most common presenting symptom is cervical lymphadenopathy. Other symptoms include epistaxis, serous otitis media, hearing impairment, nasal obstruction, cranial nerve paralysis (CN VI, the abducens nerve, is most commonly involved), *retrosphenoidal syndrome of Jacod* (ie, difficulty with facial expression, as well as eye and jaw movement problems), *retroparotidian syndrome of Villaret* (ie, trouble swallowing and tongue and neck movement problems), and referred otalgia.

B. Laboratory Findings

Laboratory studies should include complete blood count and blood chemistries, including liver and renal function tests. EBV titers are elevated in patients with nonkeratinizing poorly or undifferentiated nasopharyngeal tumors and should be checked in the case of an unknown primary tumor of the head and neck.

C. Imaging Studies

Standard imaging studies include CT with bone windows to rule out cortical bone involvement and MRI of the head and neck. Unless contraindicated, an MRI scan should be obtained. A chest X-ray should be obtained to rule out metastatic disease, and a FDG-PET scan is recommended to assess for regional and distant metastases

D. Special Tests and Examinations

Additional tests and examinations should include a pretreatment dental evaluation and fiberoptic endoscopic examination. In the absence of an FDG/PET scan, bone scan can be considered for detection of distant metastases.

Differential Diagnosis

The differential diagnosis for nasopharyngeal carcinoma includes infection, Tornwaldt cyst (a nasopharyngeal cyst, usually midline, which may cause foul discharge), malignant metastasis from another primary site, and lymphoma.

Treatment

Because of the difficulty in obtaining adequate surgical margins, the primary treatment for nasopharyngeal carcinoma is with definitive radiation therapy, even in early-stage lesions. Radiation therapy fields include bilateral neck and supraclavicular nodes, as well as retropharyngeal nodes, owing to the high propensity for nodal metastases. Prophylactic doses of 5000 cGy are given to nodal regions at risk with a boost of 2000–3000 cGy to the primary tumor and involved nodal regions. Several techniques have been used to deliver the boost, including brachytherapy, 3D conformal treatment planning (3DCRT), and IMRT. IMRT offers advantages over other treatment modalities in that it allows for the precise delivery

Table 23–3. 2010 AJCC Staging: Nasopharynx.

Primary Tumor (T)			
T_x:	Primary tumor cannot be assessed		
T_0:	No evidence of primary tumor		
T_{is}:	Carcinoma in situ		
T_1:	Tumor confined to the nasopharynx, or extends to the oropharynx and/or nasal cavity without parapharyngeal extension[a]		
T_2:	Tumor with parapharyngeal extension[a]		
T_3:	Tumor involves bony structures of skull base and/or paranasal sinuses		
T_4:	Tumor with intracranial extension and/or involvement of cranial nerves, hypopharynx, orbit, or with extension to the infratemporal fossa/masticator space		
Regional Lymph Nodes (N)			
Nasopharynx	Regional lymph nodes cannot be assessed		
N_x:	No regional lymph node metastasis		
N_0:	Unilateral metastasis in lymph node(s) ≤6 cm in greatest dimension, above the supraclavicular fossa, and/or unilateral or bilateral retropharyngeal nodes, ≤6 in greatest dimension[b]		
N_1:			
N_2:	Bilateral metastasis in lymph node(s), ≤6 cm in greatest dimension, above supraclavicular fossa[b]		
N_3:	Metastasis in lymph node(s)[b] >6 cm and/or extension to supraclavicular fossa		
N_{3a}:	>6 cm in greatest dimension		
N_{3b}:	Extension to the supraclavicular fossa[c]		
Distant Metastasis (M)			
M_0:	No distant metastasis		
M_1:	Distant metastasis		
Stage Grouping: Nasopharynx			
0:	T_{is}	N_0	M_0
I:	T_1	N_0	M_0
II:	T_1	N_1	M_0
	T_2	N_0	M_0
	T_2	N_1	M_0
III:	T_1	N_2	M_0
	T_2	N_2	M_0
	T_3	N_0	M_0
	T_3	N_1	M_0
	T_3	N_2	M_0
IVA:	T_4	N_0	M_0
	T_4	N_1	M_0
	T_4	N_2	M_0
IVB:	Any T	N_3	M_0
IVC:	Any T	Any N	M_1

[a]Parapharyngeal extension denotes posterolateral infiltration of tumor.
[b]Midline nodes are considered ipsilateral nodes.
[c]Supraclavicular zone or fossa is defined by three points: (1) the superior margin of the sternal end of the clavicle, (2) the superior margin of the lateral end of the clavicle, and (3) the point where the neck meets the shoulder, including the caudal portions of IV and VB.

of high doses of radiation with relative sparing of essential tissues, such as the parotid glands, optic apparatus, and the brainstem. Several randomized trials have demonstrated an improvement in the rate of xerostomia for patients who underwent IMRT versus conventional radiation therapy.

Advanced lesions are treated preferably with IMRT as brachytherapy boosts are not adequate in these larger lesions. Recent randomized studies (RTOG 0225) have consistently shown an advantage in treating T3 and T4 lesions with concurrent radiation and chemotherapy.

Treatment for nasopharyngeal recurrence with radiation has shown some success (40% local control and survival) in patients who received more than 6000 cGy to the site of recurrence.

Complications of Radiation Therapy

Complications of radiation therapy for nasopharyngeal carcinoma include xerostomia, although this has dramatically decreased since the introduction of IMRT, chronic external otitis, otitis media, hearing loss, dental problems, pituitary dysfunction, trismus, and soft tissue or bone necrosis.

Prognosis

With IMRT and concomitant chemotherapy, 3-year locoregional control rates of 85%–100% have been achieved, with prognosis dependent on stage at presentation. The 3-year overall survival rates are lower, 80–95%, emphasizing the propensity for these lesions to metastasize. Treatment for recurrent nasopharyngeal carcinoma with radiation doses > 6000 cGy gives a 5-year local control and overall survival rate of 40%.

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Baujat B, Audry H, Bourhis J et al. Chemotherapy in locally advanced nasopharyngeal carcinoma: an individual patient data meta-analysis of eight randomized trials and 1753 patients. *Int J Radiat Oncol Biol Phys* 2006;64:47–56.

Lee N, Xia P, Quivey JM et al. Intensity-modulated radiotherapy in the treatment of nasopharyngeal carcinoma: an update of the UCSF experience. *Int J Radiat Oncol Biol Phys* 2002;53(1):12 [PMID: 12007936].

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Nutting C, A'Hern R, MS Rogers et al. On behalf of the PARSPORT Trial Management Group. First results of a phase III multicenter randomized controlled trial of intensity modulated (IMRT) versus conventional radiotherapy (RT) in head and neck cancer (PARSPORT: ISRCTN48243537; CRUK/03/005). *J Clin Oncol* 2009;27:18s (abs)

WEB SITES

The Cancer Group Institute (Background information on nasopharyngeal cancer): http://www.cancergroup.com

National Cancer Institute (Description of treatment for nasopharyngeal cancer): http://www.cancer.gov

We would like to acknowledge Mark D. DeLacure, MD for his contribution to this chapter in the previous editions of CDT

Mandibular Reconstruction

24

Jeffrey H. Spiegel, MD, FACS &
Jaimie DeRosa, MD

ESSENTIALS OF DIAGNOSIS

Mandibular reconstruction may be indicated for the following:

- Segmental defect of mandible following tumor ablation.
- Chronic osteomyelitis of the mandible or comminuted nonhealing mandible fracture.
- Acquired or congenital malformation of the mandible.

General Considerations

Among the most exciting advances in modern surgery has been an improved ability to reconstruct surgical defects and areas of tissue loss. Reconstruction of an area implies recreating not only the shape and appearance of the missing or injured tissues, but also the function. That is, ideally, the reconstructed region would look, move, feel, and sense precisely the way the native tissues once did when they were in good health.

It is in the head and neck where the need for accuracy in both functional and aesthetic reconstruction becomes the most evident. In general, it is a person's face that identifies him or her to others, and the face is the interface through which a person both detects the feelings and sentiments of others and conveys his or her own emotions.

Pathogenesis

Several disease processes may result in significant injury to the mandible. Severe trauma (eg, a gunshot wound) can result in a comminuted nonhealing fracture or tissue loss. Similarly, a neoplastic process (most commonly squamous cell carcinoma) can invade the mandible. Regrettably, the current state of medicine is such that the surgical removal of some disease processes (eg, certain malignant conditions) still provides the best chance of curing these otherwise fatally progressive disorders. Thus, the ability to reconstruct the mandible retains significance.

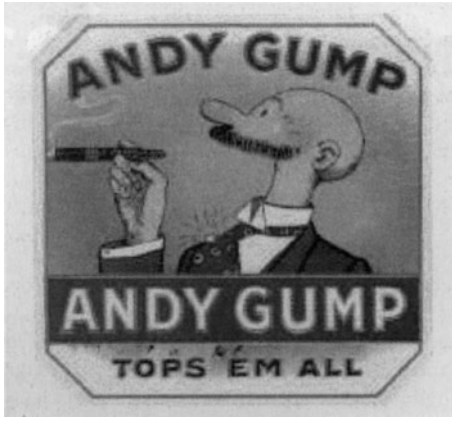
Aesthetically, the mandible provides the shape for the lower third of the face, defines the border between the face and the neck, and positions the mentum and lower lip (with the mandibular dentition). Functionally, the mandible supports the masticatory forces and the mandibular dentition. The mandible helps support the tongue in both position and function—a fact easily remembered when one recognizes the significant role a small mandible with a large tongue can play in creating obstructive sleep disturbance. Masticatory bite forces can be significant, with an average of 726 N and maximal forces at the molar occlusal surfaces of 4346 N. Thus, the mandible must be strong and rigid.

Treatment

To choose an appropriate reconstruction method, the following factors should be considered in reconstructing the mandible: (1) the length and location of the mandibular defect, (2) associated soft tissue loss, (3) the overall health and well-being of the patient, (4) the patient's potential prognosis, (5) potential donor sites, (6) primary versus delayed repair, and (7) the patient's dental health and potential for dental rehabilitation.

A. Reconstruction Options

The easiest form of mandibular reconstruction is no reconstruction. That is, when faced with a segmental defect, simply close the surrounding soft tissues over the defect, leaving one or two "free-swinging" mandibular segments. This leaves the patient with a significant cosmetic and functional deficit, although for a small lateral defect in an edentulous patient, the cosmetic and functional deficit may be smaller than expected. Certainly, however, for a person missing a large segment of mandible or the anterior segment of the mandible, this leaves a significant deformity where the lower lip



▲ **Figure 24–1.** An Andy Gump cigar label. Note how the character's face appears to end at the upper lip (absence of the mandible). Ironically, the character is smoking a cigar.

and the mentum are extremely retrusive, a situation known as the "Andy Gump deformity" (Figure 24–1).

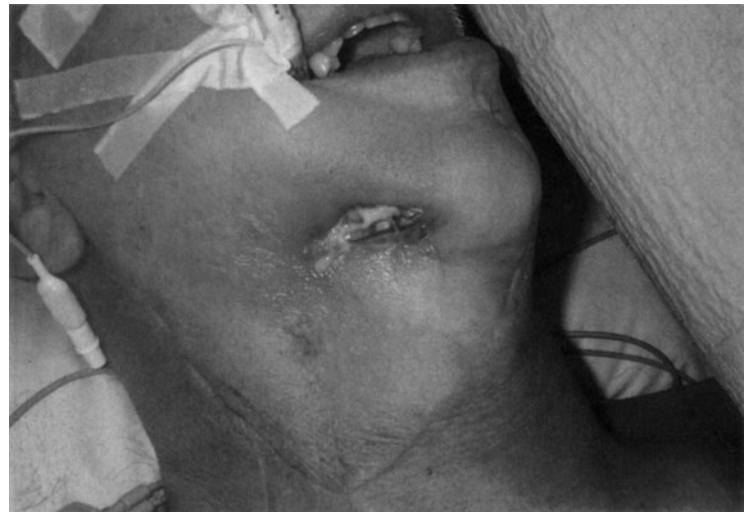
B. Soft Tissue Closures

The earliest soft tissue closures used local tissues, cheek or tongue flaps, or pedicled flaps from the neck, scalp, forehead, or deltopectoral region, many of which required a staged reconstruction. However, without any rigid structural support, neither the form nor function of the mandible was reliably reconstructed with these methods. Sometimes, bone fragments pedicled on local flaps were tried, although they had less than desired reliability, particularly in the face of radiation before or after surgery.

C. Alloplastic Implants

The advent of alloplastic implants helped correct some of the problems that soft tissue closure alone did not address. These include steel, titanium, and other alloy (eg, Vitallium) implants that are fashioned into either a bar or a tray, which can then be conformed to the shape of the missing mandibular segment. Over time, titanium has become the most common metal with which to fashion implants as it retains strength, biocompatibility, and rigidity, but can still be contoured using handheld instruments. All alloplastic implants can eventually suffer metal fatigue and fracture owing to the repetitive stress put on the material through mastication. Unfortunately, materials strong enough to withstand the forces without the risk of fracture are too strong to be contoured in the operating room by the surgeon.

Mandibular replacement with alloplastic implants can provide a rapid, effective mandibular reconstruction without a secondary donor site defect. However, in addition to the risk of plate fracture, there can be a significant risk for plate extrusion and exposure with subsequent infection (Figure 24–2). Experience has demonstrated that a mandibular reconstruction plate, particularly if "wrapped" or otherwise insulated with a muscle pedicle flap (eg, a pectoralis major flap), is an adequate reconstructive option for lateral mandibular defects. Although microvascular free-tissue transfer provides some improvements and benefits, for a lateral defect, a mandibular bar is an acceptable contemporary reconstruction. However, for defects involving the anterior mandible, as well as the symphysis and the parasymphysial regions, mandibular reconstruction with a metal bar has a significantly higher risk of complications than reconstruction with revascularized bone. This may be due to the increased arc of rotation that the bar passes through at the anterior mandible, which causes excessive force on the overlying soft tissue, eventually leading to bar exposure. Also,



▲ **Figure 24–2.** Patient after partial mandibulectomy with alloplastic (titanium) implant extruding a year after surgery. Note granulation tissue and purulent drainage.

unfortunately in many cases, metal bars without underlying bone grafting seem to have an increased chance of becoming exposed following radiation treatments. This can create a very complicated wound-healing challenge, typically requiring removal of the implant.

D. Alloplastic Trays

Alloplastic trays filled with bone chips have been used and in some cases have been successful, although some physicians have noted that 50% or more of their patients end up with an unsatisfactory result of using this method. Other times, bone grafts can be used in the form of cancellous bone chips without a tray. In addition, irradiated bone grafts are used. However, in all of these cases, the grafted bone serves as a scaffold for osteoblasts to create new bone, and in the inevitably infected field encountered at the time of ablation, new bone growth is unpredictable and unreliable. Furthermore, irradiated fields create an additional impediment to good bone healing.

E. Vascularized Bone

If bone substitutes (eg, metal bars), and free-bone grafts (in the form of chips or irradiated grafts) are unreliable, the next thing to try would be vascularized bone. Indeed, a variety of pedicled and free-bone flaps have been utilized.

1. Pedicled bone flaps—Initially, pedicled bone flaps were used. Physicians have tried to rotate the clavicle on the sternocleidomastoid muscle, the trapezius muscle, or even on the deltopectoral flap. Regrettably, only mixed success was obtained because the blood supply to the bone in each of these situations was unreliable and random. Somewhat better results were obtained with the pectoralis major muscle with the fifth rib, but again, only unreliable results were achieved. Rib grafts were also pedicled off of the latissimus dorsi muscle, but are not a great choice because, in general, this flap provides an unnecessarily large amount of muscle and soft tissue, with a usually inadequate amount of bone to provide a good reconstruction. Better results have been obtained by transferring the spine of the scapula onto the trapezius muscle. This flap provides approximately 10 cm of bone, and as long as the transverse cervical vessels are not injured during any part of the ablative procedure, the flap has fair reliability.

2. Osteotomies—At various times, a series of sliding osteotomies has been designed for use in the remaining mandible to allow the bone to be advanced to fill in gaps. Although interesting, the nature of the mandibular defect and the subsequent radiation may make these osteotomies unreliable.

F. Free-Tissue Transfer

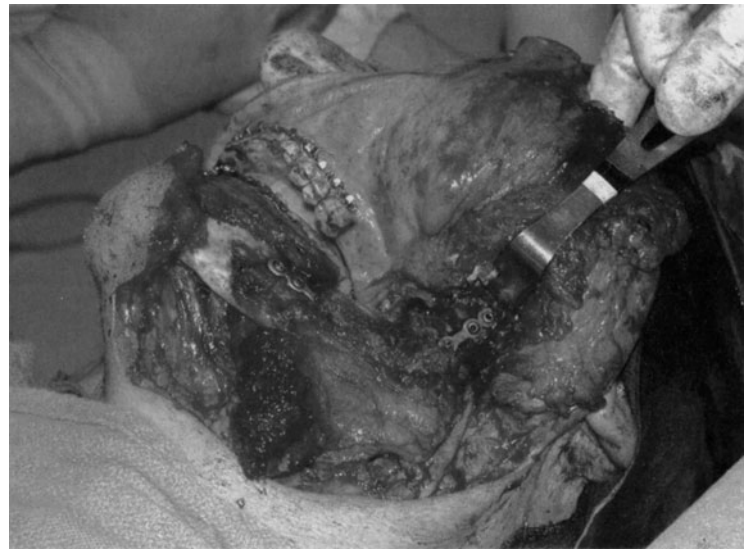
To date, the best results have been achieved by free-tissue transfer. This technique provides both vascularized bone and soft tissue and has no restriction on pedicle range or length.

Free-tissue transfer techniques were not widely known even a few years ago, but at this time most academic medical center departments of otolaryngology have at least one surgeon who is trained in microvascular methods. Unfortunately, microvascular transfer remains a relatively long and complex procedure, and although certainly valuable for large defects, it is more difficult to decide what to do for small defects. Often the extensive surgery required for a "free flap" seems to be too much when faced with a small anterior defect, however; still, no better alternative is available. Several flaps have been tried, and the four most commonly used osseous free flaps are (1) the radial forearm, (2) the scapula, (3) the iliac crest, and (4) the fibula. Each differs in the amount and nature of the soft tissue and bony components. All of these flaps, except the scapula flap, are sufficiently distant from the head and neck to allow for a second team of surgeons to (conveniently) simultaneously harvest the flap while the ablation is being performed.

1. Radial forearm flaps—The radial forearm flap allows the transfer of a large amount of pliable thin fascia and skin from the ventral surface of the forearm. Arterial supply is through the radial artery; therefore, an Allen test must be carefully performed before harvesting this flap to be certain that the hand has adequate vascular supply from the ulnar artery alone. Venous drainage is through the vena comitans of the radial artery or through the cephalic vein. Approximately 10 cm of bone can be taken. Although the bone is strong cortical bone, it is not thick because only one-third of the cross-sectional area of the radial bone can be taken without greatly increasing the risk of stress fractures of the forearm. Tapering the edges of the graft in a "boat tail" fashion further reduces the risk of postoperative fractures, as does a prolonged immobilization of the arm in a splint (3 weeks or longer). Overall, since only a small amount of bone is obtained, this flap is useful for only certain mandibular defects and is probably best suited for reconstruction in which a large amount of soft tissue is required with only a small segmental mandibular defect.

2. Scapular flaps—The scapular flap is among the most versatile of free flaps, since a very large amount of soft tissue is available with the bone. Unfortunately, the usual need to change the position of the patient during surgery from supine to lateral to harvest the flap makes this flap less desirable to harvest than its usefulness might suggest.

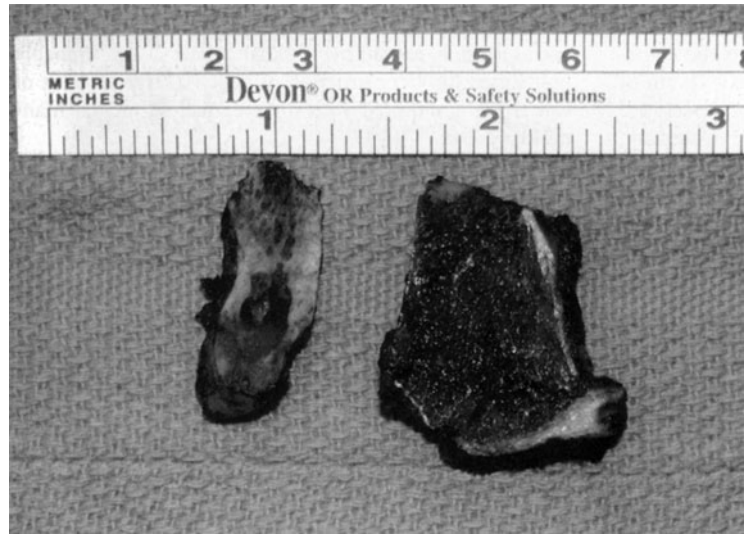
The lateral scapula provides 12 cm of bone that can support an osseointegrated implant for dental rehabilitation (unlike the bone of the radial forearm flap). The circumflex scapular system provides the blood supply to the flap and, with dissection, the bone and large skin islands can be harvested off of the subscapular artery. Two venae comitantes (veins that travel closely in approximation to the artery) accompany this artery for venous drainage. In general, the scapular system of flaps may be the most versatile of all reconstructive options, providing a good amount of bone and the most independently mobile soft tissue components of any of the osseous composite flaps.



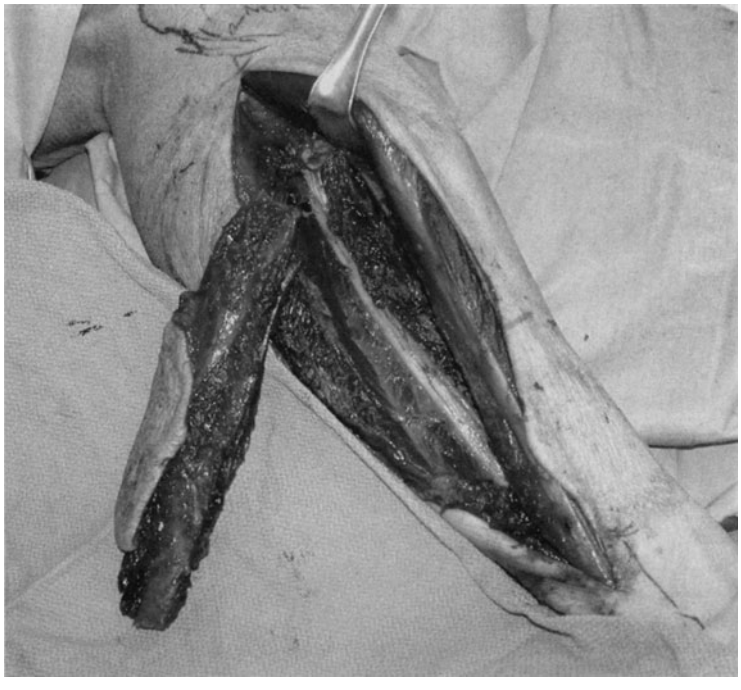
▲ **Figure 24–3.** Inset iliac crest bone flap at the left mandibular angle. Note how the bone can be contoured without osteotomies due to the large bone stock available at the iliac crest.

3. Iliac crest flaps—Based on the deep circumflex iliac artery and vein, the iliac crest flap has proved to be quite useful for mandibular reconstruction. Because of the great variety in which the bone can be harvested and contoured, three-quarters or more of the mandible can be reconstructed with this flap (Figure 24–3). Furthermore, the natural curvature of the iliac crest bone can be used to help approximate the natural shape of the mandible. The bone is thick and can more than make up for the thickness of the mandible (Figure 24–4). A relatively thick and nonpliable skin flap can be harvested with the iliac crest, although it is often helpful to use a Doppler probe to initially identify perforating vessels to the skin.

The versatility of this flap was greatly enhanced when it was noted that the internal oblique muscle is reliably vascularized by an ascending branch off the deep circumflex iliac artery. This provides a thin, pliable muscle flap that can be used to reconstruct a soft tissue defect. For example, with a "through and through" defect of the lateral mandible and cheek, three effects are achieved: (1) the iliac crest bone can



▲ **Figure 24–4.** Comparison of cross sections of a mandible **(left)** and an iliac crest **(right).** Note that the iliac crest bone is more than thick enough to recreate the mandible and accept implants for dental reconstruction.



▲ **Figure 24–5.** Harvesting of the right fibula. The bone and skin have been isolated on the right peroneal vessels.

replace the mandibular bone, (2) the skin paddle can replace the skin of the external cheek, and (3) the internal oblique muscle can be used to reconstruct the mucosal surface defect and then left either to have mucosa grow over it or to be covered with a skin graft. Removing the internal oblique muscle necessitates great care in closure to prevent an abdominal hernia.

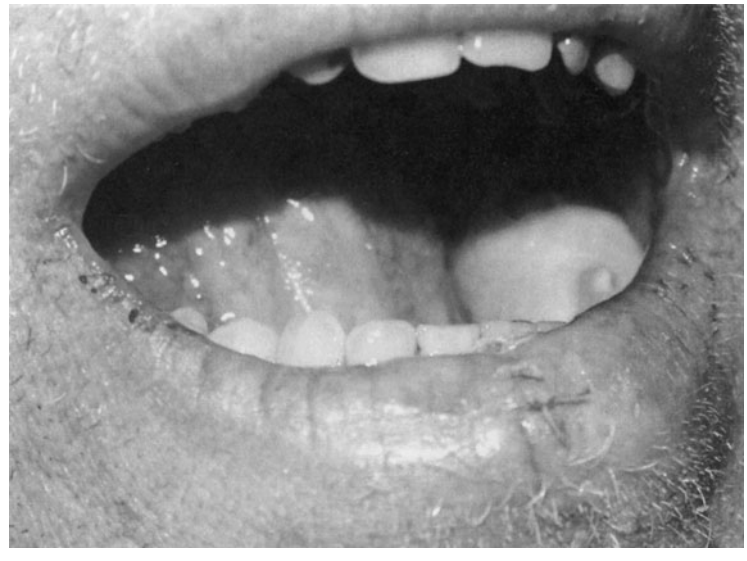
Another excellent use for the iliac crest flap is for the reconstruction of a near-total glossectomy with mandibulectomy. In this situation, the iliac crest bone can be positioned transversely so that the bone forms the floor of the mouth. This then elevates the soft tissue skin flap of the iliac crest flap into a good position to assist with swallowing once it is fashioned into a "neo-tongue."

4. Fibular flaps—Probably the most commonly used free-tissue flap for mandibular reconstruction, the fibular flap has several advantages. A very long segment of bone is available (approximately 25 cm), since the entire fibula can be harvested except for 8 cm, which should be preserved at the proximal and distal ends for joint stability (Figure 24–5). In addition, a reliable skin paddle is obtained and additional vascular soft tissue is available as the flexor hallucis longus muscle can be harvested with the flap (Figure 24–6).

The fibular flap is based on the peroneal artery and veins. Preoperative vascular imaging is helpful to protect vascularity to the foot because vascular disease and anatomic irregularities can eliminate the normal three vessels that supply blood to the leg. Angiograms were once routinely ordered, although magnetic resonance imaging can be modified in protocol to provide adequate imaging of vascular anatomy. In addition, if desired, this flap can have sensory reinnervation through the lateral cutaneous branch of the peroneal nerve. Blood supply to the bone is through the periosteum; therefore, as long as most of the periosteum is not disturbed, numerous osteotomies can be made into the harvested fibula bone to allow for good custom contouring of the bone in recreating the mandible (Figure 24–7).

G. Distraction Osteogenesis

Distraction osteogenesis is a new technique that has some value in mandibular reconstruction. In this technique, an appliance is attached to the mandible, and a thin piece of the end of the mandibular segment is cut free from the rest of the mandible. This thin segment is slowly advanced through the use of a "key" attached to the appliance. As it is advanced, the space between the advancing segment and the bulk of the mandible is filled in with new bone. Once enough new bone has been made, the free ends are "roughened" and then the remaining segments of mandible are plated, as for a mandibular fracture. Although exciting in concept, this technique does not allow for primary reconstruction because the distraction process takes time. Plus, at least one additional procedure is required. Thus far, the technique has been used primarily in cases of congenital mandibular insufficiency.



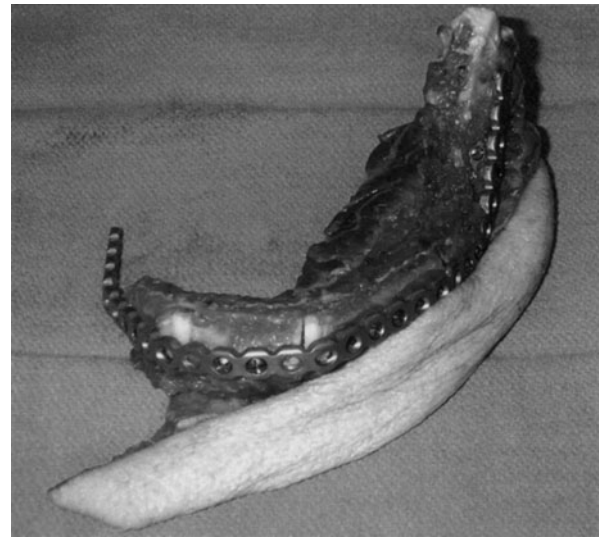
▲ **Figure 24–6.** Postoperative photograph of viable skin from the fibula flap reconstructing the mucosa of the left "alveolar ridge" over the fibula bone.

H. Bone Generation

Of current interest is the possibility of creating new bone through the use of growth factors and hydroxyapatite mixtures. The nature of the expression of the various bone morphogenic proteins is becoming increasingly understood, and soon it may be likely to bridge a bone gap with a bone-like powder that is mixed with bone growth factors, resulting in new, strong bone within a predictable period. Certainly, the ability to generate bone is far closer than the ability to generate good soft tissue coverage; therefore, the use of the osseous microvascular flap may be limited.

▶ Complications

The most common complications of mandibular reconstruction include flap failure, fistulas, donor site morbidity, and the extrusion of alloplastic materials. A compromised vascular supply can lead to an ischemic flap and the need to either urgently revascularize or debride the tissue. In addition, small areas of dehiscence can lead to a salivary fistula, with the associated vascular risks. Sensory and motor nerves to the hand and foot are at risk during flap harvests, which can lead to donor site morbidity; gait abnormalities can result. Finally, alloplastic materials can extrude, even when placed onto a revascularized bone flap.



▲ **Figure 24–7.** Fibular flap contoured to reconstruct the missing segments of the mandible. This tissue will then be inset and microvascular anastomoses will be performed to recreate a vascular supply.

Mandpe AH, Singer MI, Kaplan MJ, Greene D. Alloplastic and microvascular restoration of the mandible: a comparison study. *Laryngoscope* 1998;108(2):224 [PMID: 9473072]. (Reviews indications for microvascular repair and when there are true benefits over a reconstruction bar.)

Urken ML, Buchbinder D, Costantino PD et al. Oromandibular reconstruction using microvascular composite flaps: report of 210 cases. *Arch Otolaryngol Head Neck Surg* 1998;124(1):46 [PMID: 9440780]. (Leaders and innovators in microvascular reconstruction review their results.)

Verdaguer J, Soler F, Fernandez-Alba J, Concejo J, Acero J. Sliding osteotomies in mandibular reconstruction. *Plast Reconstr Surg* 2001;107(5)1107 [PMID: 11373549]. (A description of alternatives to microvascular reconstruction or reconstruction bars.)

25 Jaw Cysts

Richard A. Smith, DDS

Cysts of the maxilla and mandible are common occurrences. Bone cysts occur more frequently in the jawbones than in any other bone because of the presence of epithelium from odontogenic elements (eg, teeth) and nonodontogenic epithelial remnants of embryonic structures.

A cyst is defined as an epithelial-lined pathologic cavity that may contain fluid or a semisolid material. A group of cystic lesions devoid of an epithelial lining is classified as pseudocysts. A jaw cyst is usually located deep within the jawbone, but it may occur on a bony surface, producing a saucerization.

ESSENTIALS OF DIAGNOSIS

- Well-defined, totally or predominantly radiolucent, and sometimes expansile lesions.
- Usually slow growing and benign.
- Initially asymptomatic unless long-standing with significant enlargement or secondary infection.
- Usually initially discovered on routine dental X-rays.
- Requires histopathologic examination for diagnosis.

General Considerations

Jaw cysts encompass a group of lesions that are variable in their incidence, etiology, location, clinical behavior, and treatment. The most common jaw cyst is the radicular cyst, which is odontogenic and inflammatory in nature. The odontogenic developmental cyst is the second most common jaw cyst. Nonodontogenic cysts, pseudocysts, and ganglionic cysts of the temporomandibular joint (TMJ) are much less common. Cysts occur in both the mandible and the maxilla: inflammatory radicular cysts occur around the roots of nonvital teeth; odontogenic developmental dentigerous cysts and keratocysts occur in the common regions of impacted and unerupted teeth; nonodontogenic developmental cysts are found in regions of epithelial embryonic remnants; pseudocysts usually present in site-specific regions; and ganglionic cysts develop in the TMJ. Each type of jaw cyst usually has a specific behavior pattern, ranging from small 5- to 6-mm osteolytic defects to massive involvement of the jaw and contiguous structures.

Classification of Jaw Cysts

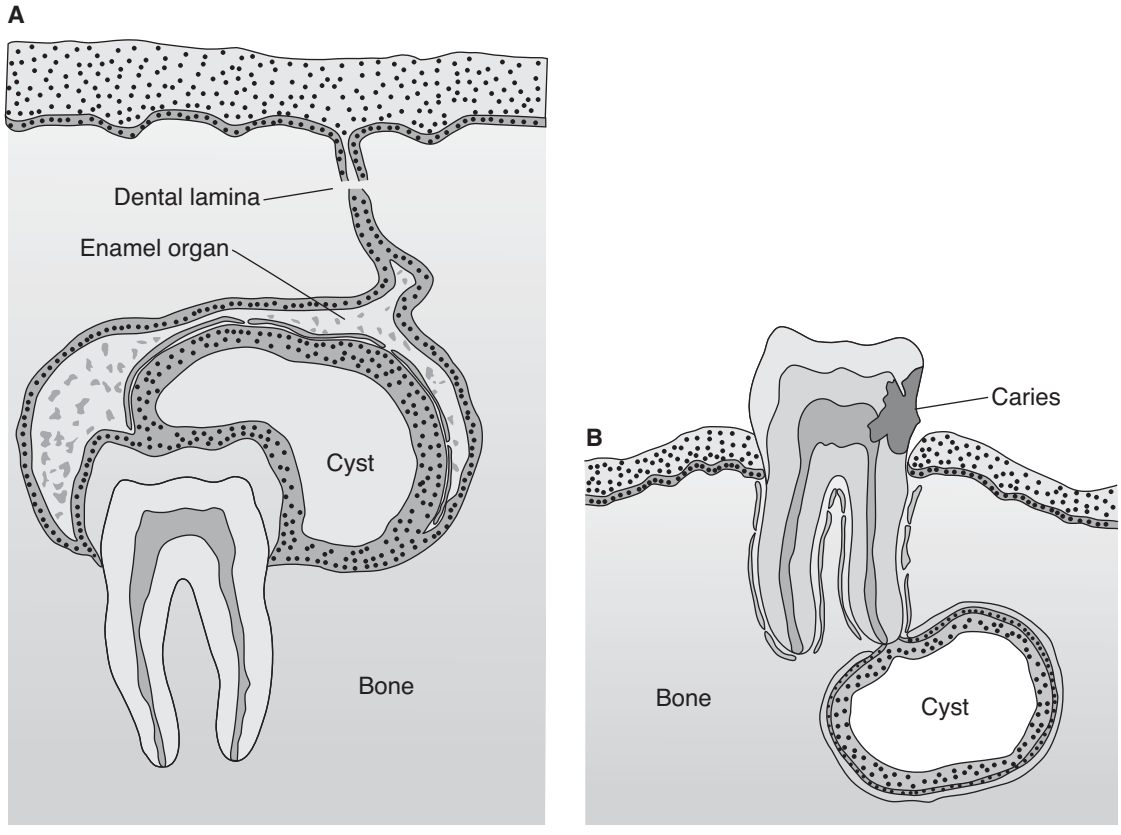
The classification of jaw cysts includes (1) odontogenic cysts, (2) nonodontogenic cysts, and (3) pseudocysts. The ganglion cyst, which presents in the TMJ, has been added to this conventional classification for completeness; it is significant to clinicians managing the pathology of the head and neck region.

Pathogenesis

The pathogenesis of jaws cysts varies according to the specific cyst type. Inflammatory cysts derive their epithelial lining from the proliferation of odontogenic epithelium within the periodontal ligament; dentigerous developmental cysts result from the proliferation of reduced enamel epithelium. Figure 25–1 illustrates the development of dentigerous and radicular cysts. Cystic lesions may also result from cortical bone defects or trauma, they may represent reactive lesions, or they may have an unknown pathogenesis. It has been shown that there is an osmotic pressure gradient that produces fluid accumulation within the cyst lumen and generates pressure, creating cyst expansion.

Prevention

It may be possible to prevent odontogenic jaw cyst formation through the immediate treatment of nonvital teeth and the removal of impacted or unerupted teeth. Strategies should include preventing the progression of jaw cysts to large, destructive lesions that require aggressive management.



▲ **Figure 25–1.** **(A)** Development of the dentigerous cyst around the crown of an unerupted tooth. **(B)** Development of a radicular cyst around the root apex of a nonvital tooth.

Prevention is aided by routine and regular dental and oral examinations with appropriate imaging.

Clinical Findings

A. Symptoms and Signs

The patient with a small cyst is usually asymptomatic. Symptoms such as pain and swelling occur when the cyst becomes secondarily infected. The patient may report an unpleasant or even foul taste if the cyst has discharged into the mouth through a sinus tract. Teeth contiguous to all cysts, except radicular cysts, have vital pulps, unless coincidental disease of these teeth exists. Tooth vitality can be assessed with electrical pulp testers or ice. Erupted teeth contiguous to a large cyst may maintain their vitality, despite the loss of a significant amount of supporting alveolar bone. Benign jaw cysts rarely produce loosening of adjacent teeth unless the cyst becomes very large. Large cysts can displace the roots of teeth that can be evident clinically, on an X-ray, or both. The clinical absence of one or more teeth, as seen on routine dental X-rays, may suggest the presence of a developing dentigerous cyst.

Extensive cysts in the anterior maxilla may extend under the nasal floor, creating nostril distortion. An infected maxillary cyst may involve the maxillary sinus, producing maxillary sinusitis. Large mandibular cysts may involve the mandibular canal and its contents, the inferior alveolar neurovascular bundle. The mandibular canal and its contents can be deflected inferiorly without producing a neurosensory deficit. However, if an acute infection develops with pus accumulation, a decrease in lower lip sensibility may be observed.

B. Imaging Studies

The typical radiographic appearance of a jaw cyst is that of a well-defined, round-to-oval, unilocular or multilocular radiolucent cyst that is circumscribed by a dense periphery of reactive bone. Periapical and panoramic X-rays usually suffice for imaging small- to medium-sized cystic lesions, but computed tomography (CT), including cone beam, scans

are indicated for large, expansile lesions. Anatomic structures such as the mental foramen, the incisive foramen, and the maxillary sinus may be misinterpreted as pathologic cystic lesions.

C. Special Tests

Needle aspiration of a suspected jaw cyst can reveal valuable diagnostic information. Aspiration of blood from the lesion may indicate the presence of a vascular lesion or an aneurysmal bone cyst. If aspiration of a solid lesion (eg, a tumor) is attempted, no fluid can be aspirated and withdrawing the plunger of the syringe is difficult. Aspiration of a light, straw-colored fluid containing cholesterol crystals (known by their characteristic "shimmering" effect in light) is consistent with a benign odontogenic cyst. Aspiration of a whitish-to-pale-yellow material that appears similar to pus usually reveals an odontogenic keratocyst (OKC) that contains desquamated cells and keratin. A cyst that has been present for a long time and has become infected may contain a thick yellow or brown material that is difficult to aspirate.

A histopathologic examination is essential for establishing a definitive diagnosis. For small lesions, excisional biopsy is appropriate; for large lesions, an incisional biopsy is indicated to establish a diagnosis, develop a treatment plan, and obtain appropriate informed consent.

Differential Diagnosis

An orderly approach to a differential diagnosis of a jaw lesion can be accomplished by grouping possible lesions into six main categories: (1) cysts, (2) odontogenic tumors, (3) benign nonodontogenic tumors, (4) inflammatory jaw lesions, (5) malignant nonodontogenic neoplasms of the jaw, and (6) metabolic and genetic jaw diseases. An assessment of the radiographic appearance, patient age, and location of the lesion enables the clinician to establish a reasonable differential diagnosis that should ultimately be confirmed by histopathologic examination. A definitive histopathologic diagnosis may rule out more serious lesions (eg, cystic ameloblastoma).

Complications

Complications related to the destruction caused by a jaw cyst and the surgical treatment required include loss of teeth and bone; infection; cyst recurrence; neurosensory deficits; oral or facial sinuses; oral, antral, or nasal fistulas, or a combination of these three complications; and pathologic jaw fracture. Carcinoma arising in an odontogenic cyst is a rare occurrence and requires aggressive treatment.

Treatment

Because contiguous structures—including displaced teeth, resorbed roots, alveolar bone, the maxillary sinus, and the mandibular canal—may be involved or encroached upon, jaw cysts usually require surgical management. However, jaw cysts that demonstrate slow or no progression of growth may be managed by observation in the elderly or severely medically compromised individuals. The exact nature of the surgery depends on the size, location, and clinical behavior of the specific type of cyst. Treatment is necessary because (1) cysts usually increase in size, causing local tissue destruction and usually becoming infected, and (2) extensive involvement of the mandible is capable of creating a potential pathologic fracture.

SPECIFIC TYPES OF JAW CYSTS

DEVELOPMENT ODONTOGENIC CYSTS

DENTGEROUS (FOLLICULAR) CYSTS

ESSENTIALS OF DIAGNOSIS

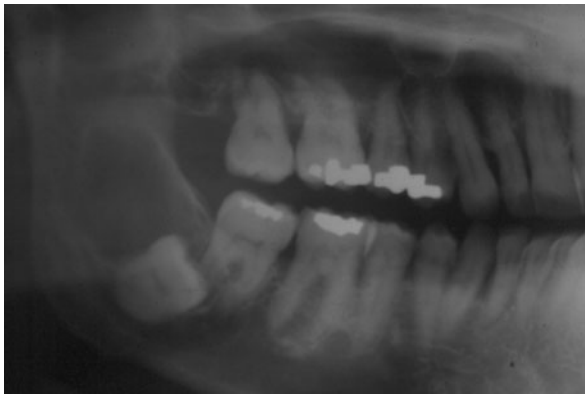
- Epithelial-lined, developmental, odontogenic cysts.
- Second most common type of jaw cyst associated with the crown of an impacted, unerupted, or developing tooth.
- Well-defined, radiolucent, sometimes expansile lesion.
- Usually slow growing and benign.
- Initially asymptomatic unless long-standing with significant enlargement or secondary infection.
- Usually discovered on routine dental X-rays.
- Requires histopathologic examination for diagnosis.

General Considerations

Fifteen to eighteen percent of jaws cysts are dentigerous, surround the crowns, and attach at the cementoenamel junction of unerupted teeth. The lower third molars and the upper canines are the most commonly involved teeth.

Pathogenesis

Dentigerous cysts derive their epithelium from the proliferation of the reduced enamel epithelium after the tooth enamel is formed. The cyst develops subsequent to an accumulation of fluid between the remnants of the enamel organ and the contiguous tooth crown. The expansion of this intrabony cyst is associated with an increase in the osmolality of the cyst fluid secondary to the migration of inflammatory cells into the cyst lumen. Epithelial proliferation may also occur simultaneously.



▲ **Figure 25–2.** Panoramic X-ray showing a dentigerous cyst appearing as a well-defined radiolucency around the crown of an unerupted mandibular third molar.

Prevention

Regular dental and oral examinations with appropriate imaging can identify developing cystic jaw lesions before any significant bony destruction can occur. The removal of impacted teeth, when indicated, serves as a preventive measure.

Clinical Findings

A. Symptoms and Signs

Small dentigerous cysts rarely produce clinical symptoms. Larger cysts can produce a bony expansion, which creates an intraoral swelling, an extraoral swelling, or both. They also can result in facial asymmetries or can become secondarily infected, which results in pain.

B. Imaging Studies

The most common radiographic appearance of a dentigerous cyst is that of a well-delineated round-to-oval mass that is associated with an unerupted tooth, which may possibly be displaced. Figure 25–2 demonstrates a typical dentigerous cyst as observed on a panoramic X-ray. Periapical and panoramic X-rays can illustrate the extent of the cyst and contiguous anatomic structures. With large lesions, CT scanning is helpful in assessing the degree of expansion perforation and the involvement of adjacent structures.

C. Special Tests

Needle aspiration with possible biopsy of the lumen of a suspected cystic lesion can give confirmatory diagnostic information and rule out a vascular lesion. If there has not been significant expansion of the cyst, with thinning of the bony cortex, it will not be possible to penetrate the bone using a needle and syringe technique. In these cases, if aspiration is desired, a small mucosal incision, followed by drilling a small hole through the buccal cortex, enables needle aspiration. Aspiration of a light, straw-colored fluid is characteristic of a dentigerous cyst. Histopathologic examination reveals a thin, nonkeratinized cyst lining. Inflammatory changes may produce epithelial hyperplasia. Mural hemorrhage can result in cholesterol clefts, giant cells, and hemosiderin in the wall of the cyst. Hyaline bodies (eg, Rushton or hyaline bodies) may be present in the epithelium.

Differential Diagnosis

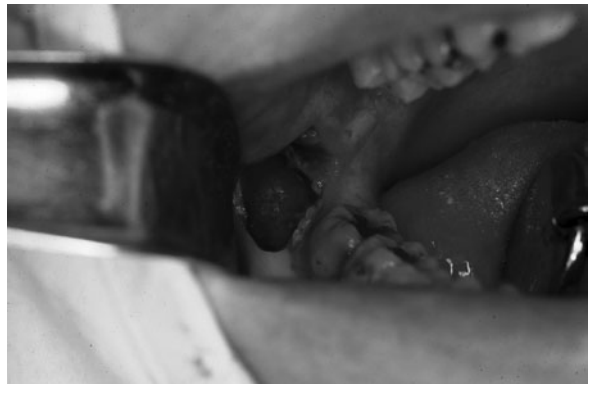
The differential diagnosis should include OKCs, ameloblastomas, cystic ameloblastomas, ameloblastic fibromas, and nonodontogenic tumors.

Complications

Complications related to the damage created by an expanding jaw cyst include bony destruction, infection, oral or facial sinuses, weakening of the jaw, displacement of teeth, resorption of adjacent tooth roots, encroachment on the maxillary sinus floor, and deflection of the inferior alveolar canal. The transformation of the epithelial lining of a dentigerous cyst into an ameloblastoma is also possible. Dysplasia or the carcinomatous transformation of the epithelial lining is possible, but rare. Complications related to the surgical management of cysts include devitalization of adjacent teeth, postoperative infection, neurosensory deficits, oral-antral fistulas, jaw fracture, and cyst recurrence.

Treatment

The treatment of choice consists of enucleation of the cyst and removal of the associated tooth. The surgical exposure is observed in Figure 25–3. The surgical flap can be reposi-



▲ **Figure 25–3.** Surgical exposure of a dentigerous cyst in preparation for enucleation, in the mandibular third molar region.

tioned and sutured with primary closure. Even large, bony cavities can regenerate new bone over several months' time. If the tissue breaks down, the cavity can be packed with a ¼-inch gauze and gradually advanced over 7–10 days, followed by frequent saline irrigations to allow healing by secondary intention. For extremely large surgical defects, primary bone grafting with autogenous cancellous chips can accelerate the healing process. Marsupialization of the cyst may be considered.

Prognosis

The prognosis after treatment of the cyst is excellent, with the expectation that the surgical defect will heal. The recurrence rate for the cyst is very low.

Rosenstein T, Pogrel MA, Smith RA, Regezi JA. Cystic ameloblastoma: behavior and treatment of 21 cases. *J Oral Maxillofacial Surg* 2001;59:1311 [PMID: 11688034]. (Cystic ameloblastomas have unexpected capacity for bony destruction and recurrence.)

Shimoyama T, Ide F, Horie N et al. Primary intraosseous carcinoma associated with impacted third molar of the mandible: review of the literature and report of a new case. *J Oral Sci* 2001;43(4):287 [PMID: 11848197]. (A primary intraosseous carcinoma occurred in a dentigerous cyst associated with an impacted third molar—mean patient age 73 years.)

ERUPTION CYSTS

ESSENTIALS OF DIAGNOSIS

- A variant of the dentigerous cyst.
- Presents as a bluish swelling on the alveolar ridge crest at the site of an erupting tooth.

An eruption cyst occurs most commonly in the molar regions of the jaws in children less than 10 years of age. This cyst results from hemorrhage or fluid accumulation in the space between the crown and the reduced enamel epithelium. A dome-shaped, sometimes painful, frequently bluish swelling of the gingiva overlies an erupting tooth. A periapical or panoramic X-ray confirms the presence of an erupting tooth. The clinical presentation is pathognomonic for an eruption cyst. There may be trauma to the cyst, producing hemorrhage, which results in discoloration and pain. Most eruption cysts rupture spontaneously, and no treatment is required. However, excision of the overlying mucosa yields relief and facilitates eruption of the underlying tooth. The prognosis is excellent, and there should not be any detrimental effect to the associated erupting tooth.

Bodner L, Goldstein J, Sarnat H. Eruption cysts: a clinical report of 24 new cases. *J Clin Pediatr Dent* 2004;28(2):183 [PMID: 14969381]. (The eruption cyst occurs within the mucosa overlying a tooth that is about to erupt, has a raised, bluish appearance on the alveolar ridge, and should be managed conservatively.)

Ricci HA, Parisotto TM, Giro EM, de Souza Costa CA, Hebling J. Eruption cysts in the neonate. *J Clin Pediatr Dent* 2008;32(3):243 [PMID: 18524277]. (Clinical surveillance should be pursued since these lesions most often spontaneously resolve.)

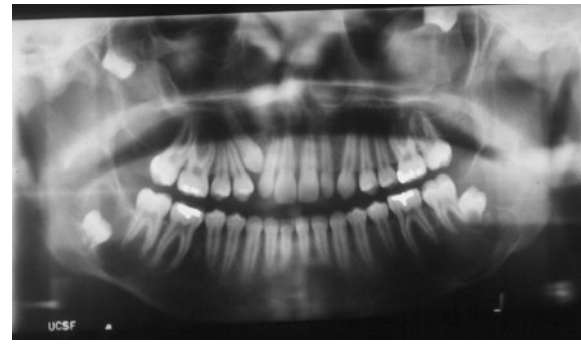
ODONTOGENIC KERATOCYSTS

ESSENTIAL OF DIAGNOSIS

- A developmental odontogenic cyst occurring in the tooth-bearing areas of the jaws or posterior to the mandibular third molar.
- Has a parakeratinized epithelial lining.
- May be a component of basal cell nevus syndrome (ie, Gorlin–Goltz syndrome).
- Has an aggressive clinical behavior with a high recurrence rate after treatment.

General Considerations

Three to ten percent of odontogenic cysts are keratocysts and can occur at any age; however, 60% of patients are between 10 and 40 years of age. OKCs may be part of Gorlin–Goltz syndrome, which includes multiple OKCs (Figure 25–4), multiple basal cell carcinomas, cutaneous abnormalities,



▲ **Figure 25–4.** A panoramic X-ray of odontogenic keratocysts in all four quadrants of the maxilla and mandible, causing displacement of the developing third molars, in a patient with nevoid basal cell carcinoma syndrome.

skeletal anomalies, and cranial calcifications. This syndrome is a genetic disorder with autosomal dominant inheritance (ie, with mutation of the "PATCHED" tumor suppressor gene), high penetration, and variable expression. The OKC has long been considered to be a developmental odontogenic cyst and, until 2005, was classified as such by the World Health Organization. The current view is that the OKC may in fact be a neoplasm based on its behavior and growth and is referred to as a keratocystic odontogenic tumor. Unlike most odontogenic cysts, the OKC does not grow and expand in a centripetal fashion but rather displays mural growth with proliferation.

Hyub H-K, Hong S-D, Kim J-W. Recurrent keratocystic odontogenic tumor in the mandible: a case report and literature review. *Oral Surg Oral Med Oral Path Oral Radiol Endod* 2009;108(2):e7 [PMID:19615649]. (The term keratocystic odontogenic tumor, rather than odontogenic keratocyst, is used because the former better reflects the potential for local, destructive behavior.)

Pathogenesis

The epithelium arises from cell rests of the dental lamina. However, it has been suggested that the cyst originates from extension of the basal cell components of the overlying oral epithelium. It has also been suggested that the growth of a keratocyst may be related to epithelial activity or enzymatic action in the fibrous cyst wall.

Prevention

Regular dental and oral examinations with appropriate imaging can assist both in identifying cystic lesions early in their course and preventing the development of large, destructive lesions.

Clinical Findings

A. Symptoms and Signs

The mandible is involved in 60–80% of OKCs, with a tendency to involve the posterior mandible and ascending ramus. These cysts have a locally aggressive clinical behavior. Small OKCs usually are asymptomatic and are identified during routine dental examination and imaging. Larger OKCs may produce pain, drainage, swelling from secondary infection, and asymmetries from bony expansion. The adjacent teeth are vital, but can be displaced.

The features associated with Gorlin–Goltz syndrome include (1) OKCs of the jaws, (2) multiple basal cell carcinomas, (3) an enlarged occipitofrontal circumference, (4) mild ocular hypertelorism, (5) epidermal cysts, (6) palmar or plantar pits, (7) calcified ovarian cysts, (8) calcified falx cerebri, (9) rib abnormalities, (10) spina bifida, (11) short fourth metacarpals, (12) vertebral anomalies, and (13) pectus excavatum.

B. Imaging Studies

Panoramic X-rays and CT scans for large, expansile lesions reveal a locally destructive, multilocular lesion that can displace teeth, resorb tooth roots, deflect the mandibular canal inferiorly, and displace the floor of the maxillary sinus superiorly.

C. Special Tests

Aspiration of an OKC produces a whitish or pale yellow, inspissated, cheese-like material that may appear similar to purulent exudates, but is actually liquid-containing masses of desquamated keratinized cells. The combination of fine-needle aspiration biopsy with immunocytochemical testing for cytokeratin-10 in sampled epithelial cells has been shown to be accurate in distinguishing OKCs from nonodontogenic cysts.

Histopathologic examination of the cyst reveals an epithelial lining with a wavy or "corrugated" appearance and a thickness of 6–10 cell layers. The epithelium demonstrates basal palisading and a thin, refractile, parakeratinized lining. Any budding of the basal layer may produce "daughter cysts," which may be related to the high recurrence rate. A protein level >4 mg/100 mL is highly suggestive of a keratocyst.

Differential Diagnosis

The differential diagnosis should include dentigerous cysts, ameloblastomas, cystic ameloblastomas, ameloblastic fibromas, and nonodontogenic neoplasms.

Complications

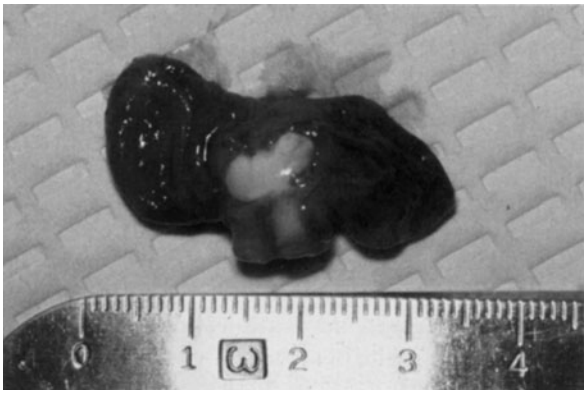
Complications are related to the aggressive clinical behavior of the keratocyst, which results in bony destruction. They are also related to a high recurrence rate, which may be due to the thin, friable cyst wall that is difficult to enucleate intact from the bone. Squamous cell carcinoma has been reported to occur in maxillary OKCs.

Treatment

Enucleation (Figure 25–5) or decompression and marsupialization are the treatments of choice.

Pogrel MA. Treatment of keratocysts: the case for decompression and marsupialization. *J Oral Maxillofac Surg* 2005;63:1667 [PMID: 16243185]. (Decompression can be performed by making a small opening in the cyst and maintaining its patency with some type of drain.)

Small cysts (approximately 1 cm) may be managed with enucleation, curettage, and peripheral ostectomy. For larger cysts, enucleation followed by cryotherapy with liquid



▲ **Figure 25–5.** Specimen of an enucleated, odontogenic keratocyst and an associated unerupted tooth in a patient with nevoid basal cell carcinoma syndrome.

nitrogen may reduce recurrence rates. There have been reports of the effective use of the "Carnoy solution" to eliminate satellite cysts; these cysts are eliminated by the use of a chemical lavage that causes tissue fixation. The potential for keratocysts to involve the overlying soft tissue through cortical perforation may necessitate a supraperiosteal dissection and excision of the overlying mucosa.

Prognosis

Long-term follow-up is essential because of the high recurrence rate. Most recurrences become evident within 5 years of the initial treatment.

Diaz-Fernandez JM, Infante-Cossio P, Belmonte-Caro R, Ruiz-Laza L, Garcia-Perla-Garcia A, Gutierrez-Perez JL. Basal cell nevus syndrome. Presentation of six cases and literature review. *Med Oral Patol Oral Cir Buccal* 2005:1;10(Suppl 1):E57 [PMID: 15800468]. (Basal cell nevus syndrome may be associated with aggressive basal cell carcinomas and malignant neoplasias, for which early diagnosis and treatment are essential.)

Makowski GJ. Squamous cell carcinoma in a maxillary odontogenic keratocyst. *J Oral Maxillofac Surg* 2001;59(1):76 [PMID: 11152194]. (Description of a case of a malignant growth that developed in an odontogenic keratocyst.)

Myoung H, Hong SP, Hong SD et al. Odontogenic keratocyst: review of 256 cases for recurrence and clinicopathologic parameters. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001;91(3):328 [PMID: 11458242]. (Report of a large series of case reviewing the age at diagnosis, gender of the patient, cyst location, radiographic findings, histopathologic findings, and recurrence rates.)

Schmidt BL. The use of enucleation and liquid nitrogen cryotherapy in the management of odontogenic keratocysts. *J Oral Maxillofac Surg* 2001:59(7):720 [PMID: 11429726]. (The combination of enucleation and liquid nitrogen therapy may offer patients improved treatment in the management of odontogenic keratocysts.)

Stoelinga PJ. Long-term follow-up on keratocysts treated according to a defined protocol. *Int J Oral Maxillofac Surg* 2001;30(1):14 [PMID: 11289615]. (Brief discussion of the etiology and pathogenesis of odontogenic keratocysts and a treatment protocol for effective management.)

Stoll C, Stollenwerk C, Riediger D, Mittermayer C, Alfer J. Cytokeratin expression patterns for distinction of odontogenic keratocysts from dentigerous and radicular cysts. *J Oral Pathol Med* 2005;34(9):558 [PMID: 16138895]. (Immunochemical detection of cytokeratin 17 and 19 seems to be a valuable additional parameter differentiating odontogenic keratocysts from other odontogenic cysts.)

GINGIVAL (ALVEOLAR) CYSTS OF NEWBORNS

ESSENTIALS OF DIAGNOSIS

- Superficial, keratin-filled cyst found on the alveolar mucosa of infants.
- Present at birth.

Gingival cysts are fairly common in newborns but are rarely identified because they have a tendency to rupture and disappear. Similar inclusion cysts, such as Epstein pearls and Bohn nodules, are found on the palates of newborns. These cysts form from remnants of the dental lamina. They are asymptomatic, small (usually 1–2 mm in diameter), whitish papules on the mucosa of the alveolar process of neonates. The appearance of these lesions is pathognomonic. No treatment is required since these lesions spontaneously involute as a result of cyst rupture. The prognosis is excellent, and there is usually no recurrence.

LATERAL PERIODONTAL CYSTS AND VARIANT, THE BOTYROID ODONTOGENIC CYST

ESSENTIALS OF DIAGNOSIS

- A rare type of odontogenic developmental cyst.
- Occurs lateral to a tooth root, most commonly in the premolar region of the mandible (a common location of supernumerary teeth).

Lateral periodontal cysts are uncommon and are usually discovered on routine dental X-rays. The origin of this cyst may be related epithelial rests in the periodontal membrane. These lesions are usually asymptomatic, with possible

expansion of the buccal plate of bone. The adjacent teeth are usually vital, and there may be evidence of root divergence caused by expansion of the cyst. Lateral periodontal cysts are characterized by a round-to-ovoid radiolucency that is lateral to or between the roots of teeth. These cysts are lined by nonkeratinized epithelium and, unless secondarily infected, do not have an inflammatory component. The differential diagnosis includes OKCs and lateral radicular cysts. Complications include local bone destruction, divergence of adjacent tooth roots, and recurrence. Cyst enucleation is the treatment of choice. The prognosis is very good, although cyst recurrence is possible. A more aggressive variant of the lateral periodontal cyst is the botryoid odontogenic cyst.

Ucok O, Yaman Z, Gunhan O, Ucok C, Dogan N, Baykul T. Botryoid odontogenic cyst: report of a case with extensive epithelial proliferation. *Int J Oral Maxillofac Surg* 2005;34(6):693 [PMID: 16053898]. (Botryoid odontogenic cyst is considered a rare multilocular variant of the lateral periodontal cyst, can be aggressive, and can extend beyond the typical inter-radicular location.)

CALCIFYING ODONTOGENIC CYSTS (GORLIN CYSTS)

ESSENTIALS OF DIAGNOSIS

- A rare odontogenic, developmental cyst with occasionally aggressive behavior.
- Occurs equally frequently in the maxilla and the mandible; most cases are reported in the incisor or canine regions.

The mean reported age of onset is 33 years, with most cases presenting in the second and third decades. The epithelium is derived from odontogenic sources within the jaw or gingiva. This lesion is considered by some clinicians to be a neoplasm rather than a cyst. It is usually painless and occurs in the tooth-bearing areas of the jaws, but it may be peripheral to the bone in about 25% of cases. Lesions that are extraosseous appear as localized sessile or pedunculated gingival masses. The calcifying odontogenic cyst usually appears as a unilocular or multilocular and well-delineated radiolucency. Radiopacities may appear in the lesion as irregular calcifications or toothlike structures in approximately 50% of cases. The distinctive histopathologic feature of this lesion is "ghost cell" keratinization of the epithelial lining. The keratin may undergo dystrophic calcification. A differential diagnosis should include adenomatoid odontogenic tumors, cystic odontomas, calcifying epithelial odontogenic tumors, and ameloblastic fibroodontomas. Complications include local bony destruction and the potential for loss of contiguous teeth in aggressive cases. The cyst should be removed by enucleation. The prognosis is good, and only a few cases of recurrences have been reported.

GLANDULAR ODONTOGENIC CYSTS

ESSENTIALS OF DIAGNOSIS

- This recently described odontogenic developmental lesion is uncommon.
- Occurs in the tooth-bearing areas of the jaws.

This lesion can occur in any jaw site in adults but is more common in the anterior regions. Most cases of glandular odontogenic cysts reported have been in the adult mandible, and they can be locally aggressive. This cyst usually presents as a multilocular radiolucency of the jaw. Glandular odontogenic cysts are lined by a nonkeratinized epithelium, with localized areas of mucus and clear cells in a pseudoglandular pattern. The differential diagnosis should include OKCs. Local bone destruction can result from the growth of this lesion. Surgical management should be based on the extent and aggressiveness of the lesion. The prognosis is good based on relatively few reported cases, but the potential for recurrence exists.

Krishnamurthy A, Sherlin HJ, Ramalingam K, Natesan A, Premkumar P, Ramani P, Chandrasekar T. Glandular odontogenic cyst: report of a case and review of the literature. *Head Neck Pathol* 2009;3(2):153 [PMID: 19644539]. (The increased recurrence rates can be due to its intrinsic biologic behavior, multilocularity of the cyst, and incomplete removal of the lining following conservative treatment.)

ODONTOGENIC INFLAMMATORY CYSTS

RADICULAR CYSTS (PERIAPICAL CYSTS)

ESSENTIALS OF DIAGNOSIS

- The most common type of jaw cyst.
- Associated with a nonvital tooth subsequent to dental caries entering the tooth pulp, trauma, or surgical devitalization.
- Usually presents as a radiolucent lesion around the apex of a tooth root.

General Considerations

This odontogenic inflammatory cyst represents 65–70% of all jaw cysts and can occur around the apex of any tooth. If a tooth associated with a radicular cyst is extracted and the cyst is not removed, it may remain and continue to expand, producing a residual cyst.

Pathogenesis

The radicular cyst is the result of dental pulp inflammation that progresses to the periapical area through the apical foramen of the tooth or through a lateral root canal. The epithelium is derived from the epithelial rest of Malassez. This cyst develops within a periapical granuloma at the tooth apex.

Prevention

The prevention of radicular cyst formation can be accomplished by regular dental examination and imaging to identify nonvital teeth. Once these nonvital teeth are identified, they are treated with endodontics (eg, root canal therapy) or extraction to prevent potential cyst development.

Clinical Findings

A. Symptoms and Signs

Small radicular cysts do not usually become acutely infected, are frequently asymptomatic, and can be identified on routine dental X-rays. Larger cysts may produce expansion of the bone, displacement of tooth roots, and crepitus when palpating the expanded alveolar plate. The discoloration of nonvital teeth and a negative response of the affected tooth to electric pulp testing or ice are the presenting signs. In addition, infected radicular cysts are painful, the involved tooth is sensitive to percussion, and there may be swelling of the overlying soft tissues and lymphadenopathy.

B. Imaging Studies

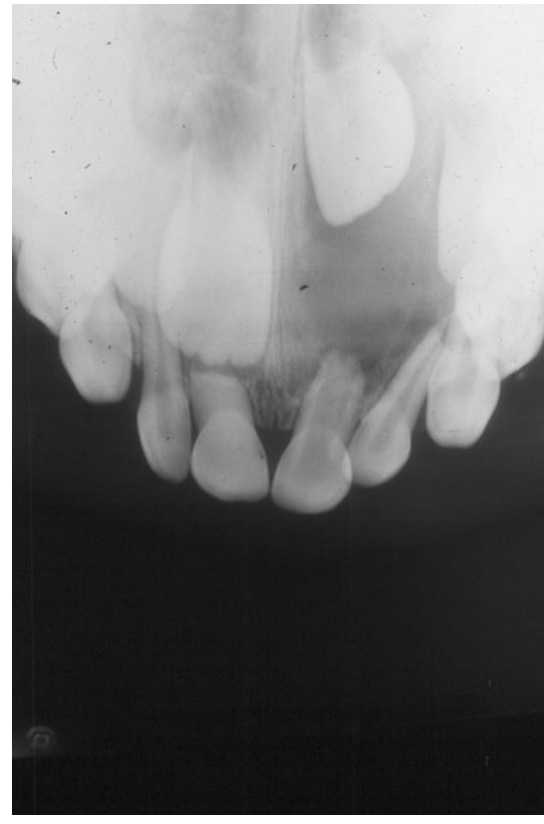
Dental X-rays (periapical, occlusal, and panoramic) show a cyst around the end of the root (most commonly, the maxillary anterior teeth) that can extend beyond the boundaries of the involved tooth (Figure 25–6).

C. Special Examinations

Histopathologic examination reveals a cystic lesion with a nonkeratinized epithelial lining. Remnants of cellular debris and fluid containing proteins predominantly derived from the plasma are usually found within the lumen of the cyst.

Differential Diagnosis

The differential diagnosis should include periapical granulomas, periapical scars (ie, fibrous healing defect), the early stage of periapical cemental dysplasia, giant cell lesions, bone neoplasms, traumatic bone cysts, and metastatic disease.



▲ **Figure 25–6.** Occlusal X-ray demonstrating a radicular cyst associated with a nonvital deciduous maxillary central incisor, causing displacement of the succedaneous permanent central incisor tooth.

Complications

Complications include the loss of supportive alveolar bone and the loss of teeth.

Treatment & Prognosis

Treatment of radicular cysts involves endodontic therapy for small cysts (ie, <5 mm), endodontic therapy plus periapical surgery and cyst enucleation for larger lesions, or, if the tooth is not restorable, tooth extraction combined with cyst enucleation. The prognosis is excellent following the appropriate treatment and recurrences are rare unless the cyst is left in situ.

Caliskan MK. Prognosis of large cyst-like periapical lesions following nonsurgical root canal treatment: a clinical review. *Int Endod J* 2004;37(6):408 [PMID: 15186249]. (Root canal treatment using calcium hydroxide as an antibacterial dressing in healing large, cyst-like periapical lesions.)

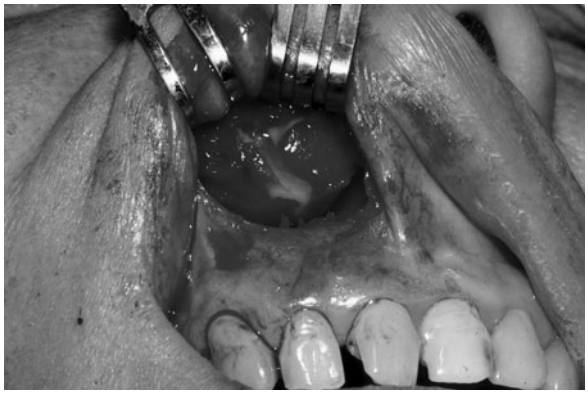
NONODONTOGENIC CYSTS

NASOLABIAL CYSTS (NASOALVEOLAR CYSTS)

ESSENTIALS OF DIAGNOSIS

- Rare nonodontogenic developmental cyst.
- Occurs as a unilateral swelling (10% incidence of bilateral occurrence) of the upper lip lateral to the midline, superficial to the maxilla.

The nasolabial cyst is observed most often in adults in the fourth to sixth decades of life with a 3:1 female-to-male predilection. It is believed that the epithelium is derived from remnants of the nasolacrimal duct. A swelling appears in the lateral aspect of the upper lip and is generally painless unless secondarily infected. The swelling may elevate the nasal vestibule mucosa and cause obliteration of the nasolabial fold. It may cause nasal obstruction or interfere with the flange of an upper denture. There are no radiographic signs, except for a possible saucerization of the underlying labial surface of the maxilla. The nasolabial cyst is lined by pseudostratified columnar epithelium, which frequently demonstrates cilia and goblet cells. The differential diagnosis should include odontogenic developmental cysts, salivary gland neoplasms, inclusion cysts, and sebaceous cysts. Secondary infection is a potential complicating factor. Transoral surgical excision is the treatment of choice, as observed in Figure 25–7, but transnasal endoscopic marsupialization has also been reported. The prognosis is excellent and recurrence is rare.



▲ **Figure 25–7.** Surgical exposure of an infected nasolabial cyst in preparation for enucleation.

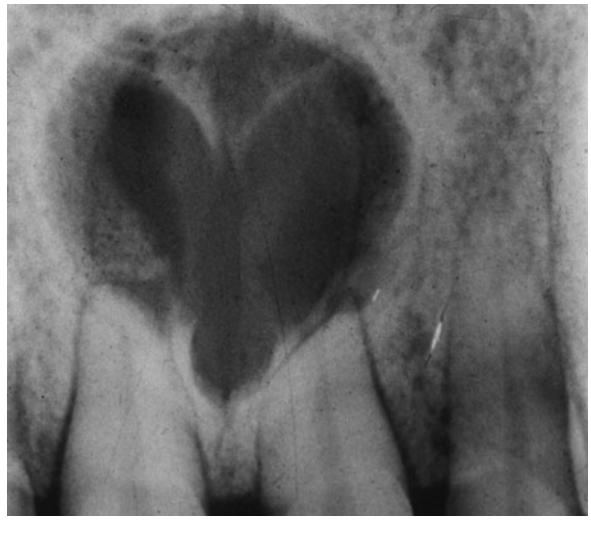
Chao WC, Huang CC, Chang PH, Chen YL, Chen CW, Lee TJ. Management of nasolabial cysts by transnasal endoscopic marsupialization. *Arch Otolaryngol Head Neck Surg* 2009;135(9):932 [PMID: 19770428]. (Transnasal endoscopic marsupialization is an effective treatment for nasolabial cysts, is less costly, and has fewer complications than sublabial excision.)

NASOPALATINE CYSTS (INCISIVE CANAL CYSTS)

ESSENTIALS OF DIAGNOSIS

- Relatively common nonodontogenic, developmental cyst.
- Occurs in the palatal midline behind the maxillary central incisors in the region of the incisive canal.

Nasopalatine cysts occur in 2–5% of jaw cysts. This cyst derives its epithelium from the embryonic remnants of the nasopalatine duct. The lesion is usually asymptomatic unless secondarily infected. The maxillary central incisors are vital. There may be palatal bone expansion or palatal mucosal swelling. The patient may complain of a salty taste, which results from drainage. This cyst presents as a well-defined, oval- or heart-shaped mass that is created by the anterior nasal spine; it occurs between and apical to the maxillary central incisors. Periapical and occlusal radiographs demonstrate the lesion very clearly (Figure 25–8). It is difficult



▲ **Figure 25–8.** Occlusal X-ray of a nasopalatine cyst in the midline contiguous to the maxillary central incisors with apical root resorption.

to determine at times whether the mass is a large incisive foramen or whether it represents a nasopalatine cyst. If the affected area is asymptomatic, if the cyst is less than approximately 7 mm, and if there is a question of the existence of pathology, it is reasonable to follow up the patient clinically and radiographically. The epithelial lining varies from stratified squamous presentation to one that is pseudostratified and ciliated. A differential diagnosis should include periapical cysts, granulomas, and keratocysts. Complications include the loss of bony support for the adjacent incisor teeth, root divergence, root resorption, as well as neurosensory deficit of the anterior palatal mucosa after cyst excision. Surgical enucleation via a palatal flap is the treatment of choice. The prognosis is excellent and recurrence is rare.

Elliott KA, Franzese CB, Pitman KT. Diagnosis and surgical management of nasopalatine cysts. *Laryngoscope* 2004;114(8):1336 [PMID: 15280704]. (Nasopalatine duct cysts are the most common cystic lesion of nonodontogenic origin of the maxilla with enucleation as the preferred treatment and low recurrence rates.)

PSEUDOCYSTS

ANEURYSMAL BONE CYSTS

ESSENTIALS OF DIAGNOSIS

- Rare intraosseous jaw lesion characterized by blood-filled spaces associated with a fibroblastic tissue containing multinucleated giant cells and osteoid and woven bone.
- Appears more frequently in the mandible than in the maxilla.

This lesion is typically observed in patients under 30 years of age. Aneurysmal bone cysts are considered reactive rather than neoplastic or cystic lesions. The pathogenesis is unknown, but it is believed that a vascular malformation occurs, producing an alteration of hemodynamic forces that create the cyst. Smaller lesions may be asymptomatic and are identified on routine X-rays; larger lesions present as occasionally painful, nonpulsatile swellings over the jaw. A multilocular jaw mass with cortical expansion is characteristic. Histopathologic examination reveals a fibrous connective tissue stroma containing variable numbers of multinucleated cells in relation to sinusoidal blood spaces. The differential diagnosis should include ameloblastomas, developmental odontogenic cysts, central giant cell granulomas, and central vascular lesions. Complications include a destructive osteolytic process of the involved jaw. Complete excision is the treatment of choice. The prognosis is generally good, provided the lesion is completely removed. Curettage procedures yield high recurrence rates.

Sanchez AP, Diaz-Lopez EO, Rojas SK et al. Aneurysmal bone cyst of the maxilla. *J Craniofac Surg* 2004;15(6):1029 [PMID: 15547399]. (An aneurysmal bone cyst is a nonneoplastic, uncommon solitary bone lesion recognized by distinct radiographic and histopathologic characteristics that can reach a considerable size and is treated by surgical excision.)

Roychoudhury A, Rustagi A, Bhatt K, Bhutia O, Seith A. Aneurysmal bone cyst of the mandible: report of 3 cases. *J Oral Maxillofac Surg* 2009;67(9)1996 [PMID:19686939]. (Extensive and recurrent lesions may require resection and reconstruction to limit blood loss and have a more predictable cure.)

TRAUMATIC BONE CYSTS

ESSENTIALS OF DIAGNOSIS

- An empty or possibly fluid-filled bone cavity that appears to scallop the roots of vital teeth.
- Rather than an epithelial lining, there is a fibrous or granulation tissue component, or no identifiable lining.
- Usually identified on routine dental radiographic examination.

General Considerations

A traumatic bone cyst is usually observed during the second decade of life and is seen in the mandibular body and symphysis. It is a relatively uncommon lesion that can occur in the humerus and other long bones. This cyst is sometimes referred to as a solitary, simple, hemorrhagic cyst.

Pathogenesis

The pathogenesis of this lesion is unknown; theories suggest that its pathology results from a traumatic episode that causes a hematoma to form within the intramedullary bone. Rather than forming a blood clot, it breaks down, producing osteolysis and an empty bone cavity.

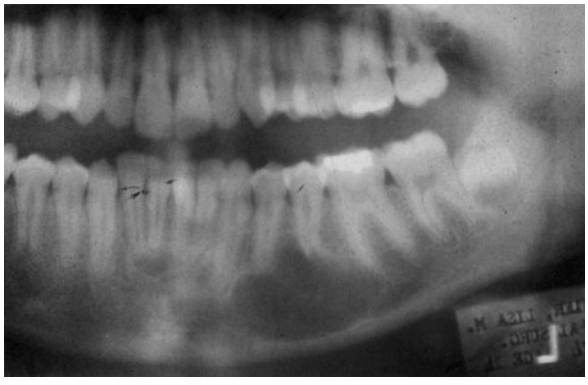
Prevention

There are no known preventive measures. Regular dental visits with appropriate imaging are recommended.

Clinical Findings

A. Symptoms and Signs

The traumatic bone cyst is usually asymptomatic and rarely presents with pain or bony expansion. Although the lesion is around the root apices, tooth vitality is maintained.



▲ **Figure 25–9.** Panoramic X-ray of a mandibular traumatic bone cyst in the left mandibular body. The radiolucency scallops the roots of vital premolars and the first molar.

Traumatic bone cysts that occur in association with florid osseous dysplasia have been reported. Percussion of the teeth contiguous to this cyst may produce a dull percussion sound compared with the more high-pitched sound that is heard when percussing teeth not involved with a hollow bone cavity.

B. Imaging Studies

Radiographically, the traumatic bone cyst appears as a well-defined lesion around the roots of contiguous teeth, usually in the mandible (Figure 25–9). Adjacent tooth roots may be displaced.

C. Special Examinations

Histopathologic examination of surgical specimens usually reveals fragments of fibrous or granulation tissue and bone fragments.

Differential Diagnosis

The differential diagnosis includes OKCs, central giant cell granulomas, or odontogenic tumors.

Complications

Complications include local bone destruction and the displacement of tooth roots.

Treatment

Surgical exploration is the treatment modality most commonly used to rule out the existence of other more aggressive and significant lesions. The aspiration or surgical curettage of the cavity frequently induces hemorrhage, with subsequent healing of the bony cavity.

Prognosis

Traumatic bone cysts may heal spontaneously without surgical intervention, but with surgical exploration, the healing may be accelerated, with bone fill expected in 6–12 months. The prognosis is excellent, and recurrence is traditionally not expected but has been reported.

Khoud BN, Orset E, Lebeau J, Brix M. Solitary bone cysts of the jaws. *Rev Stomatol Chir Maxillofac* 2009;110(4):221 [PMID: 19660773]. (There may be up to a 26% recurrence rate, requiring radiographic follow-up.)

STATIC BONE CYSTS

ESSENTIALS OF DIAGNOSIS

- A mandibular anatomic defect that has a cyst-like appearance on X-ray.
- May occur in the incisor or in the cuspid or premolar regions of the lingual aspect of the mandible.
- Usually a unilateral phenomenon but may occur bilaterally.

A static bone cyst is an anatomic defect in the mandible (Figure 25–10). These cysts are also known as Stafne bone cysts, lingual mandibular salivary gland depressions, latent bone cysts, and lingual cortical mandibular defects. It is believed to be developmental in nature but does not appear at birth and is not seen in children. Most cases are seen in middle-aged or older adults. Eighty to ninety percent of these defects are seen in males. They are stable in size (ie, static) and have been reported to occur in 0.3% of panoramic X-rays. This entity is asymptomatic and nonpalpable and is discovered during

▲ **Figure 25–10.** Cadaveric mandible with a static bone cyst.

routine radiographic examination. A static bone cyst appears as a well-circumscribed, round-to-oval mass that is located near the angle of the mandible and below the level of the mandibular canal, with no involvement of the tooth roots.

Surgical exploration is not indicated, but these defects contain salivary gland or adipose tissue from the floor of the mouth. The radiographic and clinical findings are pathognomonic for this entity. There has been a report of a salivary gland neoplasm developing in the lingual mandibular salivary gland depression. A static bone cyst does not require biopsy or excision unless a mass can be identified or imaged or there are clinical findings. The prognosis is excellent and no treatment is required.

Katz J, Chaushu G, Rotstein I. Stafne's bone cavity in the anterior mandible: a possible diagnostic challenge. *J Endod* 2001;27(4):304 [PMID: 11485274]. (Most Stafne bone cavities occur in the angle of the mandible in the area between the mandibular first molar and the mandibular angle, but some may appear in the anterior mandible, which may be more difficult to diagnose.)

GANGLION CYSTS

Ganglions are cystic lesions that develop near joints, including the TMJ. These cystic lesions are not classically described in discussions of cystic lesions of the jaw, but because of their presentation, they may be confused with parotid tumors.

There are two types of ganglion cysts: (1) those with walls that consist of fibrous connective tissue and (2) those with walls that are lined by synovial cells. Ganglions should be considered when evaluating preauricular swellings. The surgical removal with histopathologic examination of the excised tissue is the treatment of choice for jaw cysts in most cases.

Kim SG, Cho BO, Lee YC et al. Ganglion cyst in the temporomandibular joint. *J Oral Pathol Med* 2003;32(5):310 [PMID: 12694356]. (The ganglion cyst of the temporomandibular joint should be considered in the differential diagnosis of preauricular masses.)

Temporomandibular Disorders

26

Greg Goddard, DDS

General Considerations

Temporomandibular disorders (TMDs) are a set of musculoskeletal disorders affecting the temporomandibular joint (TMJ), the masticatory muscles, or both. TMDs comprise many diverse diagnoses with similar signs and symptoms affecting the masticatory system, which can be acute, recurrent, or chronic. TMDs are rarely life threatening, but can impact heavily on an individual's quality of life. Studies show that about 3–7% of the population need treatment.

TMDs occur disproportionately in women of childbearing age in a ratio of 4:1 to 6:1, and the role of estrogens seems to show an association. The prevalence drops off dramatically for both men and women after age 55.

Al-Jundi MA, John MT, Setz JM, Szentpétery A, Kuss O. Meta-analysis of treatment need for temporomandibular disorders in adult nonpatients. *J Orofac Pain* 2008 Spring;22(2):97–107 [PMID: 18548838] [PubMed—indexed for MEDLINE]. (A meta-analysis of nonpatient studies to determine the prevalence of treatment need for temporomandibular disorders in adult populations is about 15%.)

Wang J, Chao Y, Wan Q, Zhu Z. The possible role of estrogen in the incidence of temporomandibular disorders. *Med Hypotheses* 2008 Oct;71(4):564–567 [Epub Jul 1, 2008] [PMID: 18597950] [PubMed—indexed for MEDLINE]. (The overwhelming majority of patients treated for temporomandibular disorders are women and the available literature is examined to evaluate the role of estrogens in TMD.)

Etiology

The cause of TMD is variable and uncertain, and it is thought to be multifactorial in most cases. Genetic factors have recently been implicated. Most factors are not proven causal factors, but they are associated with TMDs. Predisposing factors increase the risk of TMDs. Predisposing factors are trauma, both direct (eg, blows to the jaw) and indirect (eg, whiplash injuries), and stress. Microtrauma is caused by clenching and grinding of the teeth. Stress can be a predisposing factor owing to the disruption of restorative sleep and the increase of nocturnal bruxism. Trauma and stress are also precipitating factors.

Perpetuating factors that sustain a TMD are stress, poor coping skills, harmful habits such as clenching and grinding, and poor posture. Nonrestorative sleep also may be a major factor in the perpetuation of chronic jaw pain.

Diatchenko L, Slade GD, Nackley AG, Bhalang K, Sigurdsson A, Belfer I, Goldman D, Xu K, Shabalina SA, Shagin D, Max MB, Makarov SS, Maixner W. Genetic basis for individual variations in pain perception and the development of a chronic pain condition. *Hum Mol Genet* 2005 Jan 1;14(1):135–143 (Epub 2004 Nov 10) [PMID: 15537663] [PubMed—indexed for MEDLINE]. (Genetic variants (haplotypes) are strongly associated ($P = 0.0004$) with variation in the sensitivity to experimental pain and risk of developing myogenous temporomandibular joint disorder (TMD).

Controversial Causes

A. Bruxism

Bruxism, or grinding the teeth during sleep, has been thought to be a predisposing, precipitating, and perpetuating factor. Bruxism can involve excessive activation of the masticatory muscles and excessive loading of TMJs, which can be a factor in the recovery of some patients, whereas in others bruxism does not seem to be a factor. In studies, bruxism has not been clearly demonstrated as a cause of TMD. Some individuals who severely grind their teeth do not have any signs or symptoms of TMD.

Dental and occlusal origins are not generally accepted, and the scientific evidence does not support their causal relationship. Experimental occlusal interferences have been placed with no evidence of TMD symptoms. There is no evidence of a higher incidence of TMD with any type of malocclusion, and significant proportions of the population have occlusal discrepancies without any TMD pain.

Pergamalian A, Rudy TE, Zaki HS, Greco CM. The association between wear facets, bruxism, and severity of facial pain in patients with temporomandibular disorders. *J Prosthet Dent* 2003;90(2):194 [PMID: 12886214]. (The amount of bruxism activity was not associated with more severe muscle pain.)

B. Whiplash

Whiplash has been thought to be a precipitating factor in the development of TMD. There is very little evidence that a noncontact injury can cause damage to the TMJ. However, many patients claim muscle and joint pain after a whiplash injury. The pain may be referred from the strained sternocleidomastoid muscle, which often refers pain to the ear, or it may be due to injuries to other cervical muscles and ligaments.

C. Disc Displacement

Disc displacement has been considered a pathologic condition, but many studies have shown that from 30% to 50% of populations have reducing discs. Most of these individuals have no history of TMJ pain or dysfunction. Disc displacement may be a normal biological variation. Clicking joints are not necessarily painful or pathologic. Studies reporting on the long-term follow-up of patients with disc displacement show the majority are asymptomatic 30 years later (Figure 26–1).

Clinical Findings

A. Symptoms and Signs

The most common TMD complaints are jaw, face, and head pain of moderate intensity. Limited opening, catching or sticking, and locking of the mandible are common functional complaints. Patients often have complaints of joint noises, such as clicking, popping, and grating when the mandible is opened or closed. Patients also have perceived complaints of global headache and neck and shoulder pain that are not related to jaw function. Some patients present with unexplained complaints of tinnitus, ear fullness, hearing loss, and dizziness. Complaints of abnormal tooth wear, tooth sensitivity, and teeth not meeting correctly are often expressed.

▲ **Figure 26–1.** MRI showing anterior displaced disc that does not reduce on opening.

B. Imaging Studies

Magnetic resonance imaging (MRI) reveals hard bony tissue as well as soft tissue abnormalities. Computed tomography (CT) scans are useful in showing degenerative changes of the hard tissues. Imaging should be reserved for patients whose abnormal pain, dysfunction, or both does not respond to conservative short-term treatments such as non-steroidal anti-inflammatory drugs (NSAIDs) and physical therapy. Imaging is also warranted in patients who have a sudden change in the bite or asymmetry of the mandible.

Differential Diagnosis

Temporomandibular disorders are divided into articular disorders and muscle disorders. The diagnosis is largely based on the specific system(s) that is affected. However, many patients have both muscle and articular disorders.

Treatment

The management of TMDs is based on the elimination of pain and the restoration of function and normal activities of daily living. Each specific diagnosis has its own set of management goals based on addressing the problems that affect that patient. Most management plans use conservative, noninvasive treatments; in less than 5% of cases, surgery is used.

The key elements of any conservative management plan are self-care, medication, and physical therapy. Acupuncture is often helpful, as are biofeedback and orthotic splint therapy.

List T, Axelsson S. Management of TMD: evidence from systematic reviews and meta-analyses. *J Oral Rehabil* 2010 Apr 20 [PMID: 20438615] (There is some evidence that the following can be effective in alleviating TMD pain: occlusal appliances, acupuncture, behavioral therapy, jaw exercises, postural training, and some pharmacological treatments.)

A. Self-Care

Patients with TMD can be more successfully treated by healthcare practitioners who educate patients about their disorder and involve them in their own treatment. Self-care is an essential part of patient treatment. It should be designed to meet each patient's treatment objectives. Self-care should be thoroughly explained to patients in language meaningful to

them, and it should be reinforced at each visit. This self-care results in better patient compliance and understanding and in better outcomes. The following are 20 self-care tips that have been effective in helping patients manage their TMD:

The rest of the muscles and joints allow healing.

Soft food enables muscles and joints to heal.

Not chewing gum lessens muscle fatigue and joint pain.

Relax your facial muscles: "Lips relaxed, teeth apart."

No clenching; it irritates joints and muscles.

Yawning against pressure prevents locking open and jaw pain.

Moist heat for 20 minutes promotes healing and relaxation.

Ice is for severe pain and new injuries (less than 72 hours).

Heat and ice—5 seconds of heat, 5 seconds of ice—for pain relief.

Good posture; avoid head-forward position.

Sleeping position: side lying, with good pillow support.

Jaw exercise: open and close against finger pressure.

Exercise: 20–30 minutes at least 3 times a week.

Acupressure massage between thumb and forefinger.

Over-the-counter medications: ibuprofen or aspirin.

Yoga and meditation for stress reduction.

Massage promotes healing and relaxation.

An athletic mouthguard can give temporary relief.

Avoid long dental appointments.

Do not cradle the telephone; it **aggravates** the neck and jaw.

B. Medication

The most common medications for TMD are (1) NSAIDs; (2) muscle relaxants such as cyclobenzaprine; and (3) low doses (10–50 mg) of tricyclic antidepressants such as amitriptyline, desipramine, or nortriptyline. In patients with TMJ synovitis who have a poor response to NSAIDs, a course of an oral steroid such as methylprednisolone (eg, a Depo-Medrol dose pack) for 6 days can be effective. When chronic pain is moderate to severe and does not respond to other treatments, opioid analgesics are often beneficial. Short-acting opioids such as hydrocodone should be avoided in favor of longer-acting codeine or oxycodone. Newer opioids such as tramadol have shown some promise.

Cascos-Romero J, Vázquez-Delgado E, Vázquez-Rodríguez E, Gay-Escoda C. The use of tricyclic antidepressants in the treatment of temporomandibular joint disorders: systematic review of the literature of the last 20 years. *Med Oral Patol Oral Cir Bucal* 2009 Jan 1;14(1):E3–E7 [PMID: 19114953] [PubMed—indexed for MEDLINE]. (Recommendation is given in favor of the use of tricyclic antidepressants for the treatment of temporomandibular disorders.)

C. Physical Therapy

Physical therapy has been shown to be helpful for many patients with TMD pain and dysfunction. Heat and ice have beneficial effects on reducing pain in some patients. Jaw exercises can be prescribed for increasing mobility, decreasing hypermobility, strengthening and coordinating muscles, and improving muscle endurance. Massage can be helpful because it promotes increased blood flow through the tissue in addition to inducing muscle relaxation. The evaluation of patient posture is important, and patients should be taught proper posture. A forward-head position can exacerbate neck pain and a tense jaw posture can increase jaw and muscle pain.

Mulet M, Decker KL, Look JO, Lenton PA, Schiffman EL. A randomized clinical trial assessing the efficacy of adding 6 × 6 exercises to self-care for the treatment of masticatory myofascial pain. *J Orofac Pain* 2007 Fall;21(4):318–328 [PMID: 18018993] [PubMed—indexed for MEDLINE]. (Jaw pain and neck pain improved significantly ($P < 0.01$) in both self-care and the exercise groups.)

Ismail F, Demling A, Hessling K, Fink M, Stiesch-Scholz M. Short-term efficacy of physical therapy compared to splint therapy in treatment of arthrogenous TMD. *J Oral Rehabil* 2007 Nov;34(11):807–813 [PMID: 17919246] [PubMed—indexed for MEDLINE]. (Physical therapy seems to have a positive effect on treatment outcome of patients with TMD.)

D. Ultrasound

Ultrasound can provide deep and relaxing heat to muscles and joints, helping to relieve pain and restore function. Transcutaneous electrical nerve stimulation (TENS) can be helpful in controlling pain. Joint manipulation can help improve joint mobility in cases of TMJ disc displacement without reduction.

E. Acupuncture

Acupuncture has been used for the treatment of TMDs, as well as for other musculoskeletal pains. The National Institutes of Health (NIH), in their consensus statement on acupuncture in 1997, stated that acupuncture shows promising results for postoperative dental pain, and in other situations (such as myofascial pain), acupuncture may be useful as an adjunct treatment or an acceptable alternative treatment. A number of studies of acupuncture and chronic pain found positive results in 41% of them and concluded that there is limited evidence that acupuncture is more effective than no treatment for chronic pain.

Cho SH, Whang WW. Acupuncture for temporomandibular disorders: a systematic review. *J Orofac Pain* 2010 Spring; 24(2):152–162. (There is moderate evidence that acupuncture is an effective intervention to reduce symptoms associated with TMD.)

F. Injection of Local Anesthesia

The injection of trigger points in painful muscles with a local anesthetic has been used for over 40 years and is still a popular treatment. Studies have shown that dry needling works just as well, and the difference between dry needling and acupuncture is minimal to none.

G. Splint Therapy

Splints (orthotics) are removable appliances, usually made of acrylic plastic, which fit over the teeth of either the mandible or the maxilla. Splints are the most often prescribed treatment for TMD; more than 3 million splints are made each year.

Despite the extensive use of oral splints in the treatment of TMD and bruxism, their mechanisms of action remain controversial. Oral splints should be used as an adjunct for pain management rather than a definitive treatment.

Treatment with intraoral splints has been shown to have varying levels of efficacy for the treatment of TMD and bruxism. Splints reduce the role of occlusal factors, reduce loading on the joints, and have a strong placebo effect. Splints can reduce tooth damage in patients who grind their teeth and can increase awareness of these detrimental oral habits. Not all patients get relief and some experience a worsening of symptoms with splints. There are possible complications to wearing splints, such as irreversible changes in occlusion that will necessitate either orthodontics or surgery to correct. Therefore, splints should be worn for a short to moderate time period and should be regularly monitored. Nighttime wear is typical and full-time use is contraindicated.

Klasser GD, Greene CS (2009). Oral appliances in the management of temporomandibular disorders [Electronic version]. *Oral Surg Oral Med Oral Pathol Oral Radiol Endo* Feb;107 (2):212–223. http://www.ncbi.nlm.nih.gov/pubmed/19138639. (Splints or oral appliances may be an effective treatment modality for some TMDs.)

H. Arthrocentesis

Arthrocentesis is the insertion of one or more needles into the superior joint space and irrigation with saline, with or without corticosteroids. It has been reported to be effective in cases of synovitis and limited opening due to anterior displaced disc without reduction.

I. Arthroscopy

Arthroscopy is the insertion of a cannula with fiberoptics that allows visualization of the joint space. Another cannula is then inserted with microtools that allow for debridement, the removal of adhesions, and biopsies.

J. Surgery

Surgery is reserved for those few patients (less than 5%) who do not respond to conservative treatment and in whom an identifiable structural defect can be corrected by surgery. These patients should undergo comprehensive nonsurgical rehabilitation, and surgery should be considered only after all of the contributing factors have been addressed and controlled. Many of the pain symptoms come from the muscular components of TMD, so these muscle diagnoses must be addressed and controlled. Failure to address these issues will likewise result in failed surgical treatment. Pre- and postoperative physical therapy is important for the successful outcome of any surgery. The less invasive surgical techniques seem to be just as efficacious as the more invasive open joint procedures, so arthrocentesis and arthroscopy should be considered as a first step.

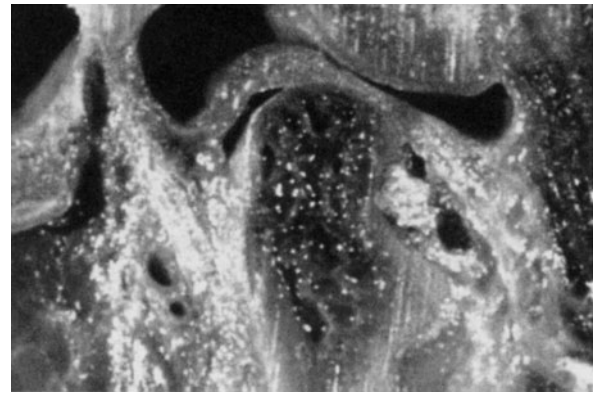
ARTICULAR DISORDERS

The TMJ is a paired synovial joint that is capable of both gliding and hinge movements. It articulates the mandibular condyle and the squamous portion of the temporal bone, with the articular disc of dense fibrous connective tissue interposed between the two bones. Unlike most other synovial joints, the TMJ is lined with dense fibrous connective tissue (Figure 26–2).

TMJ SYNOVITIS

This disorder is an inflammation of the synovial lining of the TMJ; it is characterized by localized pain that is increased by the functioning and loading of the joint. Sometimes patients complain about posterior teeth not meeting on the same side, presumably because of swelling in the joint.

Patients often present with a history of pain in the preauricular region, which is aggravated by chewing or other mandibular movement. Pain on palpation over the lateral pole of



▲ **Figure 26–2.** Sagittal section through the temporomandibular joint showing good condyle and disc relationship.

Table 26–1. Treatment Indications for Articular Disorders.

Articular Disorder	Self-Care	NSAIDs	Physical Therapy	Splint	Acupuncture	Arthrocentesis	Surgery
TMJ synovitis	X	X	X	X	X	X	
Disc displacement with reduction	X	X	X	X	X	X	
Acute disc without reduction	X	X	X	X	X	X	
Chronic disc displacement without reduction	X	X	X	X	X	X	
Osteoarthritis	X	X	X	X	X	X	
Polyarthritides	X	X	X	X	X	X	
Condylar dislocation	X	X	X				
Fibrous ankylosis			X			X	X
Bony ankylosis			X			X	X
Condylar fracture			X				X
Neoplasia			X				X

the condyle is evident. Pain is elicited on loading of the TMJ, or on distraction or compression. Range of motion is often limited (<35 mm). No radiographic changes are found; however, evidence of joint effusion is seen on MRI. Treatment indications can be found in Table 26–1.

DISC DISPLACEMENT DISORDERS

DISC DISPLACEMENT WITH REDUCTION

Disc displacement with reduction is characterized by a clicking jaw joint; an audible or palpable click is heard or felt on opening the mandible and in lateral movements of the mandible. This condition is most often painless and requires no treatment. Up to 50% of people have been shown to have displaced discs, and most do not have any pain or dysfunction. When pain accompanies the click, it is most often the result of inflammation in the joint owing to the condyle pressing on the retrodiscal tissues, synovitis, or capsulitis. Symptomatic clicking, in which there is pain on clicking and pain on loading, needs to be treated. MRI shows the anterior position of the disc in a closed position and in a normal position on opening. X-rays may show a decreased joint space, but this is not diagnostic of a displaced disc.

ACUTE DISC DISPLACEMENT

Acute disc displacement without reduction (closed lock) is characterized by a marked limitation in opening (<35 mm). It is also distinguished by a deflection of the mandible to the affected side on opening. It occurs with a sudden onset and can be painless or painful. No clicking is felt or heard, although the patient usually has a history of clicking at one time. The disc is usually anterior to the condyle and blocks the translation of the condyle, preventing normal opening and causing the mandible to deflect to the affected side. MRI shows the disc anterior to the condyle in the closed position, and it remains anterior on opening. Radiographs can show a decreased joint space that might be an indication of a displaced disc.

CHRONIC DISC DISPLACEMENT

Chronic disc displacement without reduction (closed lock) is a long-standing condition characterized by a slightly limited opening (<40 mm) that usually improves after the initial onset. The patient has no clicking, either felt or heard, although he or she usually has a history of a previously clicking joint. Pain is not usually a complaint, and patients may or may not present with it. The mandible deflects to the affected side on opening. The disc is anterior to the condyle and is either pushed further anterior on opening or is folded on itself. MRI shows the disc far anterior, often folded on itself, and pushed further forward on opening.

OSTEOARTHRITIS

Osteoarthritis is a noninflammatory arthritic condition that is characterized by deterioration and abrasion of the articular tissues. It is accompanied by remodeling of the underlying subchondral bone. Joint pain is present with function, and crepitus is often heard over the affected joint. Joint stiffness, often worse on awakening or at the beginning of a meal, can be a problem, and the patient may have a limited range of motion. Radiographic evidence of degeneration of the condyles can be seen. Synovitis often is present and accounts for pain, when present. The long-term prognosis is good because osteoarthritis tends to be self-limiting as the joint remodels.

POLYARTHRITIDES

Systemic polyarthritic disorders can affect the TMJ as well as other joints in the body. Various systemic diseases such as rheumatoid arthritis, juvenile rheumatoid arthritis, ankylosing spondylitis, psoriatic arthritis, infectious arthritis, Reiter

syndrome, gout, and Lyme disease can involve the TMJ. A common finding is pain to palpation over the TMJ. Pain is usually elicited with function, and the patient may experience a limited range of motion. Crepitus can be heard over the affected joint, and degeneration of the condyles may be seen on X-rays.

CONDYLAR DISLOCATION

Condylar dislocation is characterized by a patient who is unable to close his or her mouth. The patient's mouth is fully open upon presentation, and he or she is usually in great distress, with pain and anxiety. This condition occurs after yawning, after eating an apple or other food that requires wide opening, or with prolonged opening, as during a dental appointment. The condyle remains positioned anterior to eminence. There can be joint pain at the time of dislocation and for up to several days afterward. There is usually a history of a self-reducing dislocation.

The condyle can be reduced by manually pushing the mandible both downward and backward into the fossa. This reduction can often be done in the office by placing gloved hands, with the thumbs outside the patient's teeth, on the lateral border of the mandible and distracting the mandible in a downward direction, placing the condyles back into the fossa. If the muscles have gone into spasm, it may be necessary to administer a muscle relaxant such as diazepam; in more severe cases, the patient may need to be placed under general anesthesia before enough muscle relaxation can take place to reduce the condyles. Postoperative pain is managed with NSAIDs, and physical therapy is indicated. Self-care can assist in preventing recurrences.

FIBROUS ANKYLOSIS

Fibrous ankylosis is restricted mandibular movement with deviation to the affected side on opening. This condition results from fibrous adhesions that attach the condyle to the disc and the disc to the articular fossa. It may be caused by bleeding in the joint, but the exact mechanism is not known. A history of trauma to the TMJ usually exists. There is a marked limited opening, usually <20 mm, but the condition is not painful. The mandible deflects to the affected side on opening, and there is a marked limited lateral movement of the mandible to the contralateral side. Radiographs show an absence of condylar translation, but they do show a joint space.

BONY ANKYLOSIS

Bony ankylosis is the union of the bones of the mandibular condyle and the temporal fossa by proliferation of bone cells, which results in the complete immobility of the joint. It is usually secondary to trauma and probably due to bleeding in the joint. A history of trauma to the TMJ usually exists. There is a marked limited opening, usually <10 mm, although the condition is generally not painful. The mandible deflects to the affected side on opening, and there is a marked limited lateral movement of the mandible to the contralateral side. CT scanning or MRI shows a connection between bony articulating surfaces; X-rays show an absence of condylar translation and bone proliferation in the joint space.

CONDYLAR FRACTURE

Fractures can occur in any of the bony components of the TMJ; however, fracture of the mandibular condyle is the most common. It is often caused by a direct trauma to the jaw, usually by a blow to the chin. This condition is marked by a limited opening (<25 mm), swelling over the affected joint, and pain with function. There is often bleeding in the joint, and sequelae can include adhesions, ankylosis, and joint degeneration. The mandible deflects to the affected side, and the fracture is evident on an X-ray.

Condylar fractures are managed with immobilization, a soft diet, and physical therapy to regain the range of motion. Open joint surgery is required to reduce the fracture only in rare cases.

NEOPLASIA

Neoplasms of the TMJ can be benign, malignant, or metastatic. One percent of malignant breast tumors metastasize to the mandible.

BENIGN NEOPLASMS

Benign TMJ neoplasms include osteomas, osteoblastomas, chondromas, benign giant cell tumors, ossifying fibromas, fibrous dysplasias, myxomas, and synovial chondromatosis.

MALIGNANT NEOPLASMS

Malignant TMJ neoplasms are rare and include chondrosarcomas, fibrosarcomas, and synovial sarcomas.

METASTATIC NEOPLASMS

Metastatic TMJ neoplasms are more common than primary tumors; 1% of malignant neoplasms metastasize to the jaws. Squamous cell carcinomas of the maxillofacial region and nasopharyngeal tumors are the tumors that most commonly extend into the TMJ. Neoplasms from the parotid gland, such as adenocystic carcinomas and mucoepidermoid carcinomas, have been reported to involve the TMJ. These neoplasms often present with swelling and pain. Pain is elicited on palpation and with function. There can be an open bite on the affected side where the back teeth do not meet. Imaging shows a lesion.

NEOPLASMS OF THE MASTICATORY MUSCLES

Neoplasms of the masticatory muscles are very rare. They can be malignant or benign, are associated with swelling, and may or may not present with pain, although pain usually accompanies swelling. There is a positive finding of tumor with imaging, and both imaging and biopsy help confirm the diagnosis.

MUSCLE DISORDERS

The muscles of mastication are the masseter, temporalis, medial pterygoid, and lateral pterygoid muscles. In addition to neoplasms, which are rarely seen, more common muscle disorders may result in pain, redness, swelling, cramping, and contracture. Treatment indications can be found in Table 26–2.

MYOFASCIAL PAIN

Myofascial pain is characterized by a regional, dull, aching muscle pain, usually of mild to moderate intensity. The pain is aggravated by mandibular function when the muscles of mastication are involved. TMJ pain may result in painful masticatory muscles due to the reflex splinting of these muscles. Often, localized tender areas (ie, trigger points) in the muscle or tendon exist. When the muscle is palpated, the trigger points that elicit pain often refer the pain to distant areas. This referred pain is often felt as a headache, and myofascial pain has been associated with tension-type headaches; it is also associated with ear symptoms, tinnitus, vertigo, and toothache. Patients may also present with a sensation of muscle stiffness or tightness and a sensation of their teeth not meeting correctly. Inactivating the trigger points with a local anesthetic injection, acupuncture, or a vapocoolant spray and muscle stretch often relieves the larger area of referred pain. The pathogenesis is now thought to be due to changes in the central nervous system that are responsible for hyperalgesia of the muscles.

MYOSITIS

Myositis is characterized by moderate to severe pain, redness, and swelling associated with tissue injury. This condition can result from direct trauma or infection, often secondary to oral surgery or an intramuscular injection. Pain is usually continuous in a localized muscle area following injury or infection, and diffuse tenderness is present over the entire muscle. Pain increases with movement, and a moderate to severe limitation of opening due to pain and swelling is common. A limited range of mandibular motion is often present. Elevated serum levels indicative of inflammation, infection, or both may be present.

MYOSPASM (TRISMUS)

Myospasm, or muscle cramp, is characterized by a continuous involuntary muscle contraction with severe pain. The patient experiences an acute onset of pain at rest as well as with function. Myospasm is not a common finding in TMDs; when it does occur, it usually resolves within hours.

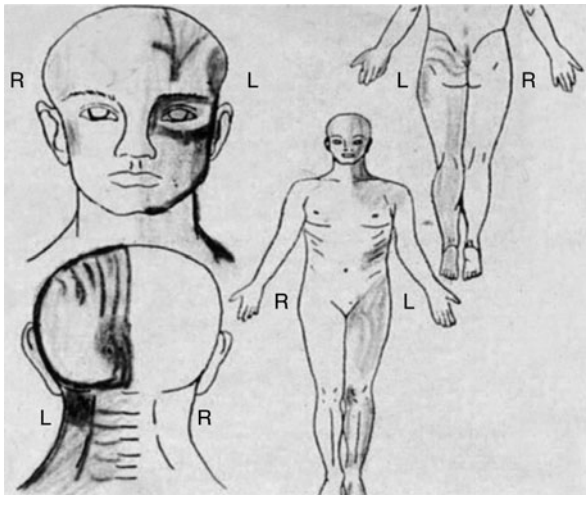
CONTRACTURE

Muscle contracture is the painless shortening of a muscle, usually secondary to a period of limited range of motion. It is characterized by an unyielding firmness on passive stretch and is usually associated with minimal or no pain unless the muscle is forced to lengthen. Muscle contracture can occur after wiring the jaws following fracture, after jaw surgery, after a prolonged infection, or with an anterior displaced disc without reduction that grossly limits the range of motion for a long period of time. The muscle undergoes fibrotic changes and becomes hard.

Table 26–2. Treatment Indications for Muscular Disorders.

Muscular Disorder	Self-Care	NSAIDs	Physical Therapy	Muscle Relaxant Medication	Splint	Acupuncture	Surgery
Myofascial pain	X	X	X	X	X	X	
Myositis	X	X	X	X	X	X	
Myospasm	X	X	X	X	X	X	
Muscle contracture	X		X		X	X	
Neoplasia			X				X
Fibromyalgia	X		X	X		X	

Data from Scrivani S, Keith D, Kaban L. Temporomandibular disorders, review article. *New Eng J Med* 2008 Dec;359:2693–705. (Review article on etiology, evaluation, diagnosis, and treatment of temporomandibular disorders suggests that the management of temporomandibular disorders consists of a combination of self-care, counseling, physiotherapy, pharmacotherapy, jaw appliance therapy, physical medicine, behavioral medicine, and surgery.)



▲ **Figure 26–3.** Typical pain diagram by a patient with fibromyalgia.

FIBROMYALGIA

Fibromyalgia is a generalized whole body muscle pain mostly affecting women between 25 and 50 years of age. It is often accompanied by fatigue, irritable bowel syndrome, muscle stiffness, and sleeping difficulties. The diagnosis is based on the presence of pain to palpation in 11 out of 18 predefined sites and pain in 3 of the 4 quadrants of the body.

Because problems with the masticatory and cervical muscles are typically painful, fibromyalgia is often misdiagnosed as myofascial pain. Studies have shown that up to 20% of patients with TMD are really fibromyalgia patients (Figure 26–3).

Clauw DJ. Pharmacotherapy for patients with fibromyalgia. *J Clin Psychiatry* 2008;69(Suppl 2):25–29 [PMID: 18537460] [PubMed—indexed for MEDLINE]. (Fibromyalgia needs an integrated treatment approach that includes pharmacotherapy and at least one, but preferably more, of the most effective nonmedicinal treatment options available (eg, education, aerobic exercise, and cognitive-behavioral therapy).

Neck Masses

27

Derrick T. Lin, MD & Daniel G. Deschler, MD

ANATOMY

Knowledge of the anatomy of the neck is essential for both the diagnosis and the treatment of disease processes in the region. Contained within the neck are several triangles, defined anatomically (Figure 27–1). Familiarity with these specific areas assists in generating a differential diagnosis of neck masses by the exact anatomic location.

The sternocleidomastoid muscle divides the neck into two major compartments, anterior and lateral.

ANTERIOR NECK

The following anatomic points define the anterior compartment of the neck: (1) the inferior border of the mandible superiorly, (2) the anterior border of the sternocleidomastoid muscle laterally, (3) the clavicle inferiorly, and (4) the vertical midline from mental symphysis to suprasternal notch medially. The structures that make up the anterior neck include the larynx, trachea, esophagus, thyroid and parathyroid glands, carotid sheath, and suprahyoid and infrahyoid strap muscles.

Triangular regions also define the anterior neck anatomically.

The **submandibular triangle** is a region contained in the anterior neck bordered by the inferior margin of the mandible and the digastric, stylohyoid, and mylohyoid muscles. This region contains the submandibular gland and the marginal mandibular branch of the facial nerve. The **submental triangle** defines a region bordered by the hyoid bone, the paired anterior bellies of the digastric muscles, and the mylohyoid muscle. The upper belly of the omohyoid muscle in the anterior neck further divides the anterior neck into an **upper carotid triangle** and a **lower muscular triangle**.

LATERAL NECK

The lateral neck, also referred to as the **posterior triangle**, is defined by the posterior aspects of the sternocleidomastoid muscle medially, the trapezius muscle laterally, and the middle third of the clavicle inferiorly. The lateral neck contains lymph node-bearing tissue, the spinal accessory nerve, and the cervical plexus. The inferior belly of the omohyoid muscle further defines a **lower subclavian triangle** in the lateral neck that contains the brachial plexus and subclavian vessels.

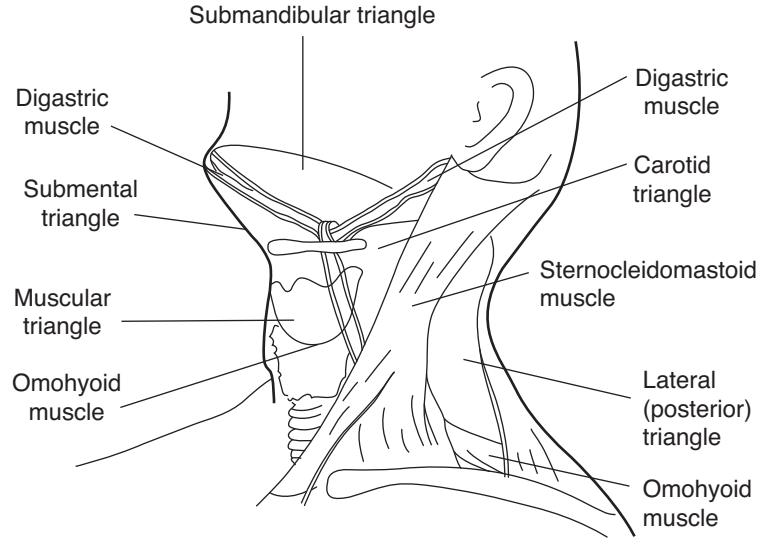
DIAGNOSIS

The differential diagnosis in a patient presenting with a neck mass is broad and extensive. Therefore, a thorough history and physical examination make up the critical first step in the evaluation of a neck mass. Information gathered from a detailed history and physical examination alone often narrows the differential diagnosis to a more manageable level (Figure 27–2).

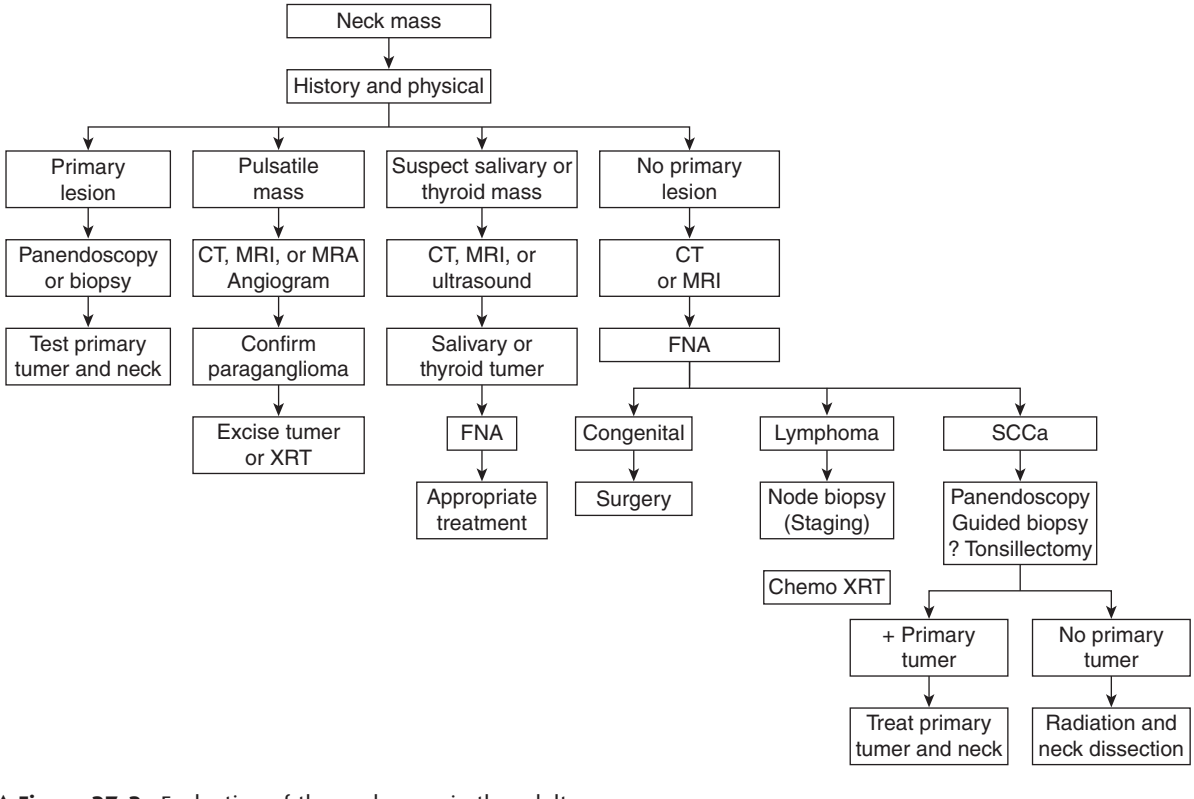
PATIENT HISTORY

The most important element in the evaluation of a neck mass is the age of the patient. Most pediatric neck masses are inflammatory or congenital and resolve spontaneously or after appropriate medical therapy. In contrast, a neck mass in an adult over the age of 40 should be considered neoplastic in origin unless proven otherwise. The probability of a benign neck mass in this age group is low, particularly in the setting of tobacco or alcohol use.

The duration, growth pattern, and absence or presence of pain are all critical aspects of the history. A region-specific review of systems, such as a change in voice, hoarseness,



▲ **Figure 27–1.** Anatomic compartments of the neck.



▲ **Figure 27–2.** Evaluation of the neck mass in the adult.

difficulty with swallowing, and ear pain are important symptoms to note in addition to generalized complaints such as fever, night sweats, and weight loss. Questions related to a patient's social history, such as alcohol and drug use, smoking, and recent travel, should also be included.

PHYSICAL EXAMINATION

The physical examination should include a systematic investigation of all mucosal and submucosal areas of the head and neck. The mobility, consistency, and tenderness of the mass should be assessed carefully. The location of the neck mass is particularly important in congenital and developmental masses because these masses typically appear in consistent locations. For example, a lateral neck mass in a child is suggestive of a branchial cleft cyst or laryngocele, whereas a midline neck mass is more suggestive of a thyroglossal duct cyst. The location also may be helpful in assessing adult patients. A neck mass located in the supraclavicular region of an older adult should focus the physician's attention to metastasis from a primary lesion located in a site other than the upper aerodigestive tract (eg, a gastrointestinal or pulmonary source). An isolated posterior triangle lymph node in an Asian adult should raise suspicion for a nasopharyngeal carcinoma.

TESTS & STUDIES

Imaging Studies

Imaging studies provide useful information in diagnosing the etiology of a neck mass. Computed tomography (CT) and magnetic resonance imaging (MRI) can (1) differentiate solid, cystic, and vascular masses; (2) localize a mass in relation to the vital structures of the neck; and (3) identify a potential head and neck source for the neck mass. Ultrasonography may be helpful in distinguishing solid from cystic masses, especially in the setting of a suspected thyroid lesion. Chest X-rays may be helpful if there is a high index of suspicion for granulomatous diseases such as sarcoidosis or tuberculosis. A chest film is also able to detect a metastasis from a head and neck cancer or a primary malignant neoplasm within the lungs. Positron emission tomography (PET), which detects increased metabolic activity, is now often used in the detection and surveillance of head and neck cancer.

Serologic Testing

Serologic testing can be used in looking for systemic diseases. For example, antinuclear antibody may be positive in Sjogren syndrome, which can present with parotid enlargement and lymphadenopathy. Serologic testing is also important in the diagnosis of many infectious diseases that may present as a neck mass, including tuberculosis, atypical mycobacteria, mononucleosis, toxoplasmosis, and cat-scratch disease. Patients with lymphoma may also have abnormalities on serologic testing.

Fine-Needle Aspiration Biopsy

Fine-needle aspiration (FNA) biopsy has become a critical step in the evaluation of neck masses. The timing of the FNA biopsy in relation to imaging studies is debatable. Advocates of obtaining imaging studies prior to the FNA biopsy believe that the FNA distorts the architecture of the mass, thus making imaging more difficult to interpret. The procedure for a FNA entails the use of a 23- or 25-gauge needle in obtaining multiple aspirations of the neck mass. FNA biopsies can differentiate a cystic mass from an inflammatory mass and malignant tissue from benign tissue. It is important to know that FNA can differentiate lymphoma from carcinoma, a distinction that is critical in directing further workup and treatment. With the recent advances in molecular biology, polymerase chain reaction (PCR) can be conducted on FNA samples to identify disease processes such as Epstein–Barr virus (EBV), which will guide the physician to the diagnosis of primary nasopharyngeal carcinoma. When there is a suspicion on squamous cell carcinoma, FNA aspirates of a neck mass can also be analyzed for human papilloma virus (HPV), which has been implicated in oropharyngeal squamous cell carcinoma. Patients who are positive for HPV tend to be younger, nonsmokers, and nondrinkers. The primary tumor can usually be found in the tonsil or base of tongue region. These patients also have a much better prognosis than those who are HPV negative.

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Amedee RG, Dhurandhar NR. Fine-needle aspiration biopsy. *Laryngoscope* 2001;111(9):1551 [PMID: 11568593]. (Fine-needle aspiration biopsy has a high overall diagnostic accuracy of 95% for all head and neck masses, 95% for benign lesions, and 87% for malignant ones.)

Brown RL, Azizkhan RG. Pediatric head and neck lesions. *Pediatr Clin North Am* 1998;45(4):889 [PMID: 9728193]. (Outlines the workup and differential diagnosis of pediatric neck masses.)

Chang DB, Yang PC, Luh KT et al. Ultrasonic evaluation of cervical lymphadenopathy. *J Formos Med Assoc* 1990;89(4):548 [PMID: 1976745]. (Study of 75 patients with cervical lymphadenopathy who underwent real-time ultrasonographic study of the neck. The study concluded that ultrasonography is a valuable tool to evaluate cervical adenopathy and to clarify the histopathologic features of the affected lymph node with the aid of aspiration cytology.)

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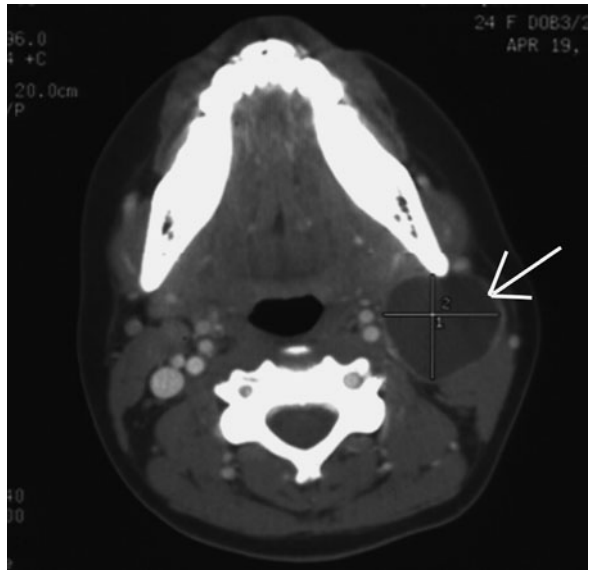
Weymuller EA Jr. Evaluation of neck masses. *J Fam Pract* 1980;11(7):1099 [PMID: 7452169]. (Provides an algorithm for the diagnosis of neck masses.)



▲ **Figure 27–3.** Axial CT scan of branchial cleft cyst (arrow).

CONGENITAL NECK MASSES

BRANCHIAL CLEFT CYSTS

Branchial cleft cysts arise from the failure of the pharyngobranchial ducts to obliterate during fetal development. They most frequently present in late childhood or early adulthood, when the cysts become infected—usually after an upper respiratory tract infection. A branchial cleft cyst appears as a tender, inflammatory mass located at the anterior border of the sternocleidomastoid muscle (Figure 27–3).

Classification

Branchial cleft cysts fall into three categories: first, second, and third branchial cleft anomalies.

A. First Branchial Cleft Anomalies

First branchial cleft anomalies make up less than 1% of all branchiogenic anomalies and usually appear on the face or near the auricle. There are two types of first branchial anomalies, Type I and Type II.

1. Type I—Type I first branchial cleft cysts are duplication anomalies of the external canal and are composed of ectodermally derived tissue. They may pass into the parotid gland and close to the facial nerve.

2. Type II—Type II anomalies may comprise ectodermally and mesodermally derived tissues. These lesions typically present below the angle of the mandible, pass through the parotid gland in close proximity to the facial nerve, and end either inferior to the external auditory canal or into the canal at the bony cartilaginous junction.

B. Second Branchial Cleft Anomalies

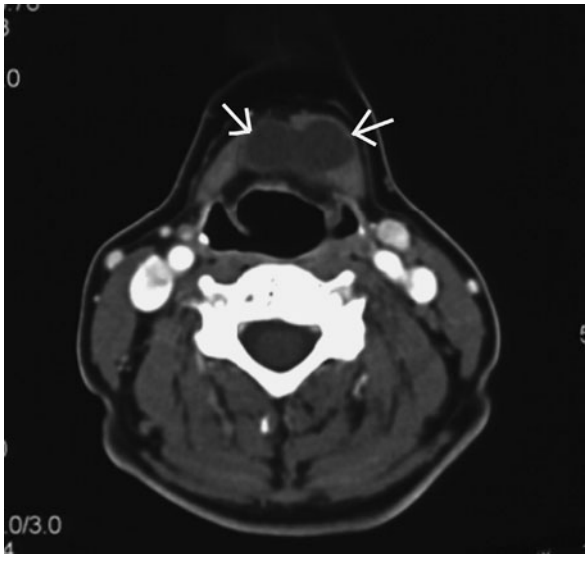
Second branchial cleft anomalies are the most common of the three types. They present as discrete, rounded masses below the angle of the mandible and at the anterior border of the sternocleidomastoid muscle. The potential tract of an associated sinus passes deep to the second arch structures (eg, the external carotid artery and the stylohyoid and digastric muscles) and superficial to the third arch derivatives (eg, the internal carotid artery), opening into the tonsillar fossa.

C. Third Branchial Cleft Anomalies

Third branchial cleft cysts present anterior to the sternocleidomastoid muscle and lower in the neck than either first or second branchial cleft anomalies. Third branchial cleft cysts are deep to the third arch derivatives (eg, the glossopharyngeal nerve and the internal carotid artery) and superficial to fourth arch derivatives (eg, the vagus nerve). These anomalies end in the pharynx at the thyrohyoid membrane or pyriform sinus.

Treatment

The management of branchial cleft anomalies is initial control of the infection followed by surgical excision of the cyst and tract. As a general rule, incision and drainage procedures should be avoided; however, they may be necessary for acute



▲ **Figure 27–4.** Axial CT scan of thyroglossal duct cyst (area between the arrows).

abscess treatment before definitive excision. Needle aspiration and decompression can be beneficial in preventing incision and drainage, which increases the difficulty of definitive excision.

THYROGLOSSAL DUCT CYSTS

Thyroglossal duct cysts present as midline masses of the anterior neck (Figure 27–4). Like branchial cleft cysts, they may be asymptomatic and appear only when they become infected in the setting of an upper respiratory tract infection. Thyroglossal duct cysts make up approximately one-third of all congenital neck masses. Their location may be variable at times, with some cysts presenting more laterally (ie, superior to the hyoid) or as low as the level of the thyroid gland. Thyroglossal duct cysts that occur off the midline may be difficult to differentiate from branchial cleft cysts. A pathognomonic sign on physical examination is vertical motion of the mass with swallowing and tongue protrusion, demonstrating the intimate relation to the hyoid bone.

The **Sistrunk operation** is the standard method of thyroglossal duct cyst excision. The cyst is excised with a cuff of tissue, including the center portion of the hyoid bone. During the resection of the hyoid bone, care is taken not to injure the hypoglossal nerves; making the hyoid bone cuts just medial to the lesser cornu assists in safeguarding these nerves. Since thyroid carcinomas can be present in a small percentage of thyroglossal duct cysts, all thyroglossal cysts and tracts should undergo a careful histologic examination.

LARYNGOCELES

A laryngocele is defined as an abnormal dilation or herniation of the saccule of the larynx. Secondary infection of a laryngocele is termed a **laryngopyocele.** Laryngoceles can be classified into three types: internal, external, and combined. A laryngocele is defined as internal if the dilation lies within the limits of the thyroid cartilage. If the laryngocele extends beyond the thyroid cartilage and protrudes through the thyrohyoid membrane producing a lateral neck mass, it is considered external.

Patients with laryngoceles present with hoarseness, cough, dyspnea, dysphagia, a foreign body sensation, or any combination of these symptoms. Laryngoscopy may reveal a smooth dilation at the level of the false cord, involving both the false cord and the aryepiglottic fold. A CT scan is helpful in confirming the diagnosis and delineating the extent of the lesion. If symptomatic, the management of laryngoceles consists of (1) laryngoscopic decompression for small lesions, (2) surgical excision through an external approach for larger lesions, or laser endoscopy. If an external approach is done, care must be taken to avoid injury to the superior laryngeal nerve.

PLUNGING RANULAS

Plunging ranulas are mucoceles or retention cysts of the floor of mouth that usually present as slow-growing, painless, submental masses. They arise from the sublingual gland and are defined as plunging when they extend through the mylohyoid muscle into the neck. Treatment for plunging ranulas includes excision of the mass in continuity with the sublingual gland.

LYMPHANGIOMAS

Lymphangiomas are congenital malformations of the lymphatic channels. They arise owing to failure of the lymph spaces to connect to the remaining lymphatic system. The mass is usually soft, doughy, smooth, nontender, and compressible. These masses can characteristically be transilluminated. CT scanning and MRI are important studies both to delineate the extent of the disease and to define any potential associated abnormalities (eg, hemangiomas).

Surgical excision is the mainstay of therapy. Because of the infiltrative nature of these lesions, complete surgical resection may be impossible without damaging vital structures. In such cases, debulking the mass is appropriate and accomplishes the goals of improving cosmetic appearance and symptomatic relief while preserving critical normal anatomic structures.

HEMANGIOMAS

Hemangiomas are malformations of vascular tissue. They can be classified as capillary, cavernous, or juvenile. These lesions usually present in the first few months of life, grow

rapidly during the first year, and then begin to slowly involute at 18–24 months of age. In 90% of cases, involution occurs without the need for any therapy.

Hemangiomas present as a red or bluish soft mass that is compressible and increases in size with straining or crying. Bruits may sometimes be auscultated over the lesion. CT scans, MRI, or both are valuable tools in making the diagnosis of this vascular lesion while defining the full extent of the lesion.

Because most hemangiomas involute spontaneously, these lesions can be managed conservatively with observation alone. Consideration should be given to the presence of these lesions in other not readily recognized regions, such as the subglottis, gastrointestinal tract, and spine. Intervention is indicated if the lesion is causing any of the following symptoms: airway compromise, skin ulceration, dysphagia, thrombocytopenia, or cardiac failure. Systemic corticosteroids or surgical laser excision may be warranted in such cases.

TERATOMAS

Teratomas of the head and neck make up approximately 3.5% of all teratomas. Their origin is from pluripotential cells, and by definition, they contain elements from all three germ layers. Teratomas usually present as firm neck masses and are most commonly noted at birth or within the first year of life. There is a 20% associated incidence of maternal polyhydramnios. When large enough, teratomas can cause either respiratory compromise due to tracheal compression or dysphagia secondary to compression of the esophagus and disruption of deglutition. In addition to appearing heterogeneous, calcifications may be seen on CT and MRI scans of teratomas. The most successful treatment method is surgical excision.

DERMOID CYSTS

Dermoid cysts arise from epithelium that has been entrapped in deeper tissue either during embryogenesis or by traumatic implantation. They contain a variety of tissues from all three germ layers and most often form along lines of embryologic fusion. They typically present as midline, nontender, mobile neck masses in the submental region. Surgical excision is the mainstay of treatment.

THYMIC CYSTS

The third branchial pouch gives rise to the thymus during the 6th week of fetal life, elongates in the pharynx, and then descends into the mediastinum. Thymic cysts arise when there is implantation of this thymic tissue along this descent. These cysts present as slow-growing, asymptomatic masses that may be painful if infected. On rare occasions, they grow rapidly and cause dyspnea or dysphagia. CT scanning and MRI are useful in the differential diagnosis. A definitive diagnosis is made histologically by the presence of Hassall corpuscles. Thymic cysts are treated by surgical excision.

STERNOCLEIDOMASTOID TUMORS OF INFANCY

Sternocleidomastoid tumors of infancy present as neck masses that are characterized histologically by dense fibrous tissue and the absence of normal striated muscle. This disorder is intimately related to congenital torticollis. Sternocleidomastoid tumors of infancy typically present as firm, painless, discrete masses within the sternocleidomastoid muscle; they slowly increase in size for 2–3 months and then regress for 4–8 months. Eighty percent of cases resolve spontaneously and do not need any intervention other than physical therapy to prevent restrictive torticollis. Surgical resection is reserved for persistent cases.

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INFLAMMATORY NECK MASSES

INFECTIOUS INFLAMMATORY DISORDERS

REACTIVE VIRAL LYMPHADENOPATHY

Reactive viral lymphadenopathy is the most common cause of cervical adenopathy in children. These neck masses are usually associated with symptoms of an underlying upper respiratory tract infection. The most common viral agents include adenovirus, rhinovirus, and enterovirus. These reactive lymph nodes tend to regress in 1–2 weeks.

The management of reactive viral lymphadenopathy is usually observation; however, a neck mass larger than 1 cm should be considered abnormal and warrant further investigation if it remains for more than 4–6 weeks or increases in size. If the suspected adenopathy persists, biopsies can be taken to search for other causes, such as fungal, granulomatous, or neoplastic processes.

EBV or mononucleosis can also present with lymphadenopathy, although it is usually accompanied by the enlargement of other lymphoid tissues such as the adenoids or tonsils. Patients with the EBV also have accompanying symptoms of fever and pharyngitis. Adenopathy associated with mononucleosis may last as long as 4–6 weeks. The treatment is limited to supportive management.

HIV-ASSOCIATED INFLAMMATORY DISORDERS

1. Cervical Adenopathy

Cervical adenopathy is present in 12–45% of patients with human immunodeficiency virus (HIV). Idiopathic follicular hyperplasia is the most common cause of adenopathy in these patients, although other infectious or neoplastic etiologies must be ruled out, including *Mycobacterium tuberculosis, Pneumocystis carinii,* lymphoma, and Kaposi sarcoma. The treatment of cervical adenopathy in the setting of HIV disease requires treatment of the underlying HIV infection, which is beyond the scope of this chapter.

2. Persistent Generalized Lymphadenopathy

Persistent generalized lymphadenopathy is lymphadenopathy without an identifiable infectious or neoplastic cause; it is commonly seen in patients with HIV infection. The neck is the most common site of persistent generalized lymphadenopathy. Once the diagnosis is made, the treatment of persistent generalized lymphadenopathy secondary to HIV infection requires treatment of the underlying HIV disease.

BACTERIAL LYMPHADENOPATHY

1. Suppurative Lymphadenopathy

Suppurative lymphadenopathy is most frequently caused by *Staphylococcus aureus* and group A *B-Streptococcus*. These neck masses usually develop in the submandibular or jugulodigastric region and are often accompanied by sore throat, skin lesions, and symptoms of upper respiratory tract infection. Empirical antibiotic therapy against anaerobic and gram-positive organisms is recommended as the first line of management. If this fails, either FNA or incision and drainage may be indicated.

2. Toxoplasmosis

Toxoplasmosis is caused by *Toxoplasma gondii* and is contracted through the consumption of poorly cooked meat or the ingestion of oocytes excreted in cat feces. Patients present with fever, malaise, sore throat, and myalgias. The diagnosis is made by serologic testing. Medical management is with sulfonamides or pyrimethamine.

3. Tularemia

Tularemia is caused by the organism *Francisella tularensis* and is transmitted by rabbits, ticks, or contaminated water. Patients present with tonsillitis and painful adenopathy with systemic symptoms of fever, chills, headache, and fatigue. Serologic testing and culture confirm the diagnosis. Streptomycin is the antibiotic of choice.

4. Brucellosis

Brucellosis is caused by a species of gram-negative bacilli, *Brucella.* It is transmitted most commonly to children by the ingestion of unpasteurized milk. Patients present with total body lymphadenopathy, fever, fatigue, and malaise. Serology and culture are mainstays of diagnosis, and treatment is with trimethoprim–sulfamethoxazole or tetracycline.

GRANULOMATOUS DISEASES

The differential diagnoses for granulomatous adenopathy of the neck include cat-scratch disease, actinomycosis, atypical mycobacteria, tuberculosis, atypical tuberculosis, and sarcoidosis.

1. Cat-Scratch Disease

Cat-scratch disease is caused by the bacterium *Rochalimaea henselae.* A history of contact with cats can be elicited in 90% of cases. This disease is more commonly seen in patients younger than 20 years. They present with tender lymphadenopathy, fever, and malaise. The lymphadenopathy is typically preauricular and submandibular in location. The diagnosis is made by serologic testing with indirect fluorescent antibodies. Histologically, the cat-scratch bacillus can often be demonstrated by Warthin–Starry staining. Cat-scratch disease is generally benign and self-limited.

2. Actinomycosis

Actinomycosis is a gram-positive bacillus. Studies have reported that from 50% to 96% of cases of actinomycosis affect the head and neck regions. Patients present with a painless, fluctuant, neck mass in the submandibular or upper digastric regions. The diagnosis is made by clinical suspicion and biopsy; it is confirmed histologically by the presence of granulomas with sulfur granules. Penicillin is the treatment of choice.

3. Atypical Mycobacteria

Atypical mycobacteria typically presents in the pediatric population as a unilateral neck mass located in the anterior triangle of the neck or parotid region. These patients have brawny skin, induration, and pain. The diagnosis is made by culture and skin testing. Surgical excision offers definitive treatment, although incision and curettage along with antibiotic therapy constitute an alternative management strategy.

4. Tuberculosis

Tuberculosis is seen more commonly in adults than in children. The causative organism is *M. tuberculosis.* The presenting lymphadenopathy tends to be more diffuse and bilateral in contrast to atypical mycobacteria. Tuberculin skin tests are strongly positive. Cervical tuberculosis is also known as **scrofula** and is responsive to antituberculous medications.

5. Sarcoidosis

Sarcoidosis presents most commonly in the second decade of life with lymph node enlargement, fatigue, and weight loss. Chest radiography shows hilar adenopathy. An elevated angiotensin-converting enzyme (ACE) level is seen in 60–90% of patients with sarcoidosis. The diagnosis is confirmed histologically by the presence of noncaseating granulomas on biopsy specimens. Corticosteroids may be used, depending on the severity of the disease.

FUNGAL INFECTIONS

Immunocompromised patients are particularly susceptible to fungal infections. The most common organisms include *Candida, Histoplasma,* and *Aspergillus.* Serology and fungal cultures are imperative for the diagnosis. Aggressive, systemic antifungal therapy with agents such as amphotericin B is the treatment of choice.

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NONINFECTIOUS INFLAMMATORY DISORDERS

ROSAI–DORFMAN DISEASE (SINUS HISTIOCYTOSIS)

Rosai–Dorfman disease typically presents in children with massive nontender cervical lymphadenopathy, fever, and skin nodules. It is characterized by benign, self-limited lymphadenopathy. Biopsy shows classically dilated sinuses, plasma cells, and the proliferation of histiocytes.

KAWASAKI DISEASE

Kawasaki disease is an acute multisystem vasculitis in children. Patients present with a number of symptoms: acute, nonpurulent cervical lymphadenopathy; erythema, edema, and desquamation of the hands and feet; polymorphous exanthem; conjunctival injection; and erythema of the lips and oral cavity. The diagnosis is made by clinical judgment. Early identification and treatment with aspirin and γ-globulin are imperative in avoiding serious cardiac complications.

CASTLEMAN DISEASE

Castleman disease is a rare, benign lymphoepithelial disease with the potential for development of Kaposi sarcoma and lymphoma. This disease affects both sexes equally and can

occur at any age with its peak incidence in the second to fourth decades. This disease occurs most commonly in thoracic lymph nodes (70%), followed by the pelvis, abdomen, retroperitoneum, skeletal muscle, and head and neck. The diagnosis is made by tissue biopsy with histologic subclassification to the **hyaline-vascular variant** and the **plasma cell variant.** Ninety percent of cases are of the hyaline-vascular variant, which typically presents as an asymptomatic mass. In contrast, of patients who present with the plasma cell variant, 50% have associated symptoms of fever, fatigue, arthralgia, anemia, hypogamma-globulinemia, and thrombocytosis. Furthermore, unlike the hyaline-vascular variant, the plasma cell variant often presents with multicentric disease.

The treatment of this disorder is unrelated to histologic subtype. Isolated Castleman disease is managed by surgical resection with excellent prognosis. Constitutional symptoms resolve after the surgical resection of isolated disease. Multicentric disease is treated with chemotherapy and has a more guarded prognosis.

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NEOPLASTIC DISORDERS

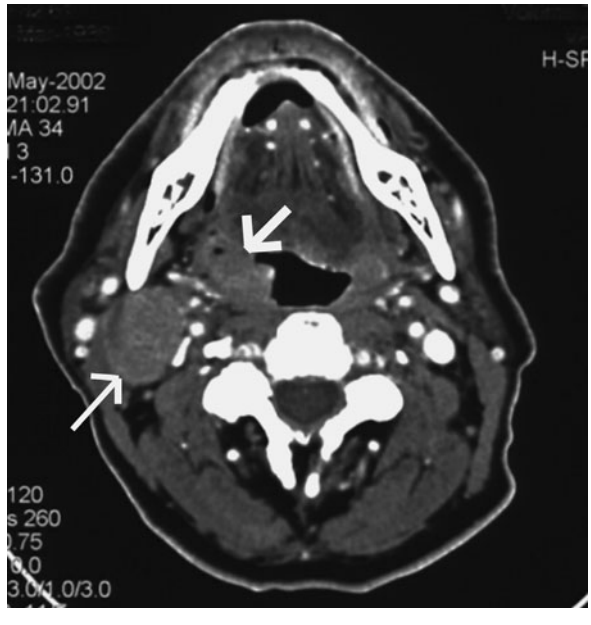
METASTATIC SQUAMOUS CELL CARCINOMAS

A newly discovered neck mass in an adult patient must be presumed malignant until proven otherwise. These metastatic malignant masses tend to present as asymptomatic lesions that progress slowly and are firm to palpation. The associated symptoms are often related to the primary site of the malignant mass and include odynophagia, dysphagia, dysphonia, otalgia, and weight loss. The most common metastatic lesion to the neck is squamous cell carcinoma.

The diagnosis of metastatic squamous cell carcinoma to the neck can be diagnosed accurately by FNA biopsy. FNA is preferred to excisional biopsy of a metastatic cervical lymph node. Some studies report that distant metastases and late regional recurrences are more frequently encountered in patients who have had pretreatment of excisional biopsies than in those patients with the same stage of disease who have not. The pretreatment excisional biopsy group also had a higher incidence of local wound complications.

When the diagnosis of metastatic squamous cell carcinoma is made in a neck mass, the physician should conduct a thorough examination of the following sites: all mucosal surfaces of the head and neck, the thyroid gland, the salivary glands, and the skin of the head and neck. Studies have reported that 50–67% of patients with metastatic squamous cell carcinoma will have their primary tumor site identified in the office examination.

Imaging studies, such as CT scans and MRI, may be helpful in the search for the primary tumor (Figure 27–5). If the initial examination and imaging fail, a direct endoscopic examination under general anesthesia should be done. If endoscopy provides no evidence of a primary lesion, then the sites most likely to contain an occult tumor should be biopsied. Knowing the location of the node assists in guiding the surgeon to suspicious areas. Enlarged nodes high in the neck or in the posterior triangle suggest a nasopharyngeal lesion, whereas enlarged jugulodigastric nodes point to a lesion in the tonsils, the base of tongue, or the supraglottic larynx. When the enlarged nodes are in the supraclavicular area, the digestive tract, the tracheobronchial tree, the breast, the genitourinary tract, and the thyroid gland should be considered as lesion sites. The most common sites of an occult primary lesion are the nasopharynx, the tonsils, and the base of the tongue. Some clinicians advocate biopsies



▲ **Figure 27–5.** Axial CT scan of neck metastasis (thin arrow) from tonsillar squamous cell cancer (large arrow).

of these regions in patients with negative direct endoscopic examinations.

Cystic neck masses in the adult require special attention. Although the benign congenital lesions listed above can present in the adult, consideration must be given to the cystic variants of metastatic disease. Squamous cell carcinoma, metastatic from tonsillar primary lesions, often presents as a cystic mass in the jugulodigastric region. FNA can be diagnostic. Cystic masses in the lower neck, central neck, and mid-jugular lymph node chains should raise the consideration of metastatic papillary thyroid cancer. FNA is often nondiagnostic, but the fluid removed has a dark-brown color indicative of metastatic papillary thyroid cancer. Thyroid ultrasound should be included in the evaluation.

THYROID MASSES

A primary thyroid tumor manifests in the anterior compartment of the neck. A thyroid mass in a patient with hoarseness and a history of neck irradiation should be considered malignant. Ultrasound, thyroid scans, and thyroid function tests should be considered when allowing for the possibility of a thyroid lesion. FNA provides the most diagnostic information in the evaluation of a thyroid mass. The treatment is based on histologic findings.

LYMPHOMAS

Lymphomas can occur in all age groups but are much more common in children and young adults. Among children with Hodgkin disease, up to 80% will have at least one neck mass. A suspicion of lymphoma should arise when a young patient presents with fever, chills, and diffuse lymphadenopathy. The results of an FNA may be suggestive for lymphoma, but this biopsy may not provide sufficient tissue for classification. Therefore, in a patient with an FNA highly suggestive of lymphoma, an open biopsy may be necessary to obtain sufficient tissue for histopathologic classification. Once the diagnosis is made, staging workup should be conducted that includes CT scanning of the head, neck, chest, and abdomen.

SALIVARY NEOPLASMS

Parotid gland neoplasms may present either in front of or below the ear, or they may present at the angle of the mandible. Submandibular gland tumors are found in the submandibular triangle. Most parotid lesions are found to be benign. Submandibular gland tumors, in contrast, although consisting of a similar spectrum of pathology as parotid neoplasms, have an increased incidence of malignant pathology compared with parotid lesions. Benign salivary lesions typically present as asymptomatic masses. Symptoms such as pain, cranial nerve involvement, rapid growth, or overlying skin involvement are highly suggestive of malignant growths. Diagnostic tests include CT scanning, MRI, nuclear scans, and sialography. FNA is the diagnostic test of choice.

PARAGANGLIOMAS

Paragangliomas are neoplasms that arise from extra-adrenal paraganglia. Carotid body tumors and glomus tumors are paragangliomas that present as neck masses in the upper jugulodigastric region in close proximity to the carotid bifurcation. They are pulsatile, and bruits can usually be heard on auscultation. They are mobile from side to side but not up and down. Histologically, they consist of clusters of epithelioid cells (Zellballen) separated by highly vascular, fibrous stroma.

Ten percent of patients with paragangliomas have a positive family history. Ten to twenty percent of patients present with multiple paragangliomas; 5–10% of all paragangliomas are malignant. The gold standard of diagnosis has been angiography in the past, but it has been supplanted by magnetic resonance angiography (MRA). Carotid body tumors demonstrate a splaying of the internal and external carotid arteries or "lyre" signs on both angiography and MRA. The treatment is surgical excision. Radiation therapy can arrest growth and is reserved for elderly patients, patients with extensive tumors who have a high risk of cranial nerve damage during resection, or patients with multiple paragangliomas. Preoperative embolization may aid in the surgical resection.

LIPOMAS

Lipomas occur most frequently in patients over 35 years of age. They are ill-defined soft masses that can occur in various neck locations. Lipomas are asymptomatic and can be diagnosed on CT scans as having fat-air density or by their bright appearance on T1-weighted MRI. The treatment is surgical excision if symptomatic. Liposarcoma can have a similar imaging appearance but demonstrates a more progressive and locally infiltrative course. Biopsy can be considered in such cases.

SOLITARY FIBROUS TUMOR

Solitary fibrous tumors are rare spindle cell neoplasms of mesenchymal origin. Most solitary fibrous tumors are located in the thorax. An estimated 5–20% of thoracic solitary fibrous tumors have been reported as malignant, but malignant extrathoracic tumors are rare. In the head and neck, the oral cavity is the most common site, but there have been case reports involving all head and neck sites. They often present as asymptomatic slow-growing masses. Treatment is by local resection. Factors that predispose to local recurrence in non–head and neck solitary fibrous tumors are diameter larger than 10 cm, the presence of a malignancy, and microscopically positive surgical margins.

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28 Neck Neoplasms & Neck Dissection

Aditi H. Mandpe, MD

NECK NEOPLASMS

ESSENTIALS OF DIAGNOSIS

- Primary neoplasms of the soft tissue in the head and neck are rare.
- The most common benign tumors are paragangliomas and nerve cell tumors.
- The most common malignant neoplasm is metastatic squamous cell carcinoma from the upper aerodigestive tract.
- The evaluation of a metastatic squamous cell carcinoma without an easily identifiable primary site is extensive and treatment is controversial.
- Neck dissections are performed to treat metastatic neoplasms and to determine the presence of occult metastasis.

General Considerations

Neck neoplasms include not only metastatic squamous cell carcinoma but also a number of other primary neck tumors. Metastatic squamous cell carcinoma arises from the upper aerodigestive tract and is present in the lymph nodes and in the neck; other primary tumors arise from the soft tissue in the neck, such as fat, fibrous tissue, muscle, blood vessels, lymphatic vessels, nerves, and paraganglia (Table 28–1). These primary tumors are fairly uncommon, often making a pathologic diagnosis difficult. The evaluation of all neck masses consists of obtaining a complete history and conducting a physical exam.

Clinical Findings

A. Symptoms and Signs

The presenting symptom of a neck neoplasm is a painless enlarging neck mass that may grow extremely slowly or very rapidly. On physical examination, there is often a well-circumscribed mass in the neck. The location of the mass sometimes suggests its cause.

B. Imaging Studies

Imaging with computed tomography (CT) or magnetic resonance imaging (MRI) is critical for these lesions, especially if these studies are performed before a biopsy is obtained. A preoperative study can better assess both the size and the extent of the lesion without confounding factors such as bleeding and edema. An MRI is often the study of choice because it allows a greater differentiation of soft tissue. A positron emission tomography (PET) scan in evaluating patients with metastatic disease can identify additional tumor masses. Additional studies such as angiography and, recently, magnetic resonance angiography (MRA) add valuable information to the diagnosis of vascular lesions (eg, carotid body tumors and vascular malformations).

C. Special Tests

1. Fine-needle aspiration (FNA) biopsy—A tissue specimen is vital for the diagnosis of neck neoplasms and can be obtained via a fine-needle aspiration biopsy (FNAB). Metastatic squamous cell carcinoma has an excellent specificity and sensitivity for FNAB. Additional studies such as flow studies, immunohistochemistry techniques, or electron microscopy may be required for an accurate diagnosis of these specimens.

2. Open biopsy—Open biopsies consist of incisional and excisional biopsies. A small superficial lesion or any lesion smaller than 3 cm should undergo an **excisional biopsy** with

Table 28–1. Differential Diagnosis of Benign and Malignant Neck Neoplasms.

Benign	Malignant
Vascular—hemangioma, lymphangioma	Lymphoma
Paraganglioma—glomus vagale, carotid body tumor	Synovial sarcomas
Neural—Schwannoma, neurofibroma	Malignant peripheral nerve sheath tumor
Fibromatosis	Fibrosarcoma
Lipoma	Liposarcoma
Rhabdomyoma	Rhabdomyosarcoma

sufficient normal surrounding tissue for adequate, clear margins. An **incisional biopsy** should only be entertained if the mass is larger than 3 cm. If metastatic squamous cell carcinoma is suspected, an open biopsy should not be considered unless all other avenues have been exhausted and at least two inconclusive FNAB.

3. Other tests—After either an FNAB or open biopsy is performed, the specimen then undergoes evaluation with light microscopy. Immunohistochemistry techniques can stain for cytokeratin, leukocyte common antigen, S-100, and myoglobin to differentiate sarcomas, melanomas, and epithelial carcinomas. Electron microscopy is used to aid in the diagnosis in patients where light microscopy and immunohistochemistry techniques prove ineffective.

BENIGN NEOPLASMS

The most common benign masses in the neck are inflammatory lymph nodes and masses of salivary and thyroid gland origins. True soft-tissue benign tumors in the neck are relatively uncommon.

PARAGANGLIOMAS

Paragangliomas arise from paraganglia, islands of cells derived from neural crest cells, associated with arteries and cranial nerves located at the carotid body, vagal body, along laryngeal nerves, and in the jugulotympanic region. The tumors derived from these regions are carotid body tumors, intravagal paragangliomas, and glomus tympanicum and glomus jugulare. While paraganglia cells are capable of producing catecholamines, the incidence of catecholamine-producing head and neck paragangliomas is exceedingly rare.

1. Carotid Body Tumors

Carotid body tumors are the most common head and neck paragangliomas. The carotid body is found at the bifurcation of the common carotid artery and responds to changes in arterial pH, oxygen, and carbon dioxide.

Clinical Findings

A. Symptoms and Signs

Symptoms are present only with large tumors and include pressure, dysphagia, cough, and hoarseness. On examination, the mass is palpated at the anterior border of the sternocleidomastoid muscle. It is typically mobile laterally but not vertically.

B. Laboratory Findings

The diagnosis requires a high index of suspicion as the location is similar to that of many other masses (eg, branchial cleft cysts and enlarged lymph nodes). Fine-needle aspiration of these lesions often yields only blood; however, if cells are obtained, FNA can offer a definitive diagnosis.

C. Imaging Studies

The angiogram in Figure 28–1 shows the typical findings of a splayed bifurcation of the carotid artery with a vascular blush. An MRI often proves useful in identifying other paragangliomas as synchronous and metachronous lesions occur in 25–48% of cases. Familial paragangliomas occur in 7–9% of cases.

Treatment

A. Surgical Measures

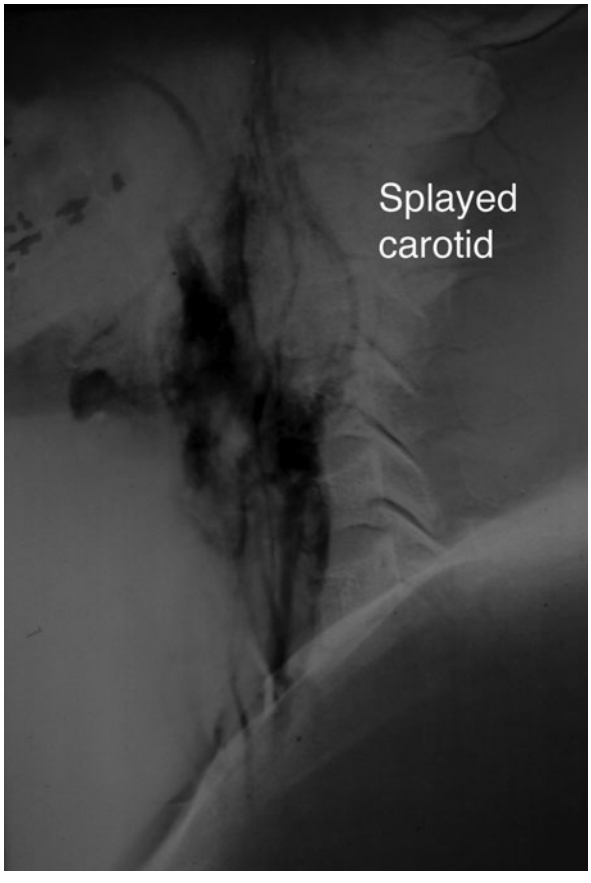
The treatment of these lesions is predominantly surgical. Preoperative embolization is useful to minimize blood loss in order to allow for a cleaner dissection. Surgical excision requires the following measures: (1) identification of the proximal and distal carotid artery and (2) identification and preservation of the vagus, hypoglossal, and spinal accessory nerves. Patients with large or recurrent tumors often require vascular reconstruction, which should be planned preoperatively.

B. Radiation Therapy

Radiation therapy is not the primary mode of therapy but has been used as the sole method of treatment in some cases such as elderly patients who are poor surgical candidates. In patients with carotid body and vagale tumors, radiation therapy alone has been shown to provide a local control rate of as much as 96%. Control rates with surgery alone range from 88% to 100%. Treatment decisions are based on surgical risks and complications; therefore, small tumors should usually be treated surgically, with radiation therapy reserved for large tumors.

2. Intravagal Paragangliomas

Intravagal paragangliomas typically occur in association with one of the vagal ganglia, most commonly the ganglion nodo-



▲ **Figure 28–1.** Angiogram of a patient with a carotid body tumor showing the classic splaying of the carotid bifurcation.

sum. Intravagal paragangliomas account for approximately 3% of all head and neck paragangliomas. Symptoms can include hoarseness, dysphagia, aspiration, tongue weakness, and Horner syndrome. Angiographic imaging shows a mass located above the carotid bifurcation, with lateral and medial displacement of the external and internal carotid arteries. FNA has been useful in the diagnosis of these tumors.

The treatment involves surgical resection, with radiation therapy reserved for patients with high surgical risk, incomplete resection, recurrent disease, and bilateral tumors. Most intravagal paragangliomas can be resected via a cervical approach. If there is intracranial extension, a middle or posterior fossa approach may be needed.

Karaman E. Isildak H, Yilmaz M et al. Management of paragangliomas in otolaryngology practice: review of a 7-year experience. *J Craniofac Surg* 2009;20:1294 [PMID: 19625854]. (The primary treatment remains surgical excision with preoperative embolization in selective cases.)

PERIPHERAL NERVE CELL TUMORS

Tumors arising from peripheral nerves typically arise from the Schwann cells in the nerve sheath. Of the many names used to describe these tumors, two in particular—schwannomas and neurofibromas—have significant clinical differences that warrant discussion. As a group, neurogenous tumors occur most commonly in the head and neck regions. They are often asymptomatic and present as lateral neck masses.

1. Schwannomas

Peripheral nerve schwannomas, more appropriately termed neurilemomas, are solitary, well-encapsulated tumors. Histologically, these tumors have characteristic Antoni A and Antoni B tissues. **Antoni A** tissue consists of palisading nuclei around central cytoplasm and **Antoni B** tissue is comprised of a loose edematous matrix. These tumors can arise from cranial nerves, peripheral motor and sensory nerves, and the sympathetic chain. They can sometimes present with a displaced tonsil or a lateral pharyngeal wall when the mass is located in the parapharyngeal space.

2. Neurofibromas

Neurofibromas differ from neurilemomas in that they are not encapsulated. The nerves in neurofibromas tend to traverse the tumors and are integral to them. While solitary neurofibromas are very rare, multiple neurofibromas are common especially in patients with **von Recklinghausen disease**. von Recklinghausen disease is an autosomal dominant disease with clinical findings of cafè-au-lait spots and neurofibromas.

The treatment of both neurilemomas and neurofibromas consists of simple surgical resection. The function of the affected nerve can typically be preserved with neurilemomas unless the neoplasms are intimately involved with some cranial nerves. These tumors rarely recur and malignant transformation is exceedingly rare.

LIPOMAS

Lipomas are the most common benign soft-tissue neoplasms. They arise from the subcutaneous tissue and present as painless, smooth, encapsulated, and round masses. Fifteen to twenty percent of all lipomas occur in the head and neck. Most of these neoplasms are solitary lesions and are easily treated with excision. Recurrences are very rare.

MALIGNANT NEOPLASMS

The most common malignant neoplasm in the neck is a cervical metastasis from a primary tumor in the upper aerodigestive tract. In most cases, when a lymph node metastasis in the neck is identified, the primary tumor also can be identified and the treatment proceeds according to the principles dictated by the stage of the primary disease. In less than 10%

of cases, the primary site is not located and further evaluation is required. Malignant neoplasms of the salivary, thyroid, and parathyroid glands also can present as malignant cervical masses or with metastases to cervical lymph nodes. (See the following chapters for information on these neoplasms: Chapter 17, Malignant Diseases of the Salivary Glands; Chapter 41, Malignant Thyroid Disorders; and Chapter 42, Parathyroid Disorders.) Other common primary malignant neoplasms of the head and neck are lymphomas. Rarely are sarcomas seen in the head and neck.

UNKNOWN PRIMARY SQUAMOUS CELL CARCINOMA

Clinical Findings

A. Symptoms and Signs

A common problem with an unknown primary squamous cell carcinoma is determining the site of the primary tumor when a known metastatic node has been identified. The incidence of an unknown primary tumor is between 2% and 8% of all patients with head and neck squamous cell carcinoma. The patient examination shows a mass in the neck with no masses or abnormalities in the upper aerodigestive tract. It is often on an FNAB that the diagnosis of squamous cell carcinoma is made.

B. Imaging Studies

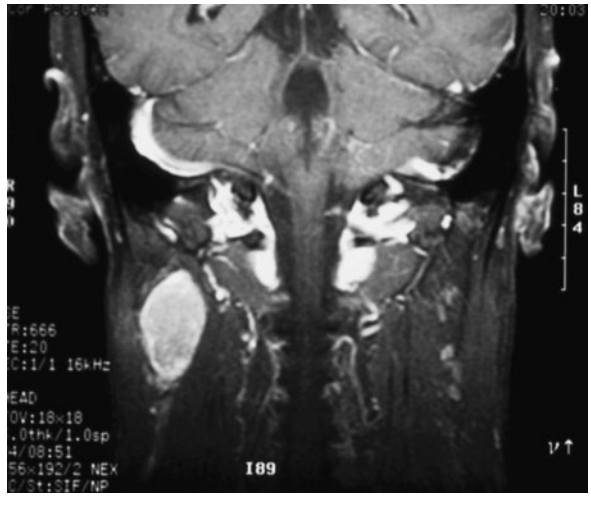
1. Positron emission tomography (PET)—The PET scan with a combination of CT scan is now preferred over an MRI as an initial imaging modality. It shows increased glycolytic activity of tumor cells identifying a potential tumor site. PET scans can identify small tumors, typically in the base of the tongue and in the tonsil, which would have otherwise escaped detection. PET/CT combination scans have been used to follow patients after treatment to evaluate for recurrence.

2. MRI—If better imaging is required for a therapeutic intervention, such as surgical planning, an MRI can be advantageous as it allows for better soft-tissue distinction (Figure 28–2).

C. Diagnostic Tests

All patients with unknown primary tumors should undergo an exhaustive search for the primary site so that (1) site-specific treatment can be employed; (2) the area can be closely monitored for recurrence; and (3) treatment morbidity, especially with radiotherapy, is markedly reduced.

The next step in the site search is a direct laryngoscopy with biopsy, esophagoscopy, bronchoscopy, and tonsillectomy. If studies suggest a primary site that can be confirmed on direct laryngoscopy, a directed biopsy is often sufficient for the diagnosis. It is more likely that no abnormalities are noted and blind biopsies are obtained. The typical sites harboring a primary cancer are in the nasopharynx, the palatine tonsil, the base of tongue, and the pyriform sinus. The mucosa can be easily biopsied from the nasopharynx, the base of tongue, and the pyriform sinus. A tonsillectomy should be performed rather than just a biopsy as 18–26% of patients can harbor a primary tumor in the tonsil.



▲ **Figure 28–2.** Coronal T1-weighted MRI showing a cervical metastasis from an unknown primary site.

Staging

The staging of neck tumors is based upon the system created by the American Joint Committee on Cancer. This system takes into account the number and size of lymph nodes in the neck; a portion of this staging system is shown in Table 28–2.

Treatment

The treatment of patients with an unknown primary tumor has been controversial. While the necessity of treating the neck is undisputed, the order of surgery and radiation therapy is debated, as is the extent of the surgery needed. Some clinicians advocate primary radiotherapy with surgery to follow, while others promote primary neck dissection with postoperative

Table 28–2. Staging of Regional Lymph Node Metastasis.

N_x	Regional lymph nodes cannot be assessed
N_0	No regional lymph nodes
N_1	Single ipsilateral lymph node, <3 cm
N_{2a}	Single ipsilateral lymph node, 3–6 cm
N_{2b}	Multiple ipsilateral lymph nodes, none >6 cm
N_{2c}	Multiple bilateral or contralateral lymph nodes, none >6 cm
N_3	Lymph node >6 cm

Data from the American Joint Committee of Cancer, 1997.

radiation therapy. The advantage of primary radiotherapy is that all potential tumor sites can be treated and the neck mass may decrease in size to facilitate or in some cases avoid the neck dissection. The advantage of primary surgery is that a lower total dose of radiation may be given to the neck to prevent some complications of radiation therapy.

The need to treat all potential primary sites also is debated. Wide-field radiation therapy to encompass all potential mucosal sites carries significant morbidity, though intensity-modulated radiotherapy (IMRT) does reduce the toxicity to vital structures such as the parotid glands, optic nerve, and spinal column. Proponents of this treatment maintain that wide-field radiation therapy decreases the risk of future tumor emergence. The emergence rates of primary tumors are estimated to be 3–8% a year in patients with primary sites treated with radiation, compared to a 32–44% in patients who do not undergo this treatment modality.

The complications of radiation treatment can be severe and include xerostomia, mucositis, and persistent dysphagia. For large, unresectable tumors, palliation is an option.

Cianchetti M, Mancuso AA, Amdur RJ et al. Diagnostic evaluation of squamous cell carcinoma metastatic to cervical lymph nodes from an unknown head and neck primary site. *Laryngoscope* 2009;119:2348 [PMID: 19718744]. (Diagnosis should still continue to include a complete examination, imaging with PET/CT and panendoscopy with biopsy.)

Waltonen JD, Ozer E, Hall NC, Schuller DE, Agrawal A. Metastatic carcinoma of the neck of unknown primary origin: evolution and efficacy of the modern workup. *Arch Otolaryngol Head Neck Surg* 2009;135:1024 [PMID: 19841343]. (A complete examination, imaging with PET/CT and biopsies with tonsillectomy is best for identifying an occult primary.)

Miller FR, Karnad AB, Eng T et al. Management of the unknown primary carcinoma: long-term follow-up on a negative PET scan and negative panendoscopy. *Head Neck* 2008;30:28 [PMID: 17657782]. (The risk of identifying a primary tumor after treatment in a patient with a negative PET and negative panendoscopy is less than 6%.)

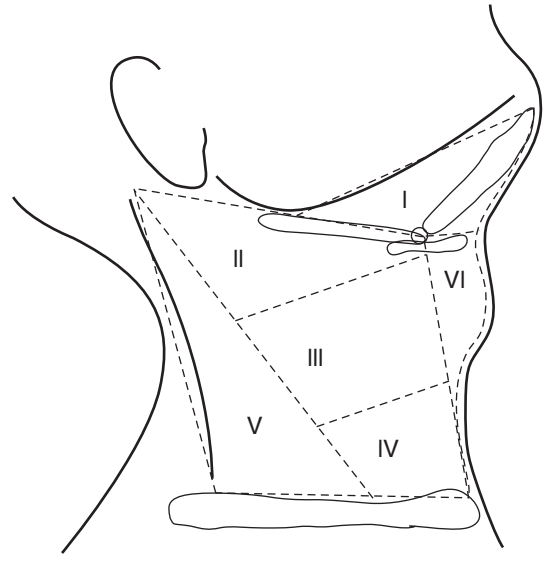
Frank SJ, Rosenthal DI, Petsuksiri J et al. Intensity-modulated radiotherapy for cervical node squamous cell carcinoma metastases from unknown head-and-neck primary site: M.D. Anderson Cancer Center outcomes and patterns of failure. *Int J Radiat Oncol Biol Phys* 2010;Epub [PMID: 20207504]. (IMRT delivers excellent outcomes in treating the tumor with few severe late complications.)

Chen AM, Li BQ, Farwell DG et al. Improved dosimetric and clinical outcomes with intensity-modulated radiotherapy for head-and-neck cancer of unknown primary origin. *Int J Radiat Oncol Biol Phys* 2010:Epub [PMID: 20421143]. (IMRT is better at reducing treatment related late complications such as xerostomia.)

NECK DISSECTION

General Considerations

A neck dissection is a systematic removal of lymph nodes in the neck. It serves to eradicate cancer of the cervical lymph nodes and can help determine the need for additional therapy when no lymph nodes are clinically identified. The indications for a neck dissection in the setting of no clinically palpable nodes are based on the propensity of metastasis from the primary site and the size of the primary tumor.



▲ **Figure 28–3.** Zones of the neck used in classifying the location of a cervical metastasis.

Classification of Neck Zones

The evaluation of the drainage pattern from the primary tumor sites in the upper aerodigestive tract has led to the understanding and identification of nodal groups at risk for cervical metastasis. The neck has been divided into six such groups called zones (Figure 28–3).

A. Zone I: The Submandibular and Submental Triangles

Zone I consists of the submandibular triangle and the submental triangle. The submandibular triangle is bordered by the mandible superiorly, the posterior belly of the digastric muscle posteroinferiorly, and the anterior belly of the digastric muscle anteroinferiorly. The submental triangle is the region between the bilateral anterior bellies of the digastric muscle and the hyoid bone.

B. Zone II: The Upper Jugular Region

Zone II is known as the upper jugular region. Its boundaries are (1) the skull base superiorly, (2) the carotid bifurcation inferiorly, (3) the posterior border of the

sternocleidomastoid muscle laterally, and (4) the lateral border of the sternohyoid and stylohyoid muscles medially. The tissue encompassed within these boundaries includes the upper portion of the internal jugular vein and the spinal accessory nerve. A subsection of Zone II, the **submuscular triangle**, includes the most superior aspect of this zone and lies laterally to the spinal accessory nerve at the skull base.

C. Zone III: The Middle Jugular Region

Zone III is the middle jugular region. It is bordered by (1) the carotid bifurcation superiorly, (2) the junction of the omohyoid muscle and the internal jugular vein inferiorly, (3) the posterior border of the sternocleidomastoid laterally, and (4) the lateral border of the sternohyoid muscle medially.

D. Zone IV: The Lower Jugular Region

Zone IV is the lower jugular region and extends from the omohyoid superiorly to the clavicle inferiorly; it also extends to the posterior border of the sternocleidomastoid muscle laterally and the lateral border of the sternohyoid muscle medially.

E. Zone V: The Posterior Triangle

Zone V is the posterior triangle and includes all of the lymph nodes between the posterior border of the sternocleidomastoid medially and the anterior border of the trapezius muscle laterally; it extends to the clavicle inferiorly. This triangle encompasses the course of the spinal accessory nerve. The supraclavicular region is part of Zone V.

F. Zone VI: The Anterior Compartment

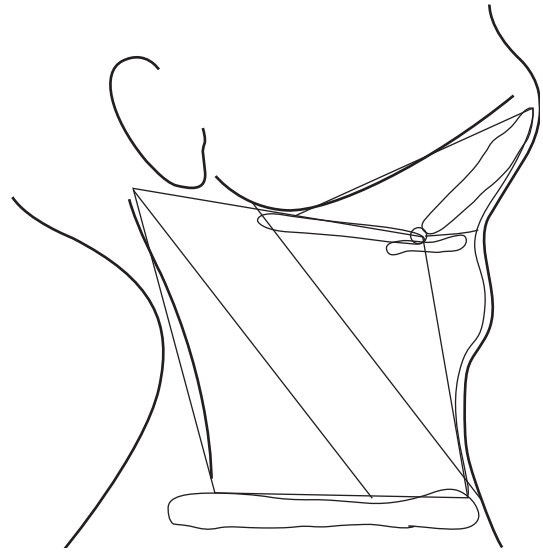
Zone VI is the anterior compartment and includes midline lymph nodes. The borders of this region are the hyoid bone superiorly, the suprasternal notch inferiorly, and the carotid sheaths laterally. This region is typically only dissected in conjunction with laryngectomy and thyroidectomy.

▶ Treatment

The current classification of neck dissections includes radical neck dissection, modified radical neck dissection, selective neck dissection, and extended radical neck dissection.

A. Radical Neck Dissection

Radical neck dissection is defined as an en bloc removal of all nodal groups between the mandible and the clavicle; this removal includes the sternocleidomastoid muscle, the internal jugular vein, and the spinal accessory nerve inclusive of Zones I–V. Since this dissection was first classified, many modifications have been proposed, especially in staging neck dissections when no palpable nodes are present (Figure 28–4).



▲ **Figure 28–4.** Surgical margins of a radical neck dissection.

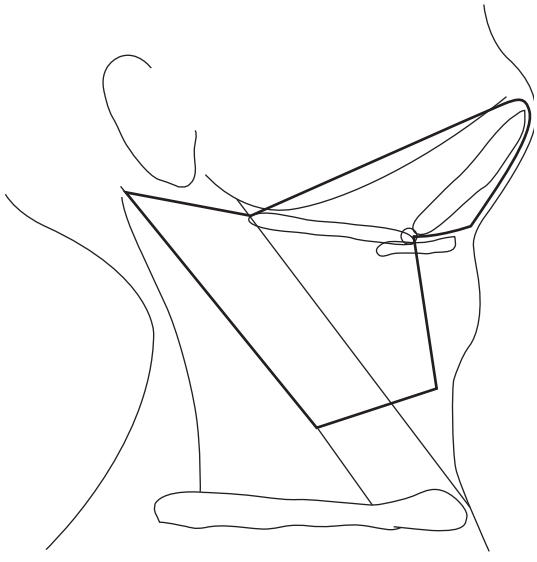
B. Modified Radical Neck Dissection

A modified radical neck dissection involves sparing at least of one of these three structures—the sternocleidomastoid muscle, the internal jugular vein, or the spinal accessory nerve—while still dissecting Zones I–V. The indications for a modified radical neck dissection include definitive treatment of the neck in the presence of metastatic disease. Since the spinal accessory nerve is rarely directly involved with disease, it tends to be preserved to decrease the pain associated with shoulder dysfunction. On occasion, all three structures can be preserved if they are not directly involved with pathologic nodes.

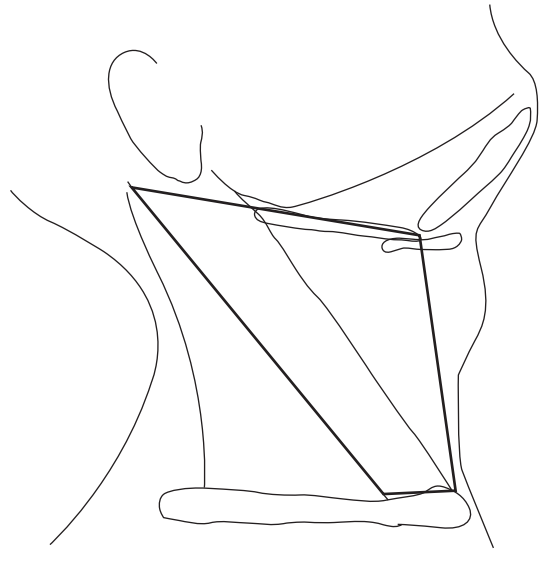
C. Selective Neck Dissection

A selective neck dissection involves the preservation of one or more zones that are typically removed in a radical neck dissection. This procedure is performed when both the treatment of the primary lesion is surgical and the risk of occult metastasis to the cervical lymph nodes is greater than 20%.

1. Supraomohyoid neck dissection—A supraomohyoid neck dissection involves Zones I–III and is usually performed in conjunction with oral cavity tumors and N_0 neck disease (Figure 28–5; also refer to Table 28–2). Its most common role is in the dissection of the contralateral neck at high risk for cervical metastasis in order to avoid postoperative radiation therapy.



▲ **Figure 28–5.** Surgical margins of a supraomohyoid neck dissection.



▲ **Figure 28–6.** Surgical margins of a lateral compartment neck dissection.

2. Lateral compartment neck dissection—A lateral compartment dissection includes Zones II–IV (Figure 28–6); it is used in conjunction with the surgical resection of tumors of the larynx, hypopharynx, and pharynx. When lateral compartment dissections are needed, they are usually performed bilaterally as the lesions are fairly midline.

3. Posterolateral neck dissection—Posterolateral neck dissections include Zones II–V and include nodes in the retroauricular and suboccipital regions (Figure 28–7). These dissections are often performed when cutaneous malignant tumors metastasize to the neck.

4. Anterior compartment neck dissection—The anterior compartment neck dissection includes Zone VI and is used for tumors found in the larynx, hypopharynx, subglottis, cervical esophagus, and thyroid. It includes the removal of the thyroid lobe and necessitates both the identification and the preservation of the parathyroid glands, with reimplantation as needed.

D. Extended Radical Neck Dissection

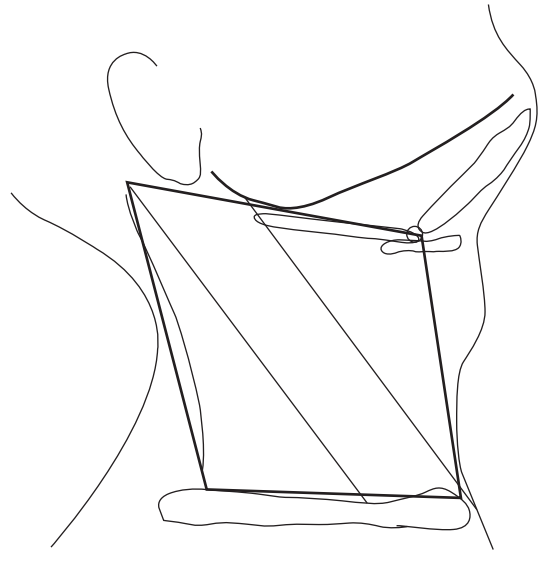
Extended neck dissections involve the additional removal of muscle, nerves, vessels, and lymph node groups as dictated by the primary disease and the presence of metastasis. Patients with disease extensive enough to warrant the consideration of a carotid resection should be evaluated preoperatively for carotid reconstruction.

Complications

The complications associated with neck dissections can occur either intraoperatively due to poor technique or postoperatively due to poor nutritional status, alcoholism, and underlying medical conditions such as diabetes.

A. Intraoperative Complications

Surgical complications usually stem from injury to the nerves present in the field. The mandibular branch of the facial nerve can be injured in a submandibular dissection, as can



▲ **Figure 28–7.** Surgical margins of a posterolateral neck dissection.

the lingual and the hypoglossal nerves. Injury to the vagus nerve is uncommon but it can lead to vocal cord paralysis, a decreased sensation of the hemipharynx, and dysphagia with a risk of aspiration. Dissection in the neck, below the deep layer of the deep cervical fascia, can cause inadvertent injury to the phrenic nerve that becomes symptomatic only in patients with significant pulmonary disease.

B. Postoperative Complications

1. Hematomas—A hematoma is a common postoperative complication. The immediate evacuation of a hematoma either by milking the drains (if small) or by exploration is necessary to both prevent wound infections and protect skin flaps.

2. Wound infections—The incidence of wound infections in neck dissections without concomitant pharyngeal surgery and with the use of perioperative antibiotics is 2–5% but increases when performed in conjunction with pharyngeal or laryngeal surgery. The use of perioperative antibiotics in the latter group has decreased the incidence of wound infections as well.

3. Chylous fistulas—A relatively uncommon complication is a chylous fistula; it occurs due to injury to the thoracic duct. Even with meticulous surgical technique, the incidence of a chylous leak is between 1% and 2%. This leak often becomes evident after the resumption of enteral feeds. The drain output tends to increase and is of a milky quality. The initial management includes pressure dressings and placing the patient on a medium-chain fatty acid diet. Most leaks resolve with this conservative therapy. However, if the drainage persists, is >600 cc/d, or is noted immediately postoperatively, surgical exploration with ligation of the stump may be necessary.

4. Carotid artery exposure and rupture—The most feared complication after neck surgery is carotid artery exposure with carotid rupture. Improved surgical techniques and the use of a pedicled and free musculocutaneous flap have minimized this risk. However, patient factors such as preoperative radiation therapy, poor nutritional status, infection, and diabetes continue to be risk factors. Should the carotid artery be exposed and a sentinel bleed occur, it is advisable to electively ligate the carotid artery both proximal and distal to the rupture. The carotid artery can sometimes be managed with embolization by highly experienced neurointerventional radiologists.

Ozer E, Karapinar U, Ryoo C, Agrawal A, Schuller DE. When to address level I lymph nodes in neck dissections? *Otolaryngol Head Neck Surg* 2010;142:355 [PMID: 20172380]. (Level I sparing neck dissection can be safe for selective primary tumors located in the oropharynx, larynx, and hypopharynx.)

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Clinical Voice Assessment: The Role & Value of the Phonatory Function Studies

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Krzysztof Izdebski, FK, MA, PhD, CCC-SLP, FASHA

The purpose of a clinical voice evaluation is to provide the referring laryngologist with patient-specific, clinically relevant pathophysiologic information of the actual voice production process used by the dysphonic patient, the nature of the dysphonic sound generated by a patient, and the physiologic conditions responsible for the sound production. The generated report must be clear and explanatory enough to aid the referring laryngologist with differential diagnosis and treatment planning. Moreover, the generated information must be capable of predicting treatment outcomes and powerful enough to warn the treating physician of any possible complications to the voice that may result from the proposed or planned treatment—whether medical, surgical, therapeutic, or a combination. Clinical voice evaluation is not a quick procedure. It may take up to 1 hour to conduct phonatory function studies (PhFS) on a noncomplicated patient, whereas it may take a substantially longer time to evaluate a patient who is a professional voice user.

The clinical exam comprises a battery of PhFS composed of at least of two primary parts: (1) an acoustic portion that examines the nature of the generated sound (CPT 92520 and 92506), and (2) a visual portion that examines via stroboscopic transoral or transnasal approach the glottis and surrounding area including the subglottis. Visualization of the subglottis is of paramount clinical value when examining papilloma, trauma, and/or subglottic stenosis patients. The exam must result in a clinically relevant description of the parameters that specify and regulate the vibratory patterns of the vocal cords and/or the other vocal tract elements that are causative of dysphonia. This portion of the exam is coded as 31579 using CPT code. (*Note:* When examining alaryngeal patient, or when utilizing other procedures or tests, additional CPT codes apply.)

PHONATORY FUNCTION STUDIES (PhFS)

PhFS are considered a standard of modern voice care because they provide information beyond subjective clinical impressions; they also provide objective descriptions of normal and pathologic phonatory processes. These processes include (1) mapping acoustic voice characteristics, (2) correlating voice with physiologic findings, (3) providing guidelines for the development of efficacious treatment plans, (4) predicting the progress and outcomes of treatment plans, (5) providing preoperative–postoperative lesion mappings, and (6) providing documentation for medicolegal purposes. PhFS are reproducible and allow a contrast of individual results to a database specific to the patient's age and gender. The information these studies provide also allows for a frank discussion with the patient and education of the patient, including discussion of the risks and alternatives associated with various treatments.

The acoustic portion (92520 with the various modifiers used) records and analyzes the voice of the patient. This portion is of paramount value, specifically when a surgical intervention is planned and when the patient uses voice as a tool of labor. Not having a voice recording of a patient as a part of record is simply inexcusable and must be treated as a serious error on the part of the practicing laryngologist. Having a voice recording is a must even if a litigation is not pending. *Do not ignore* this part of the exam. Acoustic recordings—if possible video recordings—should encompass content (vocal-text) relevant to the work needs and work conditions of the patient.

The physiologic portion (31579) visualizes via stroboscopic exam (phonoscopy) the mechanics of phonation and also maps the location, the extent, and the effects of phonatory lesions (when present), and their contribution to dysphonia. Keep in mind that a mismatch may be present between the acoustic and the visual data, that is, large lesion but a relatively good voice, or a small lesion or no lesion at all and a very poor voice, that not all glottic lesions require an immediate surgical procedure, and that not having an organic finding warrants a diagnosis of a functional dysphonia or even worse, a finding of malingering. In today's clinical practice, it is therefore necessary to have at your disposal a comprehensive documentation

of the phonatory mechanism. Documentation that shows objectively the location of the lesion or the mechanism of dysphonia is a necessity when postoperative dispute occurs. When operating on a patient, one must have preoperative stroboscopic mapping and voice recordings. Once visualization is conducted, the relevant videographs should be taken to the operating room (OR), placed in OR records. It behooves to compare preoperative visual documentation with direct MDL observation in the OR, for the purposes of validating preoperative findings with operative findings.

In addition to these two primary components, special tests may also be a part of the PhFS battery. These include delayed auditory feedback, voice load tests, nerve blocks, manual compression tests, and EMG.

In addition to the goals discussed, the information derived through PhFS is crucial in providing pre- and postsurgical documentation, in mapping acoustic and visual lesion(s), and in matching the presence or absence of lesions to the voice quality produced. PhFS are also crucial in documenting follow-up and when considering treatment revision in patient education; moreover, they are a must in medicolegal proceedings.

Izdebski K, Manace ED, Skiljo-Haris J. The challenge of determining work-related voice/speech disabilities in California. In: Dejonkere PH, ed. *Occupational Voice—Care and Cure*. The Hague: Kugler Publishing, 2001:149–154.

Izdebski K, Ross JC, Klein JC. Transoral rigid laryngovideostroboscopy (phonoscopy). *Semin Speech Lang* 1990;1:16.

Leonnard R, Izdebski K. Laryngeal imaging with stroboscopy: its value in therapeutic assessment. In Pais Clemente M, ed. *Voice Update*, International Congress Series 1997, The Hague, Netherlands: Elsevier, 1997.

VOICE PRODUCTION

Voice is an acoustic product resulting from the semicyclical vibrations of the two vocal cord(s) (ie, vocal folds) that are located in the larynx, commonly referred to as the *voice box*. Therefore, abnormal voice is a consequence of the underlying phonatory pathophysiology, reflecting the physical conditions of the vocal cords and the rest of the vocal tract, comprising the subglottic and supraglottic structures.

The vibration of the vocal cords is age and gender dependent and is controlled by myoelastic properties and aerodynamic forces; the vibration is generated as the air expelled under pressure from the lungs passes between the vocal cords and sets the cords into an oscillatory motion.

The myoelastic properties consist of the paired intrinsic laryngeal muscles (ILM), which are responsible for the size, shape, length, mass, stiffness, and tension characteristics of the vocal cords. The ILM include the thyroarytenoid muscles, the pairs of lateral cricoarytenoid muscles, the posterior cricoarytenoid muscles, and the interarytenoid muscle, which consists of both transverse and oblique portions. The ILM are innervated by the recurrent laryngeal nerves (RLNs) and all muscles, with the exception of the posterior cricoarytenoid muscles (the only vocal cord abductor), are responsible for vocal cord adduction and vocal cord approximation needed for vocalization to take place. The bilateral cricothyroid musculature is responsible for the thyroid cartilage downward tilt that elongates the vocal cords. These muscles are principally responsible for pitch elevation. The nonmuscular myoelastic properties include membranes (mucosa), ligaments, glandular elements, a blood supply, and nerves, all of which are located within the articulating cartilaginous housing that comprises the thyroid, the cricoid, and the two arytenoid cartilages.

Normal voice is actually generated by the vibratory wave-generating oscillations of the membranous portion of the vocal cords (the mucosa), which slides/glides in an undulating (phase locked) manner over the underlying muscle. When the mucosa, the submucosal space, the muscles, the vascular elements, the cartilages, or the compression of the glottis are affected, including the subglottic and supraglottic structures, pathologic voice quality results, and voice may not be a product only of the true vocal cords, but may be produced in alternative ways, including, for example, false vocal fold(s) vibration or, supraglottic vibration against the, that is, the epiglottis, etc. Therefore, PhFS must be capable of revealing altered phonation and of describing the glottic and the nonglottic mechanism that either generates, confuses, or coproduces the sound of the patient. Why? Because "fixing" the alternative phonatory generator may actually cause further loss of the voice. This is especially crucial when trying to rehabilitate voice in the blunt or penetrating laryngeal trauma patient. This description is also of paramount importance in differential diagnosis of dysphonia in patients in whom no visible VC pathology is noted, but in whom a dysphonic output is present.

The entire voice box rests on the trachea and is suspended above from the hyoid bone, which communicates with the base of the tongue. When this connection is affected by as little as minor lingual tension or inappropriate vertical larynx positioning, the result may include altered voice production.

In addition to the intrinsic articulation accomplished at the cricoarytenoid and cricothyroid (ie, synovial type) joints, the entire larynx is subject to vertical motions produced by the action of the paired extrinsic laryngeal musculature. These vertical laryngeal motions are crucial in phonation (singing), swallowing, respiration, and yawning, and in speech articulation. When this vertical movement is affected, voice production may be severely compromised even if the glottis looks "normal" on a routine ear, nose, and throat (ENT) exam.

Izdebski K. Effects of laryngeal and airway trauma on phonation. Paper presented at XVIII Annual Pacific Voice Conference, PVSF/UCLA. Phonotrauma: Causes and Treatments, Feb 26–27, 2010.
Shipp T, Izdebski K. Vocal frequency and vertical larynx positioning by singers and non-singers. *J Acoust Soc Am* 1975;58:1104.
Titze I. *Principles of Voice Production*. Englewood Cliffs, NJ: Prentice Hall, 1994.

MOTOR & SENSORY CONTROL

Both voluntary and involuntary phonation occurs after the efferent signals generated in the motor cortex proceed via the brainstem nuclei and the left and right branches of the vagus nerve (CN X) to reach the two vocal cords. Signals terminate in the motor end plates of the ILM via the left and right RLNs, resulting in vocal cord contractions. The entire efferent process can be accomplished within 90 ms, and it requires coordination of all vocal tract and respiratory laryngeal musculature via the central nervous system motor neurons. The coordination of these movements is achieved by a complex neural network with access to phonatory motor neuron pools that receive proprioceptive input from the various receptors associated with these three systems and by control of voluntary vocalization rather than involuntary vocalization involving different brain regions.

The RLN is a mixed nerve containing an average of 1200 myelinated axons and thousands of unmyelinated axons, including some specialized endoneural organs.

The left RLN is longer than the right nerve, but because of the differential axonal composition of both nerves, the efferent impulses manage to arrive at the two vocal cords almost simultaneously, causing the vocal cord vibration to be semiperiodic. This type of vibration makes the sound of the voice "human."

The vagus nerve also branches into the left and right superior laryngeal nerves (SLNs), which mediate the afferent signals from the larynx via their internal branches. The external branches of the SLNs are the motor branches innervating the paired cricothyroid muscles, which function as the primary pitch elevators. This specific vagus nerve branching explains why combined recurrent and SLN injuries (eg, paralysis) are rare. The action of the cricothyroid musculature is also responsible for the motion of the vocal cords seen in paralysis of the vocal cords due to RLN involvement. When some motion of the vocal cord is observed on the paralyzed side, it must be interpreted with caution as a sign of recovery, but rather as motion secondary to the ipsilateral SLN-mediated impulses. When the SLN is out in addition to the RLN, the posterior glottis will not approximate, a wider posterior gap will be present, and the arytenoids will not touch on phonation. Observing and documenting these conditions during clinical PhFS are of paramount importance for treatment planning.

Because of the contra- and ipsilateral innervation of the corticobulbar tract, a unilateral corticobulbar tract lesion will not cause unilateral vocal cord paralysis.

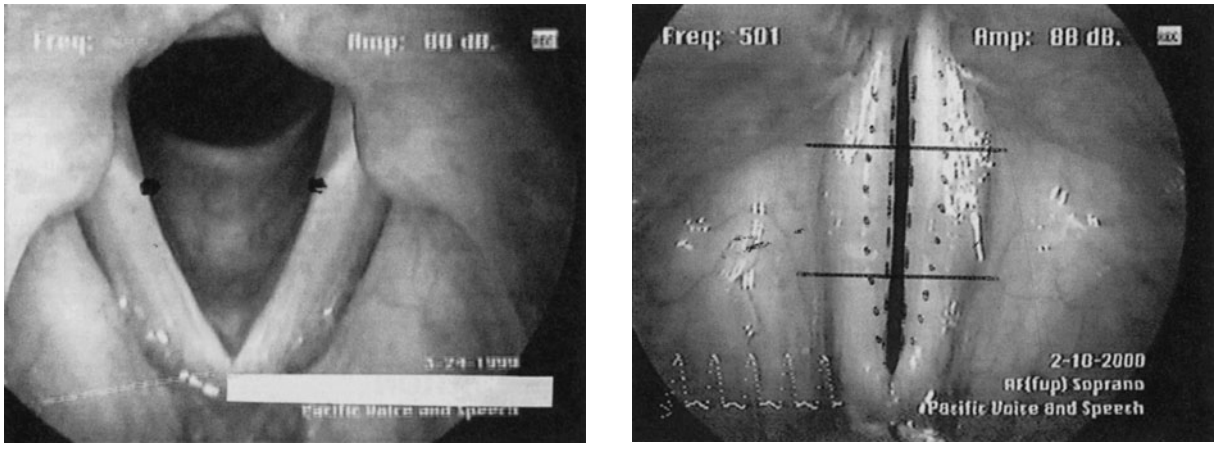
Carlsoo B, Domeij S, Hellstrom S, Dedo HH, Izdebski K. An endoneural microglomus of the recurrent laryngeal nerve. *Acta Otolaryngol Suppl* 1982;386:184.
Dedo HH, Townsend JJ, Izdebski K. Current evidence for the organic etiology of spastic dysphonia. *Otolaryngology* 1978;86:87 [PMID: 225708]. (Histologic examination of segments of the recurrent laryngeal nerve removed from patients with adductor spasmodic dysphoria revealed myelin abnormalities in 30% of the nerves examined, while neurologic examination indicated brainstem or basal ganglia disturbances.)
Jurgens U. Neural pathways underlying vocal control. *Neurosa BiobehavRev* 2002;26(2):235.

VOCAL CORDS

With regard to phonation, the vocal cords are subdivided into muscular components (the so-called "body") and nonmuscular components (the so-called "cover"). The body of the vocal cords is formed by the two thyroarytenoid muscles, which contain fast (adductive) and slow (eg, phonatory) fibers that determine the length, contour, and glottic closure shape of the vocal cords and that regulate the tension of the cover that slides over the body of the vocal cords to create the mucosal vibratory wave. The mucosal vibratory wave cannot be observed with simple visualization, but under stroboscopic illumination or superfast filming, where it is seen to undulate, proceeding from the inferior (ie, lower lip) to the superior surface (ie, upper lip) of the vocal cords (Figure 29–1).

The area between the upper and lower lips adjusts as pitch and loudness change; therefore, when a phonatory lesion is located within this space, its location and size determine the area of pitch and loudness dysfunction. Typically, more severe symptoms are caused by small but anteriorly located lesions than by larger lesions located toward the upper lip or on the superior phonatory surfaces. Typically, an anterior commissure lesion located ± 3 mm above the lower lip profoundly affects the voice, whereas even a large inferiorly located web (<3 mm below the lower lip) does not affect the voice. This is crucial to both treatment and diagnosis. To secure this observation, PhFS are needed.

The cover is subdivided into the outer and the inner layers and the lamina propria; the latter consists of three layers: superficial (the Reinke space), intermediate, and deep. The vocal ligament is the free edge of the conus elasticus, belonging to the deep and intermediate layers of the lamina propria. Obliteration of the Reinke space retards or prevents the mucosal vibratory wave, resulting in dysphonia of varying severity. However, if one vocal cord is stiff but straight (nonvibratory) and the other vibrates and approximates well against the nonvibrating vocal cord, the voice may be remarkably good despite the insufficiency of one cord. Therefore, it is important at times not to "repair" the stiff vocal cord but to leave it alone or even make it stiffer to improve the overall voice quality. Most benign phonatory mucosal lesions are typically found within the superficial



A B

▲ **Figure 29–1. (A)** The vocal cords at rest, forming a V-shaped space (the glottis), divided into the vibratory (membranous) and nonvibratory (cartilaginous) portions. **(B)** The vocal cords during phonatory approximation. The vocal cords are divided into anterior, mid, and posterior thirds. With regard to phonation, the vocal cords are divided into the upper vibratory lips (*dottedline*) and the lower vibratory lips (*dashedlines*).

layer. If the lesion is located on the superior surface of the vocal cord away from the vibratory edge, the voice may not be affected at all, even if the lesion is large. These findings are crucial in determining the extent of surgical interventions. A common sense real estate rule of "location, location, location" should prevail. In other words, it is often the location and not the size of the lesion that determines its value to the voice quality.

From the clinical point of view, vocal cords are also subdivided into the vibratory (membranous) and nonvibratory (cartilaginous) portions. At rest, they outline a V-shaped space called the glottis (see Figure 29–1). The front of this V forms the anterior glottic commissure, and the back of the V forms the posterior glottic commissure. The posterior end of each vocal cord (the thyroarytenoid muscle) inserts into the muscular process of each of the arytenoid cartilages. The maximum width of the posterior commissure occurs during inspiration or cough and measures approximately 9–12 mm, or three times the most posterior width of the muscular portion of the vocal cord at rest.

After puberty, the length of the vibratory portions of the vocal cords at rest is approximately 13 mm for women and 16 mm for men. When the vocal cords approximate for phonation, the entire glottis is closed in a male, whereas a small posterior chink is often present in a female, giving the female voice quality a slightly softer and airy tone. The specific shapes of glottic phonatory closure allow variations in normal voice qualities.

Furthermore, the vocal cords are clinically subdivided into anterior, middle, and posterior thirds, with nodular lesions usually located at the anterior third juncture and opposite each other if bilateral. An asymmetric location of mucosal lesions is found in mixed-type organic dysphonias.

Dworkin JP, Meleca RJ. *Vocal Pathologies: Diagnosis, Treatment and Case Studies*. San Diego: Singular Publishing Group, 1997.
Hirano M. Structure and vibratory behavior of the vocal folds. In: Sawashima T, Cooper F, eds. *Dynamic Aspects of Speech Production*. Tokyo: Tokyo University Press, 1977:3.
Schonharl E. *Die Stroboskopie in der Praktischen Laryngologie*. Stuttgart: Thieme, 1960.

THE VIBRATORY PROCESS

The two thyroarytenoid muscles, together with the other ILM and the extrinsic laryngeal muscles, control the relative elasticity and stiffness of the vocal cords. They also determine the shape of the mucosal vibratory wave, which in turn determines the pitch, loudness, and tone of the voice. The amplitude of the mucosal vibratory wave is wider at the lower pitches, whereas reduced mucosal vibratory wave amplitude predominates at high pitches or at any pitch level when the cover is stiff.

The duration and shape of the mucosal vibratory wave cycle form specific opening and closing phases that determine specific vibratory modes or vocal qualities (eg, fry, normal, overpressured, breathy, or falsetto). The time interval between cycles is called the **fundamental period** (F_0), whereas in perceptual terms it is referred to as a pitch period.

THE AERODYNAMIC PROPERTIES OF PHONATION

The aerodynamic properties of phonation include the subglottic air pressure (P_s), the airflow (AF), the supraglottic pressure (P^s), the intraoral pressure (P_{io}), and the glottal resistance, all of which are responsible for the Bernoulli effect, which separates the approximated vocal cords during phonation.

To generate sound, P_s must reach at least 5 cm H_2O, but P_s can exceed 50 cm H_2O in loud or overly pressured (ie, pathologic) phonation. Typically, a normal conversational voice is produced between 6 and 10 cm H_2O P_s at approximately 65–70 dB, whereas a loud voice can reach 85–95 dB.

The mean airflow in normal phonation ranges from 89 to 141 mL/s and increases as the fundamental period and the loudness are elevated. The glottal resistance cannot be measured directly, but is estimated to vary from 20 to 150 dyne/s/cm^3 depending on the pitch and the sound intensity.

Izdebski K. Overpressure and breathiness in spastic dysphonia. An acoustic (LTAS) and perceptual study. *Acta Otolaryngol Scand* 1984;97:122 [PMID: 6720314]. (Pre- and postrecurrent laryngeal nerve section speech segments spoken by adductor spasmodic dysphoria patients were analyzed by long-time-average-spectrum (LTAS) analysis and perceptually for breathiness and overpressure. Breathy phonation corresponded to a steep fall in the LTAS, whereas overpressured phonation produced higher spectral levels and a less steep fall. Correlation with perceptual assessment of weak and strangled voice was shown to be valid.)

Shipp T, Izdebski K, Schutte H. Subglottic air pressure in adductor spasmodic dysphonia. *Folia Phoniatrica* 1985;43:114 [PMID: 3220337]. (Article explaining the physiologic reasons and the techniques of subglottic pressure measurements and their application in examining pathologic voices.)

RESONATION

When the voice (F_0) resonates within the entire vocal tract (ie, the larynx, trachea, pharynx, and oral and nasal cavities) and when the vocal tract articulates, speech, singing, or other forms of communication are formed. Because of specific vocal tract configuration, in the voices of opera singers, specific sound regions are amplified; these areas are referred to as formants (F1–F5), and their combination determines the characteristic of each vowel. Opera singers form unique vocal tract shapes to allow noninjurious and efficient singing, and they show a unique clustering of powerful spectral peaks (the so-called singing formants) at about 3 kHz. This clustering results in an acoustic boost that helps a singer to compete with the sound of an orchestra. The production of singers' formants is possible when the entire larynx is lowered in the neck, but not when the larynx goes up as pitch elevates. Other acoustic features are emphasized in different singing styles. Because inappropriate larynx tracking can be potentially injurious to the voice, an examination of the vertical larynx position (VLP) is advised when evaluating the vocal problems of individuals who use their voices professionally. Ornamentation in voice can result from specific vocal tract configurations and specific time-locked acoustic events, with rate approximating 5–6 Hz for vibrato or vocal tremor. It is interesting to note that tremor-like vocal oscillations having similar rate may be present in deception.

Shipp, T, Izdebski K. Letter: Vocal frequency and vertical larynx positioning by singers and nonsingers. *J Acoust Soc Am* 1975;58(5):1104 [PMID 11945621]. (This article explains the reasons singers and nonsingers adjust their vocal tracts to produce acoustically advantageous effects.)

Shipp T, Izdebski K. Current evidence for the existence of laryngeal macrotremor and microtremor. *J Forensic Sci* 1981;26:501 [PMID: 7252466]. (The existence of laryngeal microtremors was tested using vocal vibrato in normal singers and in vocal tremor.)

Stone RE Jr, Cleveland T, Sundberg J. Formant frequencies in country singers' speech and singing. *J Voice* 1999;13:161 [PMID: 10442747]. (The study describes acoustic differences in voice quality in the same singer when the singer speaks and sings.)

LARYNGOLOGIC CONDITIONS

A multitude of laryngologic conditions can cause voice problems. Some of these conditions demonstrate a visible organic pathology on an initial routine ENT exam, either with a mirror or fiberoptics. Other conditions do not. Therefore, it is extremely important not to dismiss a patient's claim of "hoarseness," specifically in the absence of a visible pathology. Any voice condition, but specifically when hoarseness is present and the larynx looks normal, calls for PhFS to be performed as soon as possible. Delays in arriving at a diagnosis can result in medical complications (including potential legal consequences), as well as delays in treatment and a potential loss of income to the patient. Unfortunately, the concerns of many patients with dysphonia, especially patients who use their voices professionally, are often dismissed. These patients may be accused of "wrong" singing or poor training because no visible pathology was noted at the initial routine medical or ENT exam and because referrals for in-depth voice evaluations are not always initiated.

The specific conditions that can affect voice production are numerous and include the following: (1) congenital anomalies that can cause dysphonia by changing the shape and the form of the mucosal vibratory wave; (2) benign vocal cord lesions that affect the mucosal vibratory wave, resulting in air loss, noise, vocal cord stiffness, and pitch restrictions; (3) premalignant and malignant lesions that restrict or obliterate the mucosal vibratory wave; (4) infec-

tious and inflammatory disorders of the larynx, which can cause a variety of vibratory and approximation changes, depending on the severity and extent of the disease; (5) acquired voice disorders; (6) neurologic disorders that can affect all aspects of phonatory processes; (7) blunt or penetrating trauma (including chemical or thermal damage) to the larynx that causes injury (eg, fractures, dislocations, or crushes) to the laryngeal housing and the neural or vascular supplies; (8) pharmacologic agents that have either adverse effects (eg, antihistamines and virilizing drugs) or positive effects (eg, hydrating agents, asthma inhalers, corticosteroids, and bronchodilators); (9) iatrogenic dysphonia caused by (a) a clinical intervention in a nondysphonic patient (eg, vocal cord paralysis that results from an unintentional injury to the RLN), (b) the planned treatment (eg, an overinjection of polytef [ie, Teflon] during attempts to correct breathy paralytic dysphonia or irradiation), or (c) a change to the underlying nature of the primary dysphonia as a function of treatment (eg, denervation of the vocal cord to combat vocal spasticity, Botox, and vagal stimulation); (10) functional dysphonia (eg, persistent prepubertal voice in a postpubertal male, elective aphonia, ventricular dysphonia, and inhalational dysphonia); (11) gender euphoria; (12) emotional causes; and (13) environmental–occupational causes.

Gastroesophageal reflux disease (GERD) has been recently linked to a multitude of voice disorders. However, this association is controversial, and cause–effect correlation is far from being established unequivocally. Some clinicians, however, believe that GERD is the primary cause of many voice problems, whereas others minimize its role in the formation of dysphonia. When GERD is perceived as the cause of voice disorders, it is cited as causing changes that range from alterations of vocal cord mucosa to more general supraglottic tissue changes. GERD may cause a chronic or intermittent dysphonia that is characterized by vocal fatigue, voice breaks, cough, globus syndrome, and, occasionally, dysphagia.

Flower RM, Izdebski K. *Common Speech Disorders in Otolaryngologic Practice*. Rochester, Minnesota: American Academy of Otolaryngology Press, 1979.

Izdebski K, ed. *Emotions in the Human Voice*. Volumes 1–3. San Diego: Plural Publishing, 2009.

Izdebski K, Dedo HH, Wenokur R, Johnson J. Voice and vocal cord findings in asthma inhaler (Advair) users. Western Section: Triological Society. San Diego, California. February 3, 2006.

Koufman JA. Gastroesophageal reflux and voice disorders. In: Rubin JS, Sataloff RT, Korovin GS, Gould WJ, eds. *Diagnosis and Treatment of Voice Disorders*. New York: Ikagu-Shoin, 1995:161.

Rubin JS, Sataloff RT, Korovin GS, Gould WJ. *Diagnosis and Treatment of Voice Disorders*. New York: Ikagu-Shoin, 1995.

Ylitalo R, Lindestad PA, Ramel S. Symptoms, laryngeal findings, and 24-hour pH monitoring in patients with suspected gastroesophageal-pharyngeal reflux. *Laryngoscope* 2001;111(10):1735. [PMID: 11801936]. (Discussion of controversies of GERD on voice and its role in formation of various dysphonias.)

ACOUSTICS

An acoustic voice assessment provides information on the nature of the generated sound and should include physical voice recordings (analog, digital, or video) and an objective acoustic analysis; it should also include a subjective psychoacoustic analysis, a psychometric analysis, a phonometric analysis, or all of the above. The psychoacoustic and psychometric analyses require a trained ear and long-standing expertise, not unlike what is needed to assess auscultatory noises. However, the problems with these analyses result from the potential for loose terminology and a nonuniform interpretation. A subjective description of one type of dysphonia used over 350 different clinical terms. Therefore, using numerical perceptual rating scales is preferred when subjectively assessing voice problems. Attempts to use acoustic objective analysis to detect voice quality correlations with underlying pathology continue, but solutions are far from being reached.

Godino-Llorente JI, Gomez-Vilda P, Blanco-Velasco M. Dimensionality reduction of a pathological voice quality assessment system based on Gaussian mixture models and short-term cepstral parameters. *IEEE Trans Biomed Eng* 2006;53(10):1943 [PMID: 17019858]. (Paper demonstrates promising acoustic technique in detecting voice pathologies.)

Izdebski K. Spastic dysphonia. In: Darby J, ed. *Speech Evaluation in Medicine and Psychiatry*, Vol. II: *Medicine*. New York: Grune & Stratton, 1981.

Izdebski K, Shipp T, Dedo HH. Predicting postoperative voice characteristics of spastic dysphonia patients. *Otolaryngol Head Neck Surg* 1979;87:428. [PMID 503503] (Describes techniques of predicting surgical voice outcomes of selected dysphonic patients based on presurgical phonatory function studies.)

SUBJECTIVE ASSESSMENT

The subjective assessment often uses a mixture of perceptual and musical terms to describe the patient's voice quality, pitch, loudness, the duration and rate of phonation, prosody, registration, tessitura, and respiratory characteristics.

Common Assessment Findings

Below is a review of terms often used to describe clinically the various dysphonic qualities. These semantic descriptors can be quite accurate, but when the voice is abnormal the term *hoarseness* is a generic word used by most clinicians (and lay people) when referring to or describing many kinds of dysphonia. Hoarseness is frequently used as a wastebasket term and leads to a wrong impression or diagnosis. It is especially used in error when one is attempting to define a rough or harsh voice quality since this is typically associated with vocal cord stiffness and possibly cancer.

Breathy or **soft** voice is used to describe a voice that is generated by incomplete glottic closure (eg, in unilateral vocal cord paralysis, vocal cord bowing, neurologic disorders, benign mucosal lesions, and psychogenic voice disorders).

A **tight, strangled**, or **strained voice** represents an overclosed glottis and is found in dystonias and pseudobulbar palsies, including psychogenic disorders.

A **diplophonic** or **multiphonic voice** is present when the vibratory pattern between the vocal cords or within a single vocal cord is unequal. This condition can be caused by a myriad of benign and malignant mucosal lesions, neurologic complications, laryngeal fractures, or psychosomatic problems.

A **wet, gargling voice**, also referred to as **hydrophonia**, describes phonation that is produced by excessive mucus within the glottic space.

A **rough voice** may describe a true vocal cord vibration that is mixed with a ventricular vibration. This may be present when mucosal lesions are found between the lower and upper phonatory lips and when mucosal wave is partially obliterated.

A **harsh, rough, and stiff voice quality** with a short maximum phonation time should be used to refer to voices that are produced with adynamic "cover." This can be found in invasive carcinoma or in Teflon overinjection, or when mucosa is prevented from vibration by lesions pressing on the vocal cord from above.

A **shrill, metallic voice** with abrupt onset can be associated with muscular tension dysphonia, a benign phonatory lesion, and hyperfunctional dysphonia.

Sudden pitch or **loudness breaks** in the absence of clearly visible phonatory mucosal lesions may be an indicator of functional problems, postpubertal dysphonia, or virilization of the female.

A **limited upper pitch range** with soft breathy phonation, no mucosal lesions, and rotation of the posterior larynx can indicate SLN involvement.

Rapid pitch (at about 5–6 Hz) and intensity oscillations reflect vocal tremor, whereas pitch-dependent oscillations or vocal arrests reflect specific movement disorders, while in muscular tension dysphonia, or functional (psychosomatic) dysphonia, oscillations may be random.

Odynophonia describes a sensation rather than voice quality and is associated with pain or discomfort when speaking or vocalizing.

Total aphonia, or lack of voice in the absence of a phonatory cough, can indicate severe separation of the glottis caused either by organic and functional origins or following total laryngectomy. Ankylosis of the arytenoid cartilages can be suspected, but when a phonatory cough is present, total aphonia should arouse suspicion of a psychosomatic conversion dysphonia.

Stridor should be reserved to describe uncontrollable vocal production ("voicing") during inhalation, when the glottis is not abducting. Asthma-like wheezing happens only on exhalation when the vocal cords are open. When female patients inhale asthma medications, vocal cord mucosa can be affected and severe dysphonia can occur. Typically, stopping medication is enough to reverse the condition.

No matter how the voice sounds, the sound of the pathologic voice may evoke negative emotions that are noncongruent with the emotions intended by the patient. This incongruence can be very frustrating and may cause a patient to react as if the condition has a functional cause, when it clearly does not. An understanding of these factors by the examining clinician goes a long way toward enhancing bedside manners.

ACOUSTIC ANALYSIS

Acoustic analysis provides an objective and quantitative description of the generated sound in a reliable and noninvasive way. The purpose is to map out phonatory characteristics, demonstrate phonatory deficits, and correlate findings with visual (ie, physiologic) data. Barring minor technical problems, either dedicated instrumentation or a computerized approach can be used for a fast, reliable, and reproducible acoustic analysis. Acoustic analysis provides information on sound duration, loudness, pitch, and spectral context, including static and dynamic pitch changes of the voice during speech.

Izdebski K. Pathologic voice evokes wrong emotions. In: Izdebski K, ed. *Emotions in the Human Voice*. Vol 2., Chapter 8, Plural Publishing, San Diego. (Describes confusion in perception of intended emotional prosody produced by patients with various vocal pathologies.)

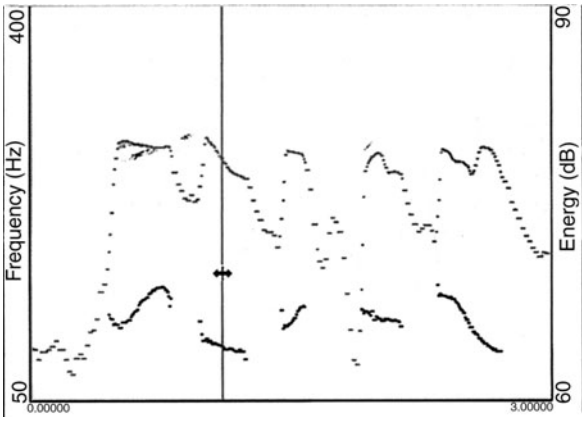
Shipp T, Izdebski K. Current evidence for the existence of laryngeal macrotremor and microtremor. *J Forensic Sci* 1981;26:501 [PMID 7252466]. (Analyzes the existence of laryngeal microtremors detected during deception versus the macrotremors found in the voice of singers and also found in vibrato and subjects with pathologic vocal tremor, using electromyographic and acoustic signals from laryngeal muscles.)

Wheeler KM, Collins SP, Sapienza CM. The relationship between VHI scores and specific acoustic measures of mildly disordered voice production. *J Voice* 2006;20(2):308 [PMID: 16126368]. (Elucidates the relation between the Voice Handicap Index and laboratory measurements and shows that these two methods give independent information and essentially correlate poorly.)

Yan Y, Izdebski K, Damrose E, Bless D. Quantitative analysis of diplophonic vocal fold vibratory pattern from high-speed digital imaging of the glottis. In: Manfredi C (ed.): *Sixth International Workshop (MAVEBA) Models and Analysis of Vocal Emissions for Biomedical Applications*. Firenze, Italy, 2009;145–148.

PITCH ASSESSMENT

Pitch expressed in musical intervals is a perceptual and therefore subjective measure. However, in objective acoustic terms, pitch refers to the fundamental frequency of the voice



▲ **Figure 29–2.** Intonation pattern of a sentence spoken by a male speaker showing pitch (lower tracing) and intensity (upper tracing) contours. (Reproduced with permission of KayPENTAX, Lincoln Park, NJ.)

or the speaking fundamental frequency, both of which are recorded in vocal cycles per second or hertz (Hz). Deviations in the fundamental frequency are expressed by jitter measures, or a pitch perturbation factor. Jitter is defined as a fundamental frequency value that is obtained by subtracting the duration of the pitch period from the duration of the period immediately preceding it. Because pitch changes over time, serial correlation coefficients may be used to more accurately represent these changes. The pitch pattern is related to the intensity profile as shown in Figure 29–2.

Fundamental frequency is age and gender dependent. The average level of fundamental frequency for a child is approximately 250 Hz; it is 200 Hz for an adult female, and for an adult male, it is approximately 120 Hz. The maximum fundamental frequency range for both genders is from 36 to 1760 Hz, or roughly the distance from D1 to A6 on a piano. Vocal training can develop an individual's voice to be an exquisite instrument; an extreme vocal span can range over four octaves (eg, from E3, which is approximately 164 Hz, up to F6, which is approximately 1760 Hz).

The speaking fundamental frequency of males typically drops with the termination of a spoken sentence without constituting a pathologic condition. In contrast, the fundamental frequency of females is often elevated at the end of a spoken sentence. This distinction is of import when examining patients with gender reassignment, patients on psychotropic medications, or those with a history of using virilizing drugs. The speaking fundamental frequency of females drops over the life span, whereas this frequency becomes elevated in male geriatric populations.

When assessing patients who sing professionally, their vocal registration should be included in the evaluation. Using a musical scale notation is a preferred method of communicating clinical findings to these patients.

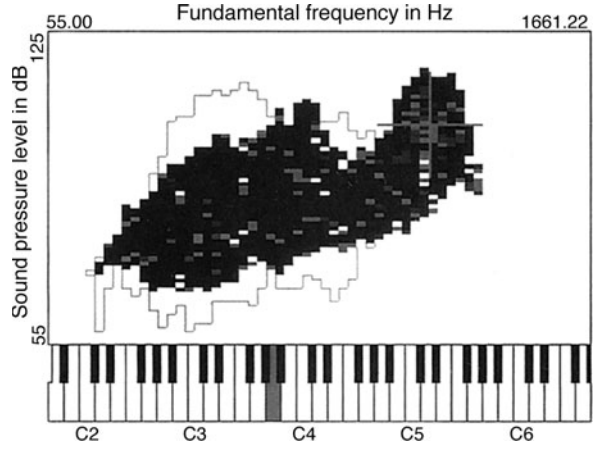
Baken RJ. *Clinical Measurements of Speech and Voice*. San Diego: College Hill Press, 1997.
Izdebski K, Ross JC, Klein JC. Rigid transoral laryngovideostroboscopy (phonoscopy). *Semin Speech Lang* 1990;1:16.

LOUDNESS ASSESSMENT

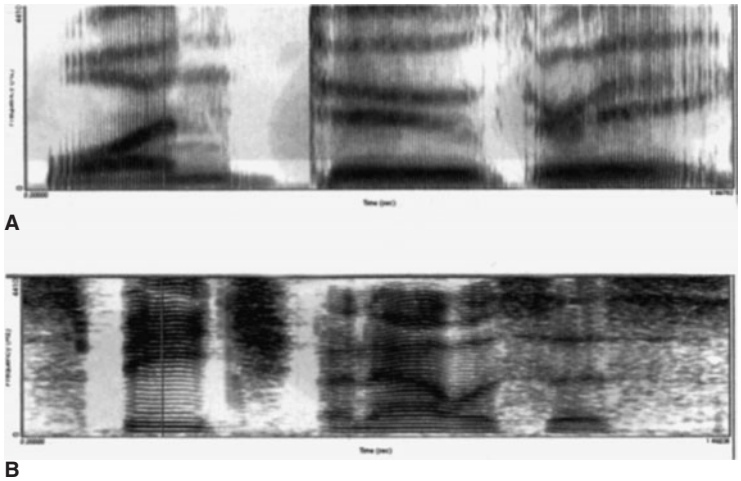
Loudness represents acoustic intensity that is measured in decibels and is dependent on both the subglottic air pressure and the airflow exiting the glottis. Obtaining the absolute phonatory intensity is difficult; therefore, it is typically reported in relative rather than in absolute decibels. Moreover, because the acoustic intensity is affected by the fundamental frequency, normal loudness is actually greatest at mid-frequency ranges and lowest at both the low and high levels of fundamental frequency. As with fundamental frequency, means, medians, standard deviations, coefficients of variation, and loudness perturbation factors (known as "shimmer") are used to describe acoustic intensity variation and dispersion. The typical loudness level of speaking is approximately 65–75 dB. Values below or above this measure are considered pathologic.

PHONETOGRAM

To make a more orderly representation of pitch and loudness, a profile of the fundamental frequency, measured in decibels and referred to as a phonetogram, has been developed. The phonetogram, which is a voice range profile, represents the minimums and the maximums of vocal loudness at selected levels of fundamental frequency within the total frequency range of a speaker (Figure 29–3). Clinically,



▲ **Figure 29–3.** A phonetogram (a voice range profile). A thin line outside the "map" corresponds to previous measurements. (Reproduced with permission of KayPENTAX, Lincoln Park, NJ.)



▲ **Figure 29–4.** A sound spectrograph. **(A)** Representation of vocal tract resonation, referred to as formants (F1–F5); the transitions are shown here as heavy, dark semihorizontal bars. **(B)** A narrow-filter spectrograph displaying the harmonic structure (partials) of the sound, shown here as narrow horizontal lines. Fundamental frequency values can be derived from the position of the tenth harmonic. The fuzzy dark portions of the spectrograph represent the noise present in voiceless consonants. (Reproduced with permission of KayPENTAX, Lincoln Park, NJ.)

a phonetogram is a reflection of the vocal capacities rather than the measurement of the glottic function. Vocal intensity profiles are used to assess vocal cord paralysis, vocal cord bowing, presbyphonia, odynophonia, functional disorders, and patients who use their voices professionally.

SPECTRAL ANALYSIS

Spectrography

Spectrography (Figure 29–4) provides a three-dimensional representation of sound: time, intensity, and frequency. Narrow-filter spectrography shows the harmonic structure (partials) of the sound, from which values of fundamental frequency can be derived. Wide-filter spectrography shows vocal tract resonation, represented by the formants (ie, F1–F5).

Spectrography provides information on (1) noise; (2) phonatory breaks; (3) vocal discontinuity; (4) diplophonia; (5) the size and speed of fluctuations in the fundamental frequency; (6) the size and speed of amplitude fluctuations; (7) the richness of harmonics; (8) the relative noise level; (9) an analysis of rising and falling tones, as well as voice efficiency over time; and (10) glottic air transfer. These features are critical when analyzing vocal cord stiffness, vibratory irregularity due to lesions that are benign, mucosal, iatrogenic (eg, with the use of Teflon or thyroplasty), or that cause adynamic vibration. These features are also significant when evaluating patients who use their voices professionally, have neurologic or functional dysphonias, have carcinoma, or experience stridor, noise, wheezing, or obstructive airway problems (eg, snoring).

Long-Time Average Spectrum

The long-time average spectrum technique is used to plot compressed speech spectrum levels over time. This technique relates the acoustic parameters to perceptual observations and has been used successfully to describe various dysphonias.

Izdebski K. Overpressure and breathiness in spastic dysphonia: an acoustic and perceptual study. *Acta Otolaryngol* 1984;97:373 [PMID: 6720314]. (Pre- and post-recurrent laryngeal nerve section speech segments spoken by adductor spasmodic dysphoria patients were analyzed by long-time-average-spectrum (LTAS) analysis and perceptually for breathiness and overpressure. Breathy phonation corresponded to a steep fall in the LTAS, whereas overpressured phonation produced higher spectral levels and a less steep fall. Correlation with perceptual assessment of weak and strangled voice was shown to be valid.)

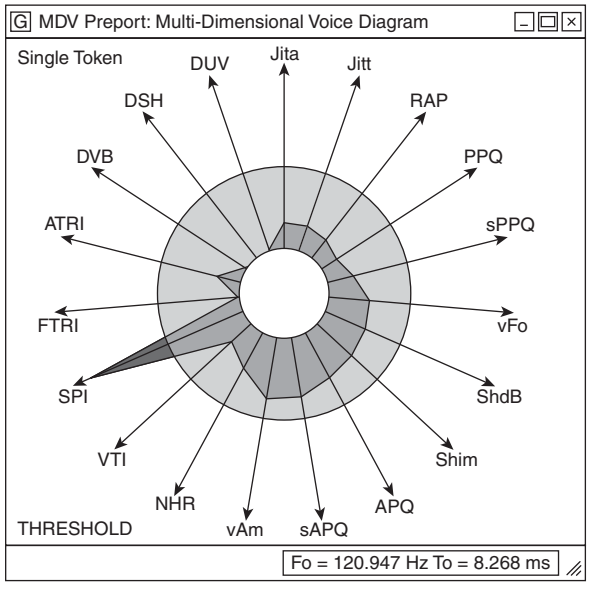
Multifactorial Analysis of Acoustic Signals

Signal processing engineers together with clinicians are working hard on providing user-friendly algorithms to represent in visual forms accurate analysis of abnormal acoustic signals over time. Although humans can process such signals intuitively in the form of an image of voice quality, processing of such signals by reproducible objective means is often more than a formidable challenge. But there is progress. Some of these methods include inverse filtering, time series analysis, chaos measurements, or very recently even the attempt to apply fuzzy states logic. One of the most promising analytical platforms to make sense with aperiodic long-term signals (hoarseness) is based on Nyquist plots.

Y. Yan, X. Chen and D. Bless. Automatic Tracing of the Vocal-fold Motion from High-speed Laryngeal Image Sequence. *IEEE Trans. On Biomedical Engineering.* vol 53(7):1394–1400, July 2006.

Multidimensional Voice Profile

The multidimensional voice profile displays, in a graphic form, multiple vocal parameters all at one time (Figure 29–5). The use of the multidimensional voice profile is advantageous in comparing pretreatment and posttreatment results. It also provides an overall description of dysphonia because single



▲ **Figure 29–5.** A multidimensional voice profile. A soft, breathy voice is shown by severe SPI (soft phonatory index). (Reproduced with permission of KayPENTAX, Lincoln Park, NJ.)

acoustic parameters alone are insufficient in delineating the complexity of phonatory pathologies. The multidimensional voice profile can compare individual clinical data with a built-in database adjusted to age and gender. Therefore, this profile is very useful in analyzing changes over time.

Rate Analysis

Instrumentally based rate analyses are used to define the rate and extent of specific acoustic variations (ie, vocal tremor, vocal arrests, or vibrato). Rate analysis is used in the differential diagnosis of vocal movement disorders and in assessing the vocal problems of singers. Pathologic vocal rates are between 5 and 6 Hz, a rate similar to the vibrato rate.

Dejonckere PH, Hirano M, Sundberg J. *Vibrato*. San Diego: Singular Publishing Group, 1995.
Shipp T, Izdebski K. Current evidence for the existence of laryngeal macrotremor and microtremor. *J Forensic Sci* 1981;26: 501 [PMID: 7252466]. (The existence of laryngeal microtremors was tested using vocal vibrato in normal singers and in vocal tremor.)

Vocal Cord Contact Area

A normal voice is produced when the glottic approximation is normal during sustained phonation. The percentage of vocal cord contact area loss can be derived from acoustic measures. When a voice is hoarse, the percentage of phonatory contact (ie, perturbations) goes down. Values below 90% are considered abnormal.

Vowel Space

Vowel quality is affected by the fundamental frequency and loudness. Therefore, substantial difficulties in maintaining vowels on target are encountered when singers must sing loudly. These elevated levels make for the poor intelligibility of sung text. Therefore, vowel production should be examined when studying patients who sing professionally.

Maximum Phonation Time

The maximum phonation time corresponds to the time an individual can phonate per each inhalation. Normal maximum phonation time values are between 17 and 35 seconds for adult males and between 12 and 26 seconds for adult females. A reduction of the maximum phonation time is expected in a hypofunctional glottis, whereas prolonging this time is characteristic for an overapproximated glottis. Although the maximum phonation time lacks diagnostic capabilities, it is useful in the preoperative and postoperative assessments of unilateral vocal cord paralysis and bowing, in monitoring medialization (eg, thyroplasty or various intracordal injections), and in lateralization procedures (eg, Botox injections, as well as nerve resections, blocks, or stimulation).

Baken RJ. *Clinical Measurements of Speech and Voice*. San Diego: College Hill Press, 1997.
Hirano M. *Clinical Examination of Voice*. New York: Springer-Verlag, 1981.

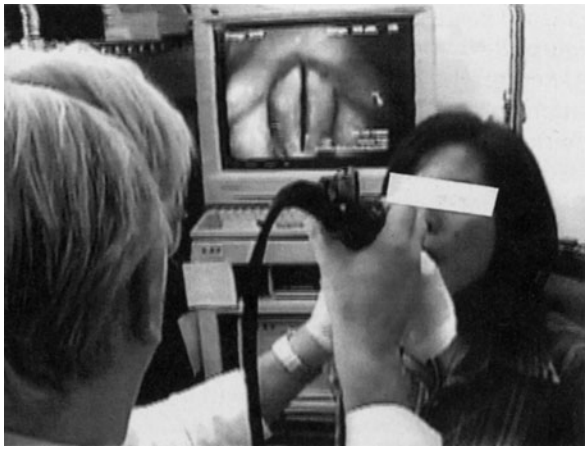
PHYSIOLOGIC VOICE EVALUATION

Physiologic voice evaluation comprises rigid or flexible stroboscopic visualization, aerodynamics, glottography, electromyography, and special studies.

PHONOSCOPY

Phonoscopy refers to stroboscopic (or laryngovideostroboscopic) visualization of the vocal cords during vibration (Figure 29–6). It is considered to be a principal procedure among PhFS studies. Many clinicians report making over 20% diagnostic and treatment planning decisions because of stroboscopic evaluation.

The technique is based on the principle of illuminating a vibrating object with light flashes just below or above the frequency at which it vibrates, therefore making the vibrating object appear at a standstill or as if it is vibrating in slow motion. Laryngovideostroboscopy or digital stroboscopy



▲ **Figure 29–6.** Phonoscopic transoral rigid procedure showing the online visualization of the vibratory process of the vocal cords. The image obtained is displayed immediately on a VCR monitor. The glottographic signal and pitch and intensity values are displayed for analysis.

provides an image of the vocal cord vibrations averaged over many vibratory cycles, while newly introduced high speed stroboscopy shows consecutive cycles and not averages it can only show short sign duration. The most detailed images are obtained via either a 90° or a 70° rigid transoral scope. The images are captured on videotape or in digital form and are displayed on a monitor for either immediate or subsequent viewing and analysis.

Phonoscopy provides the clinician with a wealth of information. Among the large amount of information it provides, phonoscopy (1) maps the location of the phonatory lesion in relationship to the acoustic findings, (2) gives fundamental frequency values, (3) shows the symmetry of vocal cord vibrations, (4) reveals the configuration of the glottic closure, (5) shows the horizontal excursion of the vocal cords (ie, their amplitude), (6) reveals the appearance and the workings of the upper and lower phonatory lips, (7) shows the type and the nature of the glottic closure, and (8) demonstrates the nature of the mucosal vibratory wave (including the presence or absence of adynamic segments). Compared with traditional exams, a phonoscopic exam significantly increases the diagnostic accuracy and therefore provides for more effective treatment options.

Phonosopic capture rate of images relates to the capacity of the recording instrumentation. With regular stroboscopy captured digitally or on the video, this rate typically does not exceed 30 frames per second. Therefore, the glottic images we evaluate and from which we make clinical decisions form essentially a composite of multiple frames of vinratory cycles over time. Still a tremendous improvement over mirror, or fiberoptic visualization, conventional stroboscopy is submissive in relation to the so-called high-speed digital (HSD) recordings, now entering the market, although mostly as an academic research tool. HSD recordings can capture frames rate up to 50,000 per second, a clinical overkill, but some commercially available clinical systems can now operate in the vicinity of 2000–4000 frames per second. To process such a vast amount of information and to make any sense out of these consecutive frames, special signal processing programs based on edge-tracking technology are being developed. Although HSD systems in current form are not here yet to stay, it is being argued that HSD is the way to go. Well at this time, regular conventional stroboscope will do, but the future for HSD appears bright.

Colton R, Casper JK. *Understanding Voice Problems: A Physiological Perspective for Diagnosis and Treatment*. Baltimore: Williams & Wilkins, 1996.

Dworkin JP, Meleca RJ. *Vocal Pathologies: Diagnosis, Treatment and Case Studies*. San Diego: Singular Publishing Group, 1997.

Hertegard S, Larsson H, Wittenberg T. High-speed imaging: applications and development. *Logoped Phoniatr Vocol* 2003;28:3,133–139.

Hirano M. *Clinical Examination of Voice*. New York: Springer-Verlag, 1981.

Izdebski K, Yan Y, Kunduk M. Acoustic and high-speed digital imaging based analysis of pathological voice contributes to better understanding and differential diagnosis of neurological dysphonias and of mimicking phonatory disorders. *Interspeech Proceedings*. Brighton, GB, 2009.

Izdebski K, Ross JC, Klein JC. Rigid transoral laryngovideostroboscopy (phonoscopy). *Semin Speech Lang* 1990;1:16.

Remacle M. The contribution of videostroboscopy in daily ENT practice. *Acta Oto Rhino Laryngologica Belg* 1996;50:265 [PMID: 9001636].

Yan Y, Ahmad K, Kunduk M, Bless D. Analysis of vocal-fold vibrations from high-speed laryngeal images using Hilbert transform based methodology. *J Voice* 2005;19(2):161–175.

Yan Y, Chen X, Bless D. Automatic tracing of the vocal-fold motion from high-speed laryngeal image sequence. *IEEE Trans Biomedical Engineering* (2006);53(7):1394–1400.

Yan Y, Izdebski K, Damrose E, Bless D. Quantitative analysis of diplophonic vocal fold vibratory pattern from high-speed digital imaging of the glottis. In: Manfredi C (ed.): *Proceedings of the 6th International Workshop: Models & Analysis of Vocal Emissions for Biomedical Applications (MAVEBA 09)*. Firenze, Italy, 2009

VIDEOKYMOGRAPHY

Videokymography (VKG) is a recently developed system used for direct observations of vocal cord vibrations by coupling a modified video camera to a standard rigid endoscope and constant light illumination, with the image obtained recorded to a standard videosystem. The most modern videokymographic technology combines two different glottic views that are presented simultaneously on a video monitor. The left half of the screen provides a standard (color) rigid view, and the right half of the screen displays a B&W high-speed kymogram image of vibratory

cycle of the vocal cords at a selected portion of the glottis (see the white horizontal line). The high-speed mode operates at 7200 images per second and displays open and closed phases, opening and closing movements, left–right asymmetries, displacements of the upper and lower vocal cord lips, and mucosal waves. In the high-speed mode, lines are displayed in succession, and the operator can focus on the portion of the glottis (eg, middle, anterior, and posterior), as shown in Figure 29–7.

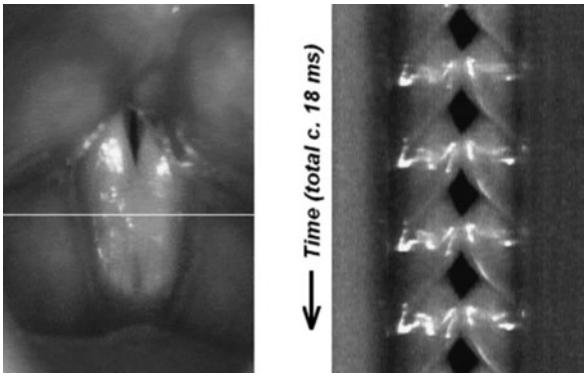
VKG is entering the clinical world, but mostly in the EU. Although it is not as intuitive as stroboscopy, it enhances understanding of vocal cord vibrations not easily captured by standard stroboscopy; hence it can be specifically useful when analyzing cases with highly perturbed signals. The new technique displaying simultaneously the two images may promote clinical adaptation of VKG.

Qiu Q, Schutte, HK. A new generation videokymography for routine clinical vocal-fold examination. *Laryngoscope* 2006;116:1824–1828 [PMID: 17003719]. (Description of simultaneous image display.)

Svec JG, Schutte HK. Videokymography: high-speed line scanning of vocal fold vibration. *J Voice* 1996;10:201–205 [PMID: 8734395]. (Principles of technique.)

Svec JG., Sram F, Schutte HK. Videokymography in voice disorders: what to look for? *Ann Otol Rhinol Laryngol* 2007;116:172–180 [PMID: 17419520]. (Discussion of clinical applications.)

Svec JG, Sram F, Schutte HK. Videokymography. In: MP Fried, A Ferlito (eds.): *The Larynx*, 3rd ed. Vol. I., pp. 253–274. San Diego, CA: Plural Publishing, 2009. (Updated information on VKG.)



▲ **Figure 29–7.** Videokymography (VKG) images representing normal healthy voice. The B&W videokymographic image (right) is obtained from the position marked by the horizontal white line in the left image and covers the total time of 40 milliseconds at the rate of 7200 images per second. These images are courtesy of Dr. Jan Švec (2010), and were obtained using a VKG camera, which displays both these images simultaneously in real time.

ELECTROGLOTTOGRAPHY

Electroglottography is another method of evaluating vocal cord vibration. This technology uses the principle of electrical impedance across tissue and open space. Electrodes are placed on the neck over the lamina of the thyroid cartilages; a weak current is passed between the electrodes, which generate an impedance curve that corresponds to the shape and nature of the vibratory cycle.

Other forms of glottographic technology include photoelectric and ultrasound glottography. A new technique of assessing vocal cord cycles based on the kymography principle has been recently introduced; however, its clinical value remains questionable at this time.

Guimaraes I, Abberton E. Fundamental frequency in speakers of Portuguese for different voice samples. *J Voice* 2005;19(4):592 [PMID: 16301105]. (This article shows usage of electroglottography to assess voice qualities across gender and age.)

Larsson H, Hertegard S, Lindestad PA, Hammarberg B. Vocal fold vibrations: high-speed imaging, kymography, and acoustic analysis: a preliminary report. *Laryngoscope* 2000;110(12): 2117 [PMID: 11129033]. (This article suggests that combined high-speed acoustic-kymographic analysis package can be helpful for specification of the terminology of voice qualities.)

Yan Y, Ahmad K, Kunduk M, Bless D. Analysis of vocal-fold vibrations from high-speed laryngeal images using a Hilbert transform-based methodology. *J Voice* 2005;19(2):161 [PMID: 15907431]. (This article assesses potential use of this tool for voice pathology analysis.)

Zagolski O, Carlson E. Electroglottographic measurements of glottal function in vocal fold paralysis in women. *Clin Otolaryngol Allied Sci* 2002;27(4):246 [PMID: 12169125]. (This article suggests that electroglottography is a suitable noninvasive tool for tracking the patients' long-term progress.)

AERODYNAMIC TESTS

The purpose of aerodynamic tests is to evaluate how air—"the voice fuel"—behaves during phonation. Aerodynamics measure subglottic and supraglottic (ie, intraoral) air pressures as well as the glottic air impedance and the type of airflow at the glottis, including the volume velocity.

Aerodynamics is important when assessing vocal cord paralysis, stenosis, webs, or patients who use their voices professionally (ie, singers). Aerodynamic tests are important when examining a voice that may have been affected by the inhalation of noxious gases or stage smoke. They are also useful when the volume of gas expired during the first second (the forced expiratory volume in the first second, or FEV_1) from the beginning of the forced vital capacity (FVC) shows deficits (eg, methacholine challenge).

Measurements of phonatory airflow are performed via pneumotachography on vocalic segments; they differ from pulmonary function studies in that airflow is measured as a function of phonation. The individual values can be fitted against expected age and gender values, with critical values for a normal population ranging from 40 to 200 mL/s. The

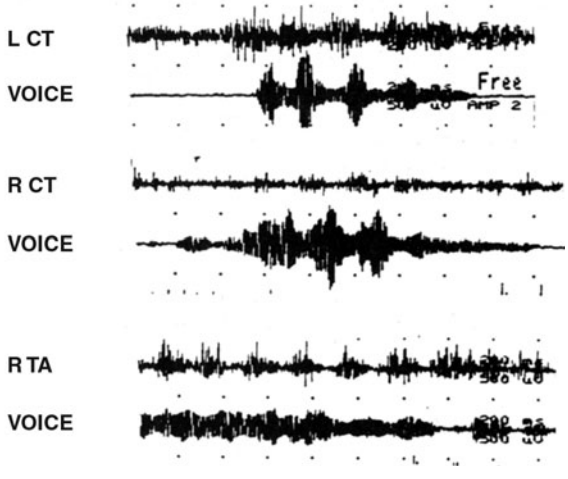
interpretation of aerodynamic tests should be conducted with caution because these tests are subject to voluntary motor responses and are affected by variations in vocal intensity and vocal register.

Granqvist S, Hertegard S, Larsson H, Sundberg J. Simultaneous analysis of vocal fold vibration and transglottal airflow: exploring a new experimental setup. *J Voice* 2003;17(3):319 [PMID: 14513955]. (This article critically reviews airflow across the glottis. The article points that relationships between these two entities is complex specifically with respect to phonation modes.)

ELECTROMYOGRAPHY

An electromyogram (EMG) examines the neuromuscular integrity of a striated muscle by recording in a visual form, an auditory form, or both the electrophysiologic properties (ie, discharges) of the muscle. These discharges provide information on the characteristics of single motor unit potential as well as on the interference pattern representing serial muscle discharges over time (Figure 29–8).

Specialized equipment is needed to conduct an EMG. Typically, either needle or hooked-wire electrodes are used. Surface electrodes can only be used to sample muscles that are close to the skin's surface (ie, the cricothyroid muscle or the extrinsic laryngeal muscles). When examining the motor unit potential, needle electrodes, preferably bipolar, should be used.



▲ **Figure 29–8.** Electromyograph (EMG) tracing. This figure shows the interference pattern representing the left cricothyroid muscle, the right cricothyroid muscle, and the right thyroarytenoid muscle. These muscles discharge over time during phonation. The EMG signals are displayed simultaneously with the acoustic signal (voice) showing a 5.5-Hz vocal tremor.

The usefulness of laryngeal EMG in diagnosing dysphonia has not been well established, including assessing unilateral or bilateral vocal cord paralysis. It is difficult at times to conclude whether the muscle is undergoing denervation or reinnervation; in this circumstance, the clinical experience of the examiner plays an important role.

Blitzer A. Laryngeal electromyography. In: Rubin JS, Sataloff RT, Korovin GS, Gould WJ, eds. *Diagnosis and Treatment of Voice Disorders*. New York, Tokyo: Ikagu-Shoin, 1995.

Dedo HH, Hall WN. Electrodes in laryngeal electromyography: reliability comparison. *Ann Otol Rhinol Laryngol* 1969;78:172 [PMID: 5763185]. (Article discusses that using unipolar electrodes will provide word information.)

Jacobs IN, Finkel RS. Laryngeal electromyography in the management of vocal cord mobility problems in children. *Laryngoscope* 2002;112:1243 [PMID: 12169907]. (Evaluates the efficacy and usefulness of electromyography, with a specific focus on the pediatric patient as well as in determining the differential diagnosis of vocal cord paralysis versus vocal cord fixation.)

Shipp T, Izdebski K, Reed C, Morrisey P. Intrinsic laryngeal muscle activity in a spastic dysphonia patient. *J Speech Hearing Dis* 1985;50:54 [PMID: 3974213]. (Description of electromyography activity from intrinsic laryngeal muscles in adductor spasmodic dysphoria demonstrated normal morphology of recurrent laryngeal nerves and intrinsic laryngeal muscles and suggested a neurologic cause for this disorder.)

Sittel C, Stennert E, Thrumfart WF, Dapunt U, Eckel HE. Prognostic value of laryngeal electromyography in vocal fold paralysis. *Arch Otolaryngol Head Neck Surg* 2001;127:155 [PMID: 11177032]. (This article analyzes the value of electromyography in predicting vocal function recovery from acute neurogenic injuries [ie, paralysis] of the vocal cords.)

Woo P. Laryngeal electromyography is a cost-effective clinically useful tool in the evaluation of vocal fold function. *Arch Otolaryngol Head Neck Surg* 1998;124:471 [PMID: 9559701]. (Outlines the clinical usefulness of electromyography in evaluating various vocal cord dysfunctions in the absence of visible organic mucosal lesions.)

Yin SS, Quu WW, Stucker FJ. Major patterns of laryngeal electromyography and their clinical applications. *Laryngoscope* 1997;107:126 [PMID: 9001277]. (Presents detailed electromyographic [EMG] techniques and describes physiologic tasks needed to study the actions of the ILM by EMG in various groups of dysphonic patterns.)

SPECIAL STUDIES

When studying complex voice problems, specially tailored voice tests often need to be designed or conducted. These special tests include acoustic, physiologic, and radiographic studies.

ACOUSTIC TESTS

Special acoustic tests include the voice load test, auditory masking, voice performance tests, phonetically balanced tests, delayed auditory feedback, and the use of an electrolarynx. These tests are useful when determining the differential diagnoses of psychogenic dysphonias.

Izdebski K. The voice load test: an objective acoustic test to assess voice quality as a factor of voice usage over time. In: *Proceedings of the 2nd World Voice Congress and 5th International Symposium on Phonosurgery*. Sao Paulo, Brazil, 1999.

PHYSIOLOGIC TESTS

Special physiologic tests include aerodynamic tests, manual pressure tests, and temporary denervation procedures. An upper esophageal insufflation test is used to test failures in acquiring voice after tracheal puncture procedures. Because sudden change in aerodynamics affects the glottic biomechanics, as does inhaling gases of other density than air (eg, helium), such tests are useful when examining a suspected psychogenic voice disorder.

The manual pressure test, also known as the laryngeal circumference pressure test, is useful in testing for muscular tension dysphonia as well as psychogenic dysphonia. It is also useful in assessing the viability of medialization procedures. Similarly, the head-positioning test, which can cause changes in vocal cord approximation, can be used as a predictor of the correction potential (therapeutic, surgical, or both) of breathy dysphonia. A neck pressure test can also be used to test failures in acquiring voice after esophageal injection (eg, following total laryngectomy).

An array of nerve blocks, as well as the so-called oral lidocaine bath, can be very useful in the differential diagnosis of psychogenic dysphonia. In addition, an RLN block is often crucial in testing for adductor spasmodic dysphonia and vocal tremor. A temporary block of the SLNs can be used in testing for abductor spasmodic dysphonia and in persistent postpubertal infantile dysphonia. The neural block test can also be used to test problems with air insufflation in patients after a total laryngectomy.

Radiologic PhFS include a videofluoroscopic exam of a nonfunctional phonatory segment after total laryngectomy. It also appears that neuroradiographic studies that use enhanced viewing to reveal fat deposits in vocal cords may be useful in studying nonmobile vocal cords. With additional testing, this technique may prove to be excellent in the differential diagnosis of voice disorders due to vocal cord paralysis or due to mechanical problems (eg, arytenoid joint dislocation or vocal cord fixation, or ankylosis).

Izdebski K, Dedo HH. Selecting the side of the RLN section for spastic dysphonia. *Otolaryngol Head Neck Surg* 1981;89:423.

Izdebski K, Manace ED, Skiljo-Haris J. The challenge of determining work-related voice and speech disabilities in California. In: Dejonkere PH, ed. *Occupational Voice: Care and Cure*. Hague, Netherlands: Kugler Publishers, 2001.

Izdebski K, Ward R. Differential diagnosis of ADD-ABDuctor spasmodic dysphonia, vocal tremor and ventricular dysphonia by auditory and phonoscopic observations. In: Clemente M, ed. *Voice Update, International Congress Series*. The Hague, Netherlands: Elsevier, 1997.

Shipp T, Izdebski K, Morrisey P. Physiologic stages of vocal reaction times. *J Speech Hear Res* 1984;27:14 [PMID: 6330455]. (Describes the cortical and mechanical muscular speeds with which humans process and execute sensory motor processes to initiate phonation.)

Benign Laryngeal Lesions

30

Michael J. Wareing, MBBS, BSc, FRCS(ORL-HNS),
Richard Millard, MBBS, MA, DLO, &
Seema Yalamanchili, MA

The human larynx plays a pivotal role in airway protection, respiration, and phonation. Most patients with benign laryngeal disorders present with dysphonia. These disorders are particularly prevalent in individuals who use their voices professionally. Malignant neoplastic disease should be excluded as an underlying cause of voice problems: Every patient who presents with dysphonia should undergo a thorough head and neck examination. Once it is established that there is no evidence of malignancy, patients can be treated appropriately, ideally within a voice clinic. A properly equipped voice clinic must have access to video-laryngeostroboscopy and be conducted with a suitably qualified speech therapist.

The diagnosis should include a thorough appreciation of the patient's lifestyle and occupational habits as well as a detailed examination of the vocal folds including stroboscopy. Most benign laryngeal lesions are treatable with a combination of surgery and speech therapy, but measures to prevent the recurrence of disease by instigating and maintaining lifestyle changes are also necessary.

ANATOMY & PHYSIOLOGY

The larynx consists of a cartilaginous framework comprising the single thyroid, cricoid, and epiglottic cartilages and the paired arytenoid, corniculate, and cuneiform cartilages. The larynx is suspended from the hyoid bone by the thyrohyoid membrane. The vocal folds run from the angle formed by the thyroid lamina anteriorly to the vocal process of the arytenoid cartilages posteriorly. Alteration in the position and length of the vocal folds is primarily the result of movement of the synovial cricoarytenoid joints, with a contribution from movement of the cricothyroid joints. Above the vocal folds run the false cords, formed by the medial border of the aryepiglottic folds. These are separated from the vocal folds by horizontal sinus known as the laryngeal ventricle, which contains numerous mucin-secreting glands.

The vocal folds are covered with a stratified squamous epithelium that has up to 20 layers; this epithelium covers the lamina propria, which has three layers, beneath which lies the vocal ligament and vocalis muscle. Loose collagen cross-linkages between the epithelium and the superior layer of the lamina propria (ie, Reinke space) allow oscillation of the mucosal wave during phonation as the epithelium is able to glide over Reinke space.

Sound is produced following creation of subglottic pressure as expiration occurs against a closed glottis. As air passes between the adducted vocal folds, the Bernoulli effect causes vibration of the mucosa of the vocal folds, producing sound. Abnormalities preventing full adduction of the vocal folds or directly interfering in vibration of the mucosa produce dysphonia.

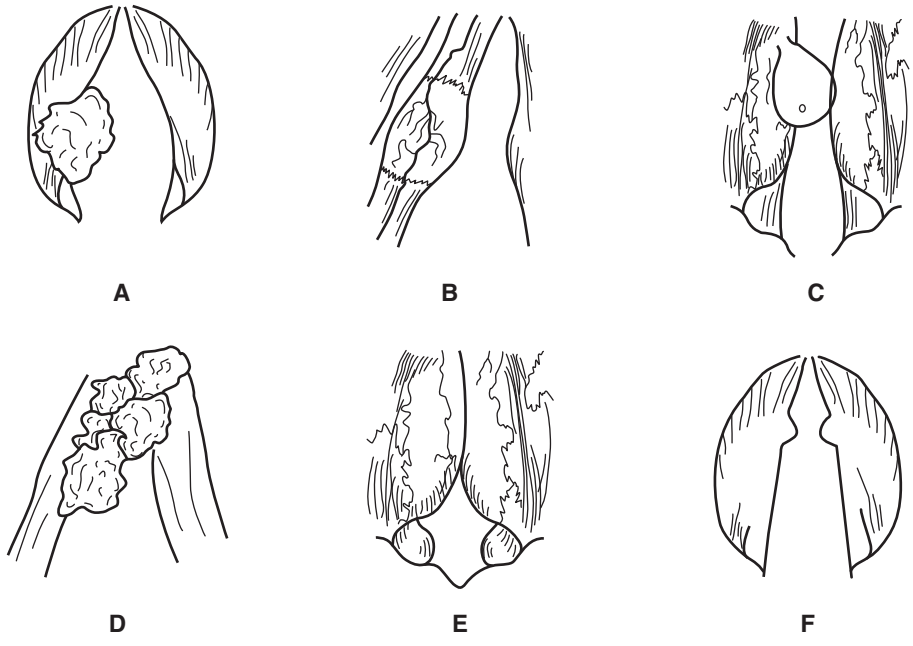
Rosen AC, Murray T. Nomenclature of voice disorders and vocal pathology. *Otolaryngol Clin North Am* 2000;33:1035 [PMID: 10986070]. (Classification of the pathology of vocal cord lesions and voice disorders.)

CLINICAL ASSESSMENT

PATIENT HISTORY

The onset, duration, and progression of any voice change should be ascertained. Any preceding upper respiratory tract infections, direct or vocal trauma, or endotracheal intubation should be noted. Persistent, progressive dysphonia in a smoker must always raise the possibility of malignant disease, particularly if associated with dysphagia or odynophagia.

A key consideration is the patient's age. Adults have a greater incidence of malignant disease, whereas in children who are hoarse the chief differential diagnosis is between vocal cord nodules and juvenile papillomatosis. An occupational history is of particular relevance because the voice disorder may be secondary to the pattern of voice use or working conditions. A history of previous surgery is



▲ **Figure 30–1.** Benign laryngeal lesions. **(A)** Vocal cord granuloma, **(B)** intracordal cyst, **(C)** pedunculated vocal cord polyp, **(D)** laryngeal papillomatosis, **(E)** Reinke edema, and **(F)** vocal cord nodules.

essential, as is documenting any previous laryngeal treatment or speech therapy. Additional patient history questions should include (1) smoking habits; (2) fluid intake, including caffeine and alcohol intake; and (3) symptoms of nasal allergy or sinusitis. Direct questioning should assess the presence of symptoms suggestive of gastroesophageal (or laryngopharyngeal) reflux, and hypothyroidism.

PATIENT EXAMINATION

The patient examination should include a full ear, nose, and throat (ENT) exam, including a conventional inspection of the larynx followed by a more detailed evaluation of vocal fold movement using video stroboscopy.

A full ENT examination is performed, including mirror indirect laryngoscopy. This guides the chances of successfully performing rigid laryngoscopy and often makes the diagnosis. The two alternative methods, which allow photodocumentation and a more leisurely view, are flexible nasolaryngoscopy, or rigid endoscopy, using a 70° or a 90° endoscope. In both techniques, stroboscopic light may be used to identify defects of the mucosal wave.

Nasolaryngoscopy allows thorough inspection of the nose, postnasal space, pharynx, and larynx in a physiologic position. Rigid endoscopy, conducted via the oropharynx, offers the most detailed view of the larynx in the compliant patient. Both methods can use video systems for photodocumentation: Visualization of the larynx by patients significantly improves understanding and compliance with speech therapy.

Figure 30–1 illustrates the characteristic appearances of some common benign laryngeal lesions.

VIDEOSTROBOSCOPY

Videostroboscopy is an important tool in monitoring rehabilitation and providing feedback during speech therapy. It is also useful in the diagnosis of lesions such as intracordal cysts and in differentiating these lesions from vocal cord nodules.

Stroboscopic examination allows visualization of the mucosal wave occurring at the medial edge of the vocal fold, the appearance being one of a "slow motion" film. This appearance is created by the flickering stroboscopic light illuminating consecutive mucosal waves at a similar point in the wave form. The frequency of stroboscopic illumination differs slightly from the frequency of the mucosal wave, creating the perception of a slowly moving mucosal wave. This effect is lost if pathology results in a mucosal wave lacking a consistent periodicity. High-speed video recording now allows direct visualization of the mucosal wave, rather than the perception of visualizing the wave created by stroboscopy. This technique has some advantages; however, it requires greatly slowed playback and therefore does not allow "live" images, which are particularly helpful in patients' understanding of their pathology.

Hertegård-Stellan. What have we learned about laryngeal physiology from high-speed digital videoendoscopy? *Curr Opin Otolaryngol Head Neck Surg* 2005;13:152 [PMID: 15908812].
Sataloff RT. Evaluation of professional singers. *Otolaryngol Clin North Am* 2000;33:923 [PMID: 10984762]. (Summary article of ENT history and examination in singers.)
Simpson CB, Fleming DJ. Medical and vocal history in the evaluation of dysphonia. *Otolaryngol Clin North Am* 2000;33:719 [PMID: 10918656]. (Review of history taking in voice disorders.)

COMMON LARYNGEAL LESIONS

PHONOTRAUMA

Pathogenesis

Most vocal cord nodules, polyps, and the condition known as Reinke edema arise as a result of repetitive trauma to the vocal cords, which is known as *phonotrauma*, and is associated with a local inflammatory response. Shear forces occur during phonation at the area of maximal wave amplitude, which is the border of the anterior and middle third of the vocal fold. Hence, vocal pathology secondary to phonotrauma tends to occur at this site.

Dikkers FG, Nikkels PG. Lamina propria of the mucosa of benign lesions of the vocal cords. *Laryngoscope* 1999;109:1684 [PMID: 10522943]. (Study demonstrating correlation between duration and pattern of phonotrauma and the histopathology of benign vocal cord lesions.)
Verdolini K, Rosen CA, Branski RC, Hebda PA. Shifts in biochemical markers associated with wound healing in laryngeal secretions following phonotrauma: a preliminary study. *Ann Otol Rhinol Laryngol* 2003;112(12):1021 [PMID: 14703104]. (Study demonstrating elevation of markers of acute inflammation in the vocal folds following prolonged voice use.)

VOCAL CORD NODULES

ESSENTIALS OF DIAGNOSIS

- Usually affects children or individuals who use their voices professionally.
- History of voice abuse common, such as frequent shouting in a young child.
- Bilateral, pale lesions at the junction of the anterior one third and posterior two thirds of the vocal cords.

General Considerations

Vocal cord nodules are the most common cause of persistent dysphonia in children. They are also a frequent cause of deterioration in the voice quality of individuals who use their voices professionally, particularly singers; these nodules are commonly referred to as "singers' nodules." Treatment strategies should be conservative; speech therapy is the primary treatment. The patient is taught how to use the voice appropriately, which often promotes regression of the vocal cord nodules.

Clinical Findings

Laryngoscopy clearly shows the presence of small, well-defined vocal cord lesions. These lesions are distinguishable from the normal vocal fold by their whitish hue and are most commonly found at the junction of the anterior third and posterior two thirds of the vocal fold. They are bilateral, though often asymmetric.

Treatment

A. Speech Therapy

Speech therapy should be used as a first-line treatment. It is the mainstay of treatment in both children and adults. Photodocumentation of the nodules in voice clinic indicates the treatment progress and aids patient compliance during speech therapy.

B. Microlaryngoscopy

Microlaryngoscopy should be performed under the following circumstances: (1) vocal cord nodules are suspected in a child, but the age or noncompliance of the patient prevents examination; and (2) in adults, either when microsurgical excision of the nodules is considered or when the diagnosis is not clear. Nodules may be excised using appropriate microsurgical instruments, or vaporized using a pulsed CO_2 laser.

Benninger MS. Microdissection or microspot CO_2 laser for limited vocal fold benign lesions: a prospective randomized trial. *Laryngoscope* 2000;110:1 [PMID: 10678578]. (Study establishing the efficacy of the CO_2 laser in the treatment of superficial benign vocal fold lesions.)
Kunduk M, Mcwhorter AJ. True vocal fold nodules: the role of differential diagnosis. *Curr Opin Otolaryngol Head Neck Surg* 2009;17:449–452. (A current update of diagnosis and treatment of nodules.)

VOCAL CORD POLYPS

ESSENTIALS OF DIAGNOSIS

- Usually unilateral, pedunculated lesions.
- Associated with smoking and voice abuse.
- Located throughout the glottis, particularly between the anterior and middle thirds of the vocal folds.

General Considerations

Vocal cord polyps are most commonly found in men with a history of voice abuse and heavy smoking. The treatment is most often surgical to confirm the diagnosis, exclude any coexisting malignant neoplasms, and provide resolution. Conservative voice therapy is often not successful.

Clinical Findings

Polyps are pedunculated, unilateral lesions that are morphologically similar to the laryngeal epithelium. They often occur on the true vocal folds and may have noticeable vascular markings. They generally occur at the point of maximal vibration, the middle of the true junction of the anterior and middle thirds of the vocal fold, in contrast to vocal process granulomas.

Treatment

The treatment involves a microlaryngoscopic examination of the larynx plus excision of the polyp both to confirm the diagnosis and to exclude any other coexistent pathology. A large polyp may conceal an occult, early laryngeal squamous cell carcinoma. Excision is performed using appropriate microsurgical instruments, or laser. Smoking and vocal abuse should also be addressed.

VOCAL PROCESS GRANULOMAS (INTUBATION GRANULOMA)

ESSENTIALS OF DIAGNOSIS

- Arise posteriorly, adjacent to the vocal process.
- Frequent history of intubation trauma.

General Considerations

Vocal process granulomas are often associated with endotracheal intubation. There is an association with gastroesophageal reflux.

Clinical Findings

Patients present with dysphonia and a combination of other symptoms, including odynophagia, cough, and globus symptoms. Vocal process granulomas are usually unilateral and are related to the vocal processes of arytenoid cartilage with an underlying perichondritis. Forceful glottic closure further traumatizes the lesion and is likely to be a factor in its failure to resolve.

Treatment

The initial focus of treatment should be on conservative voice therapy, combined with aggressive antireflux therapy. Antibiotics and systemic steroids may be of use. Microlaryngoscopy is rarely required to exclude malignancy. Recurrence after surgical excision is common; the incidence may be reduced by the concomitant use of botulinum toxin to paralyze the affected hemilarynx and hence prevent further vocal process trauma.

REINKE EDEMA

ESSENTIALS OF DIAGNOSIS

- Strong association with cigarette smoking and heavy voice use.
- Diffuse edematous changes of the vocal cords.
- Usually bilateral.

General Considerations

Although a definite mechanism of injury has not been identified, there is a very strong association of cigarette smoking with the development of Reinke edema. The distinguishing feature of this condition is the diffuse nature of the swelling, which is an accumulation of fluid in the superficial layer of the lamina propria of the vocal fold.

Clinical Findings

Patients present with diffuse swelling of the vocal cords, which is usually bilateral. The cords feel boggy when manipulated during microlaryngoscopy, and the swelling can be rolled beneath the instruments.

Treatment

Smoking cessation is the key to resolving Reinke edema. In mild cases, speech therapy may also prevent the need for surgical treatment. However, severe Reinke edema, which is intractable to speech therapy, may have to be treated surgically. Surgical measures involve making a lateral incision on the superior aspect of the vocal fold and extravasating the fluid before carefully replacing the mucosa. Trimming the excess mucosa may be required, but care must be taken not to injure the underlying vocal ligament.

LARYNGEAL CYSTS

Mucous glands are found throughout the larynx, with the exception of the medial edge of the vocal cord, and associated cysts may therefore occur also throughout the larynx.

Their presentation and treatment are dictated primarily by their site; therefore, they are dealt with here on this basis.

1. Intracordal Cysts

ESSENTIALS OF DIAGNOSIS

- Often found within the middle third of the vocal cords.
- Unilateral, associated small area of hyperkeratosis on opposite cord.
- Do not respond to speech therapy.

General Considerations

Intracordal cysts may be simple mucous retention cysts or epidermoid cysts containing keratin.

Clinical Findings

Laryngoscopy reveals a unilateral cyst, usually of the middle third of the vocal cord with a corresponding area of hyperkeratosis on the opposite cord. Stroboscopy reveals loss of the mucosal wave at the site of the lesion.

Treatment

Intracordal cysts do not respond to voice therapy and should be excised with phonosurgical instruments, using a local flap technique.

2. Saccular Cysts

ESSENTIALS OF DIAGNOSIS

- May be congenital or acquired.
- Adults generally present with voice change.
- Children commonly present with airway compromise.
- Unilateral supraglottic mass, overlying mucosa unremarkable.

General Considerations

The laryngeal saccule arises as a diverticulum from the anterior end of the laryngeal ventricle. It extends upward between the false vocal fold and the inner surface of the thyroid cartilage and contains mucus-secreting glands. A saccular cyst occurs as a result of obstruction of these glands, which may be secondary to a congenital anomaly or acquired.

Clinical Findings

Examination reveals expansion of the aryepiglottic fold by the cyst within it, which may extend into the neck through the thyrohyoid membrane. Computed tomography (CT) imaging demonstrates a cyst expanding the supraglottis; the absence of air within the lesion distinguishes it from a laryngocele. Mesodermal tissue may be apparent in the wall of congenital saccular cysts and may influence the surgical approach.

Treatment

Most saccular cysts may be managed endoscopically, either by marsupialization or excision, generally with the aid of a CO_2 laser. Lesions extending beyond the larynx and congenital cysts containing mesodermal elements are optimally managed by a transcervical approach. The excised cyst should undergo histologic examination. Cysts displaying oncocytic metaplasia (oncocytic cysts) are more often multiple and more prone to recurrence.

PAPILLOMATOSIS

ESSENTIALS OF DIAGNOSIS

- Patient age at onset is usually 2–4 years.
- Rare after age 40.
- Multiple warty lesions of "true" and "false" vocal cords.

General Considerations

Recurrent respiratory papillomatosis (RRP) is characterized by the development of exophytic warty lesions, primarily within the larynx, but which may be found in the nose, pharynx, and trachea. The condition is benign but associated with significant morbidity and mortality.

There is a bimodal distribution; juvenile-onset RRP is generally diagnosed between the ages of 2 and 4 years and is more aggressive than adult-onset disease, which peaks in the third decade.

Pathogenesis

RRP is caused by human papilloma virus (HPV), subtypes 6 and 11, and rarely by subtype 16. HPV 6 and 11 are also the most common causes of genital papillomatosis, and transmission from the genital tract is believed to be the primary cause of RRP.

Vertical transmission of the virus from mother to child occurs either as ascending uterine infection or through direct contact in the birth canal. However, the risk of a child

developing RRP after vaginal delivery in the presence of a condyloma acuminatum is estimated at only 1 in 400. The factors dictating susceptibility remain under investigation.

Clinical Findings

Papillomas typically appear as multiple, friable, irregular warty growths in the larynx. These lesions particularly affect the "true" and "false" vocal cords, but are often found at areas of constriction in the upper aerodigestive tract where there is increased air turbulence, drying, and cooling of mucosa, and at the change from ciliary to squamous epithelium.

Presentation depends on the site of the lesion. Patients with glottic lesions present with dysphonia; those with supraglottic lesions may present with stridor.

Treatment

HPV cannot be eradicated from the larynx. Even after spontaneous remission, HPV DNA can be detected in otherwise normal mucosa. The aim of treatment is therefore to remove symptomatic lesions with minimal morbidity. Suitable techniques include CO_2 laser resection, cold steel dissection, or use of the laryngeal microdebrider. Tracheostomy should be avoided and is associated with distal airway involvement. Adjuvant treatments include intralaryngeal injection of cidofovir (Vistide), which is an off-label use with no conclusive evidence of efficacy, although an excellent response has been noted in some patients.

A recent licensing of prophylactic HPV vaccines may well have a role in prevention of RRP.

Prognosis

Spontaneous remission does occur, but recurrence can arise many years later. There is a small risk of malignant change.

Derkay CS, Darrow DH. Recurrent respiratory papillomatosis. *Ann Otol Rhinol Laryngol* 2006;115:1 [PMID: 16466093]. (Summary of the current management of respiratory papillomatosis.)

Forte V, Fuoco G, James A. A new classification system for congenital laryngeal cysts. *Laryngoscope* 2004;114:1123 [PMID: 15179225]. (Classification for laryngeal cysts that correlates with management.)

Hogikyan ND, Bastian RW. Endoscopic CO_2 laser excision of large or recurrent laryngeal saccular cysts in adults. *Laryngoscope* 1997;107(2):260 [PMID: 9023253]. (Review of laser excision of saccular cysts.)

Orloff LA, Goldman SN. Vocal fold granuloma: successful treatment with botulinum toxin. *Otolaryngol Head Neck Surg* 1999;121(4):410 [PMID: 10504597].

Shehab N, Sweet BV, Hogikyan ND. Cidofovir for the treatment of recurrent respiratory papillomatosis: a review of the literature. *Pharmacotherapy* 2005;25:977 [PMID: 16006276]. (Review of cidofovir in recurrent respiratory papillomatosis.)

Steinbrook R. The potential of human papillomavirus vaccines. *N Engl J Med* 2006;354:1109 [PMID: 16540608]. (Review of human papilloma virus vaccination.)

Freed GL, Derkay CS. Prevention of recurrent respiratory papillomatosis: role of HPV vaccination. *Int J Paediatr Otorhinolaryngol* 2006;70:1799–1803.

RARE LARYNGEAL LESIONS

CHONDROMAS

Chondromas are benign tumors of the laryngeal cartilages that predominantly affect men in the fourth to sixth decades. Patients present with a slowly progressive dysphonia, dyspnea, and dysphagia; therefore, these benign growths can mimic malignant neoplasms in their presentation. Chondromas commonly appear as smooth, firm lesions of the subglottic larynx or any of the other cartilages. Occasionally, they present as a lump in the neck.

CT scanning is useful in delineating the extent of the neoplasm, whereas CO_2 laser is useful in performing a biopsy. However, the definitive treatment relies on total surgical excision of the tumor through an open approach. Endoscopic excision is reserved for small tumors.

NEUROGENIC NEOPLASMS

Neurogenic neoplasms are rare tumors and are usually either schwannomas or neurofibromas. It has now been confirmed that granular cell neoplasms are also of nerve sheath origin.

Schwannomas originate from Schwann cells that cover the nerve fibers outside the central nervous system. These lesions are solitary, encapsulated neoplasms that are benign and slow growing, although they can undergo sarcomatous change. **Neurofibromas** are benign proliferations of nerve fibers and are often multiple (eg, in von Recklinghausen disease). In contrast to schwannomas, they are not encapsulated.

Because neurogenic neoplasms are slow growing, patients present with voice change, throat clearing, and the sensation of a lump in the throat. Cough and respiratory compromise follow.

Neurogenic neoplasms are submucosal and smooth and are often located in the aryepiglottic folds. CT scans can accurately define the extent of the lesion prior to treatment. Small tumors may be resected endoscopically, but larger tumors require an open approach.

AMYLOIDOSIS

The larynx is the most common site in the respiratory tract for amyloid deposition. Patient presentation is characterized by the presence of a submucosal mass, which may arise anywhere in the larynx and may impair vocal cord mobility.

The diagnosis is confirmed by the presence of "apple green" birefringence seen with a polarizing microscope after staining with Congo red dye. Treatment involves local

resection, usually accomplished endoscopically. Laryngeal amyloid is usually primary and localized, but has been associated with cardiac involvement and thorough systemic evaluation is essential.

SARCOIDOSIS

One to five percent of patients with sarcoidosis present with lesions within the larynx. The epiglottis is the most common site of involvement. Small, noncaseating granulomas are present on histology, but other granulomatous conditions such as fungal or mycobacterial infections should be ruled out. Spontaneous remission occurs, and treatment is therefore symptomatic, with endoscopic resection when required and systemic steroids in certain cases.

WEGENER GRANULOMATOSIS

Wegener granulomatosis is a multisystem autoimmune disease that may involve necrotizing granulomata of the respiratory tract, disseminated vasculitis, and glomerulonephritis. Focal disease may arise throughout the laryngotracheobronchial tree, but is particularly associated with the immediate subglottic region. Presentation is usually with obstructive symptoms, although dysphonia may be present. Systemic disease is treated with immunosuppressive agents. Local disease without systemic involvement is optimally managed with local treatment, including intralesional corticosteroids.

Dean CM, Sataloff RT, Hawkshaw MJ, Pritikin E. Laryngeal sarcoidosis. *J Voice* 2002;16:283 [PMID: 12150382]. (Etiology, presentation, and management of laryngeal sarcoidosis.)

Franco RAJ, Singh B, Har-El G. Laryngeal chondroma. *J Voice* 2002;16:92 [PMID: 12008653]. (Summary of presentation, investigation, and management of laryngeal chondroma.)

Hoffman GS, Thomas-Golbanov CK, Chan J, Akst LM, Eliachar I. Treatment of subglottic stenosis, due to Wegener's granulomatosis, with intralesional corticosteroids and dilation. *J Rheumatol* 2003;30:1017 [PMID: 12734898]. (Discussion of intralesional corticosteroid in Wegener granulomatosis.)

Erickson VR, Hwang PH. Wegeners granulomtosis: current trends in diagnosis and management. *Curr Opin Otolaryngol Head Neck Surg* 2007;15:170–176.

Pribitkin E, Friedman O, O'Hara B et al. Amyloidosis of the upper aerodigestive tract. *Laryngoscope* 2003;113:2095 [PMID: 14660909]. (Review of laryngeal amyloidosis.)

We would like to acknowledge R Gareth Rowlands FRCS (ORL-HNS) for his contribution to this chapter in the previous editions of CDT.

31 Malignant Laryngeal Lesions

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General Considerations

Each year, 11,000 new cases of larynx cancer will be diagnosed in the United States (1% of new cancer diagnoses), and approximately one-third of these patients will die of their disease. The current male-to-female ratio for larynx cancer is 4:1, but the relative percentage of women with this, as with other smoking-related illness, has been on the rise. Larynx cancer is most prevalent in the sixth and seventh decades of life and is more prevalent among lower socioeconomic groups, for whom it is often not diagnosed until more advanced stages. More than 90% of larynx cancer is squamous cell carcinoma (SCC) and is directly linked to tobacco and excessive alcohol use. Because of the complex and multifaceted nature of this disease, treatment planning is best delivered through a multidisciplinary tumor board format.

Anatomy

The larynx functions not only to produce voice but also to divide and protect the respiratory tract from the digestive tract. It acts as a sphincter during deglutition, protecting against the penetration of bypassing food by closing off the trachea at two sites: the epiglottic flap and the closure of the vocal cords. The larynx consists of a framework of cartilages connected by ligaments, membranes, and muscles covered by a respiratory and stratified squamous mucosal epithelium (Figure 31–1).

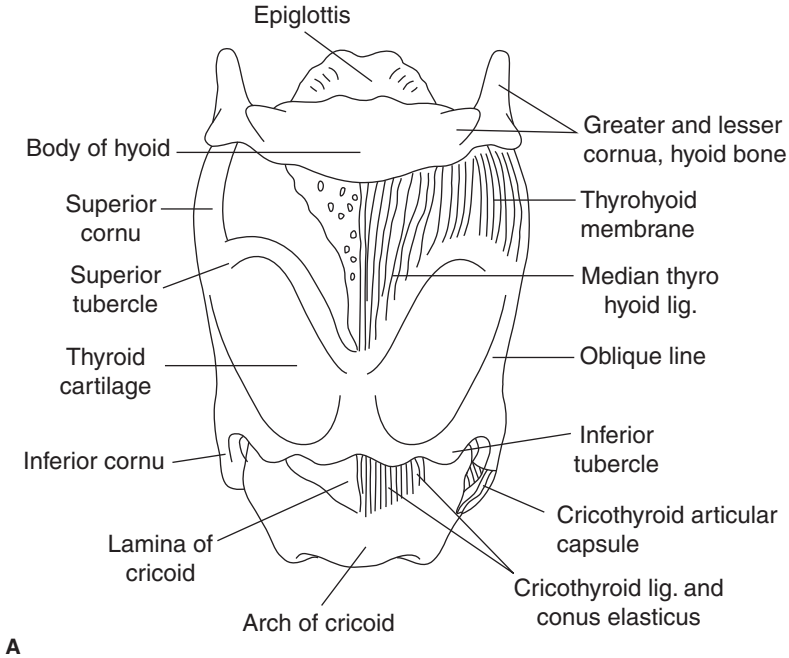
The larynx can be divided into three parts: the supraglottis, the glottis, and the subglottis (Figure 31–2). The supraglottic larynx extends from the tip of the epiglottis and vallecula superiorly to the ventricle and undersurface of the "false" cords inferiorly; it includes the arytenoid cartilages, the aryepiglottic folds, the false vocal cords, and the epiglottis. The glottic larynx encompasses the "true" vocal cords, extending from the ventricle between the true and false cords to 0.5 cm below the free edge of the true cords, including the anterior commissure and interarytenoid area. The subglottic larynx extends from the inferior extent of the glottis to the inferior edge of the cricoid cartilage.

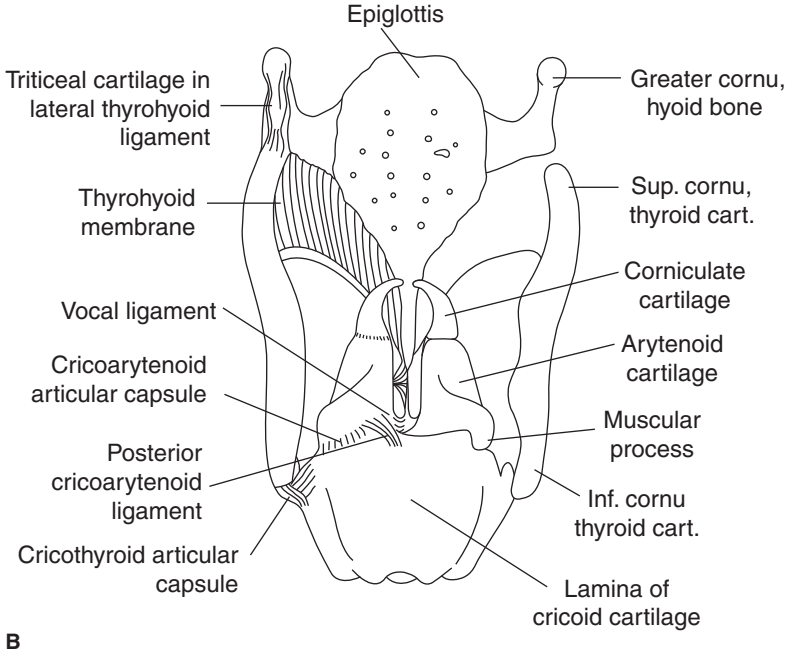
Understanding the embryologic origin of these regions of the larynx helps to explain the difference in clinical behavior between cancers arising from these laryngeal subsites. The supraglottis derives from the midline buccopharyngeal primordium and branchial arches 3 and 4 with rich bilateral lymphatics. The glottis, on the other hand, forms from the midline fusion of lateral structures derived from the tracheobronchial primordium and arches 4, 5, and 6. There is a paucity of lymphatics and, compared with supraglottic primary neoplasms, malignant glottic tumors have less of a tendency for bilateral regional lymphatic spread and remain confined to the glottis for longer periods of time.

Fibroelastic membranes and ligaments further divide the larynx into the preepiglottic and paraglottic spaces. These structures, including the conus elasticus, the quadrangular and thyrohyoid membranes, and the hyoepiglottic ligament, act as barriers to the spread of tumor (Figure 31–3). The thyroid and cricoid cartilages and their perichondrium are further barriers to tumor spread. The anterior commissure tendon (Broyle's ligament) and thyroepiglottic ligaments are not effective barriers to tumor spread, and tumors involving the anterior commissure are more likely to have direct regional spread.

The muscles of the larynx are divided into intrinsic and extrinsic groups. The intrinsic muscles are those of the vocal cords and cartilages contained within the larynx itself. The extrinsic muscles, the strap muscles and constrictors, help with laryngeal elevation and pharyngeal constriction. Innervation of the intrinsic muscles is from the recurrent laryngeal branches of the vagus nerve on both sides. Arterial blood supply is from the external carotid artery and off the thyrocervical trunk via the superior and inferior thyroid arteries. Venous drainage is into the internal jugular vein. Lymphatic drainage is to levels II, III, and IV, as well as sometimes to level VI of the neck.

Kirchner JA. One hundred laryngeal cancers studied by serial section. *Ann Otol.* 1969;78:689 [PMID: 5799397]. (Classic paper studying anatomic and histological cross section of larynx cancers.)



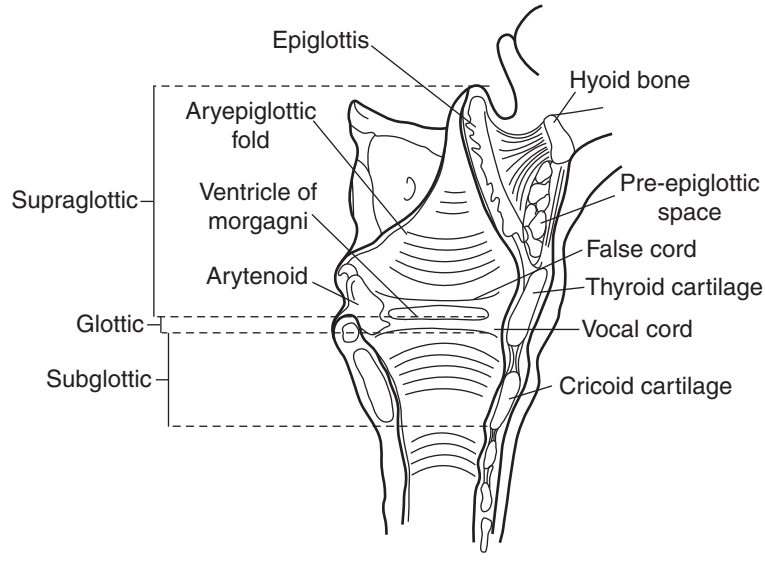


▲ **Figure 31–1.** Cartilages and ligaments of the larynx. **(A)** Frontal view and **(B)** posterior view. (Adapted, with permission, from Hollinshead WH. *Anatomy for Surgeons: The Head and Neck,* 3rd ed. JB Lippincott, 1982.)

Pathogenesis

More than 90% of patients with larynx cancer have a history of heavy tobacco and alcohol use. Cigarette smoke, in particular, is a risk factor for cancer of the larynx. The combination of smoking and alcohol use has a more than additive carcinogenic effect on the larynx.

Other risk factors have been identified. Laryngeal infection with the human papillomavirus (HPV) results in laryngeal papillomatosis, which is usually benign, but subtypes 16 and 18 are known to degenerate into SCC. Gastroesophageal reflux has been implicated; however, a causal relationship with laryngeal cancer is still uncertain, although therapies



▲ **Figure 31–2.** The supraglottic, glottic, and subglottic anatomic subdivisions of the larynx. (Adapted, with permission, from Bailey BJ (ed): *Head and Neck Surgery—Otolaryngology,* 3rd ed. Lippincott Williams & Wilkins, 2001.)

directed at suppressing acid appear to decrease the recurrence of laryngeal cancer. Various occupational exposures and toxic inhalations (such as asbestos and mustard gas), nutritional deficiencies, and previous neck irradiation have all been linked to larynx cancer as well.

Increasingly, molecular and genetic markers of malignant potential, degeneration, and metastasis are being identified, unlocking the genetic causes of larynx cancer. Attention is being paid to predictors of clinical outcome and the response to specific therapy. Once these pathways are fully understood, gene therapy and other novel therapeutic approaches can be developed. Genes and gene products being investigated for their link to larynx cancer include *p53*, the Bcl-2 family of genes, and other markers of apoptosis, proliferating cell nuclear antigen (PCNA), Ki67, cyclin D1, the *ras* gene and other oncogenes, tumor suppressor genes, and the loss of heterozygosity and changes in the DNA content of tumors.

Bradford CR. Predictive factors in head and neck cancer *Hematol Oncol Clin North Am*. 1999;13(4):777 [PMID: 10494513]. (Review of molecular and genetic predictive factors for head and neck cancer, with a focus on selecting patients for specific or adjuvant therapies.)

Bradford CR, Wolf GT, Carey TE et al. Predictive markers for response to chemotherapy, organ preservation, and survival in patients with advanced laryngeal carcinoma. *Otolaryngol Head Neck Surg*. 1999;121(5):534 [PMID: 10547465]. (The overexpression of p53 and elevated PCNA as well as the T-stage predicted successful organ preservation in the VA Larynx Trial.)

Kreimer AR, et al. Human papillomavirus types in head and neck squamous cell carcinomas worldwide: A systemic review. *Cancer Epidemiol Biomarkers Prev*. 2005;14(2):467 [PMID: 15734974]. (Review of the relationship between the different subtypes of human papillomavirus and head and neck cancers.)

Qadeer MA, Colablanchi N, Strome M et al. Gastroesophageal reflux and laryngeal cancer: Causation or association? A critical review. *Am J Otolaryngol*. 2006;27(2):119 [PMID: 16500476]. (A look at the literature on the relationship between gastroesophageal reflux disease and laryngeal cancer.)

Qadeer MA, Lopez R, Wood BG et al. Does acid suppressive therapy reduce the risk of laryngeal cancer recurrence? *Laryngoscope*. 2005;115(10):1877 [PMID: 16222214]. (Study to determine the effects of gastroesophageal reflux disease and acid-suppressive therapy on recurrence of laryngeal cancers after larynx-preserving therapies.)

Staton J et al. Factors predictive of poor functional outcome after chemoradiation for advanced laryngeal cancer. *Otolaryngol Head Neck Surg*. 2002;127(1):43 [PMID: 12161729]. (Study to determine the pre-treatment parameters that predict poor outcomes related to laryngeal function in patients who survived larynx-preservation therapies for advanced laryngeal cancers.)

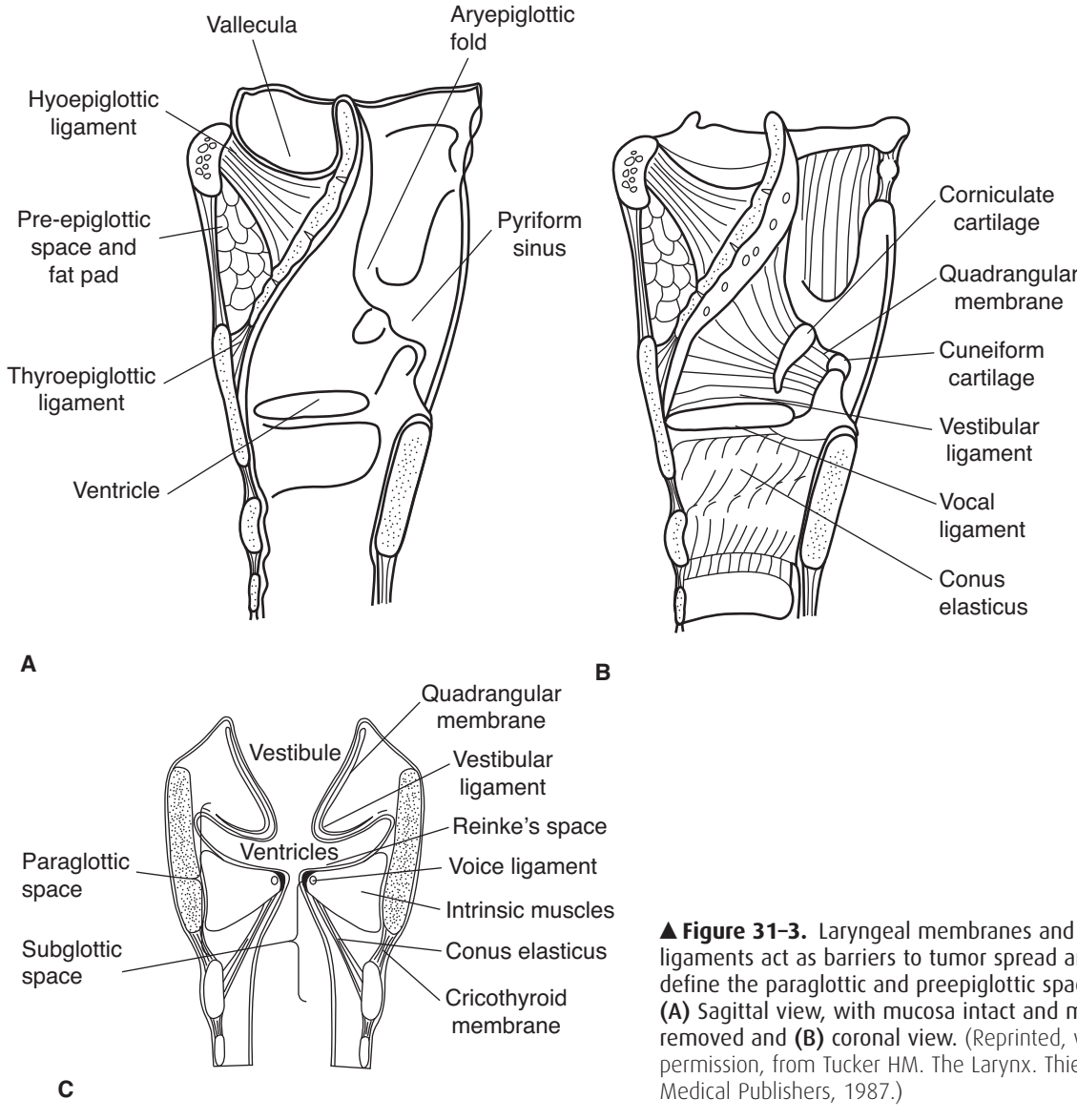
Syrjanen S. Human papillomavirus (HPV) in head and neck cancer. *J Clin Virol*. 2005;32(Suppl 1):S59 [PMID: 15753013]. (Review of the data on relationship of human papillomavirus to head and neck cancers.)

Torrente MC et al. Molecular detection and typing of human papillomavirus in laryngeal carcinoma specimens. *Acta Otolaryngol*. 2005;125(8):888 [PMID: 16158538]. (Evidence for human papillomavirus infection as an etiologic factor in some laryngeal carcinomas.)

Epidemiology

Malignant disorders of the glottic larynx outnumber those of the supraglottis (ie, 1.5:1.0) in the United States (Table 31–1). This ratio does not hold worldwide. In Finland, for example, supraglottic cancers outnumber glottic cancers. The worldwide variation in the epidemiology of larynx cancer may reflect local tobacco and alcohol use customs, other environmental factors, or also the genetic makeup of the populations affected.

Malignant disorders arising in the subglottis are universally rare. For this reason, data on the incidence of nodal



▲ **Figure 31–3.** Laryngeal membranes and ligaments act as barriers to tumor spread and define the paraglottic and preepiglottic spaces. **(A)** Sagittal view, with mucosa intact and mucosa removed and **(B)** coronal view. (Reprinted, with permission, from Tucker HM. The Larynx. Thieme Medical Publishers, 1987.)

metastases and prognosis are scant, and the discussion of the diagnosis and management of larynx cancers that follows focuses on primary supraglottic and glottic cancers. Most larynx cancers involving the subglottis are extensions of primary cancers arising in the glottis or supraglottis.

Table 31–1. Incidence of Larynx Cancer by Site.

Supraglottic—40%
Glottic—59%
Subglottic—1%

As explained above, cancers arising in the supraglottic larynx have a richer lymphatic drainage and are more often diagnosed with nodal metastases and, therefore, at a higher clinical stage (Table 31–2).

Jemal A, Thomas A, Murray T et al. Cancer statistics, 2002. *CA Cancer J Clin*. 2002;52(1):23 [PMID: 11814064]. (American Cancer Society statistics.)

Prevention

Many studies address the protective effect of retinoids, beta-carotene, and other antioxidants against the development of

Table 31–2. Larynx Cancer: Incidence of Neck Metastases by Site.

	T1	T2	T3	T4	All T
Supraglottis	15–40%	35–42%	50–65%	>65%	25–50%
Glottis	<5%	5–10%	10–20%	25–40%	
Subglottis					50%

larynx cancer. A reversal of laryngeal leukoplakia after treatment with retinyl-palmitate has been demonstrated.

Issing WJ, Struck R, Naumann A. Impact of retinyl palmitate in leukoplakia of the larynx. *Eur Arch Otorhinolaryngol.* 1997;254;S105 [PMID: 9065641]. (Study showing the reversal of laryngeal leukoplakia with this antioxidant therapy.)

Staging

Cancers of the larynx are staged according to the TNM (tumor, node, metastasis) system of the American Joint Committee on Cancer (Table 31–3). For staging purposes, positive neck nodes are considered locoregional metastases; metastases to other parts of the body (such as lung, mediastinum, liver, and bone) are considered distant. According to the 2010 update, T4 tumors are now divided into T4a or moderately advanced local disease & T4b or very advanced local disease. Stage IV tumors are still subdivided into Stages IVA, IVB, and IVC (distant metastases present). Studies before this date, however, are based on the 1998 or earlier systems in which there was a single umbrella T4 and Stage IV designation. Accordingly, the discussion in the rest of this chapter refers to the older system.

A shortcoming of the TNM staging system, which the subdivision of the T4 and Stage IV categories is starting to address, is that tumors of varying size and prognosis are frequently categorized together. Other indicators of the prognosis in laryngeal carcinoma have been identified and proposals exist to incorporate these into staging systems. These indicators include the following: (1) the histological characteristics of the tumor, such as extracapsular spread in nodal metastases, angiolymphatic invasion, perineural spread, and a high histological grade; (2) various chromosomal and molecular markers, such as p53 mutations, Ki67 or PCNA overexpression, DNA content, and loss of heterozygosity; and (3) the presence of patient comorbidities.

Greene FL, Page DL, Fleming ID et al (eds). American Joint Committee on Cancer. *AJCC Cancer Staging Manual,* 6th ed. Springer Verlag, 2002. (The definitive reference for the currently used American Joint Committee on Cancer staging system.)

Piccirillo JF. Importance of comorbidity in head and neck cancer. *Laryngoscope* 2000;110(4):593 [PMID: 10764003]. (Prospective study, including 341 head and neck cancer patients, demonstrating the prognostic value of comorbidity and providing data in support of incorporating comorbidity into accepted staging systems.)

Clinical Findings

A. Symptoms and Signs

Signs and symptoms of malignant laryngeal lesions include hoarseness, dysphagia, hemoptysis, a mass in the neck, throat pain, ear pain, airway compromise, and aspiration.

Because only the slightest change in contour, thickness, or vibratory characteristics of the vocal cord results in perceived changes in the voice (namely, hoarseness), glottic larynx cancers often come to medical attention while still at an early stage. Patients with supraglottic cancers, however, typically present at a more advanced stage because tumors are bulkier (ie, at a higher T stage) before voice changes, dysphagia, airway compromise, or aspiration become apparent. Furthermore, because the supraglottis has a richer lymphatic supply, supraglottic primary lesions tend to metastasize earlier and are more often diagnosed at the advanced N stage. Clinical cervical adenopathy at the time of diagnosis portends a poor prognosis and advances the overall stage. Significant weight loss often accompanies the diagnosis of an advanced larynx cancer because of swallowing difficulties. Of note, throat and ear pain are usually symptoms of advanced-stage tumors.

B. Physical Examination

When a larynx cancer is suspected, complete head and neck examination is performed, focusing on the larynx and the neck. The quality of the voice is noted. A breathy voice may indicate a vocal cord paralysis and a muffled voice, a supraglottic lesion.

1. Laryngoscopy—Laryngoscopy (or visualization of the larynx) is done in the office setting using either a laryngeal mirror (indirect laryngoscopy) or a fiberoptic endoscope. Irregularities in the contour, color, vibratory characteristics, and mobility of the vocal cords are noted. Malignant laryngeal lesions can appear to be fungating, friable, nodular, or ulcerative, or simply as changes in mucosal color (Figure 31–4). A stroboscopic video laryngoscopy can highlight subtle irregularities in the mucosal vibration, periodicity, and closure of the vocal cords. Careful attention must be paid to the airway status. Some large, bulky lesions require urgent airway intervention with either intubation, tumor debulking, or tracheotomy. Direct laryngoscopy is performed under general anesthesia and provides the definitive examination of tumor extent.

2. Neck examination—The neck is examined by palpation for enlarged lymph nodes and by noting their location, size, firmness, and mobility. Restricted laryngeal crepitus (the "clicking" movement from side to side across the pharynx and prevertebral fascia) can reveal postcricoid or even retropharyngeal invasion.

3. Assessment of nutritional status—Nutritional status should also be assessed and supplementation discussed, if indicated. Caloric dietary supplements may suffice in some cases; others may require gastrostomy or other feeding tube placement.

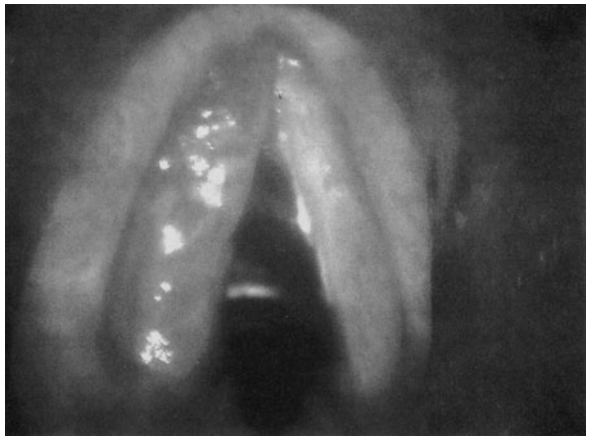
Table 31–3. T (Tumor), N (Nodes), M (Metastases) Staging for Malignant Laryngeal Disorders.

Supraglottis			
T_1	Tumor limited to one subsite of supraglottis		
T_2	Tumor involving more than one adjacent subsite of supraglottis, glottis, or region outside the supraglottis (vallecula, tongue base, medial wall of pyriform sinus)		
T_3	Tumor causes vocal cord fixation and/or invades preepiglottic space, postcricoid area Moderately advanced local disease		
T_{4a}	Tumor invades through thyroid cartilage, and/or invades tissues beyond the larynx Very advanced local disease		
T_{4b}	Tumor invades prevertebral space, encases carotid artery or invades mediastinal structures		
Glottis			
T_1	Tumor limited to vocal cord; may involve anterior or posterior commissure		
T_2	Tumor extends to supraglottis, glottis, and/or impaired vocal cord mobility		
T_3	Vocal cord fixation Moderately advanced local disease		
T_{4a}	Tumor invades through thyroid cartilage, and/or invades tissues beyond the larynx Very advanced local disease		
T_{4b}	Tumor invades prevertebral space, encases carotid artery or invades mediastinal structures		
Subglottis			
T_1	Tumor limited to the subglottis		
T_2	Tumor extends to vocal cord with normal or impaired mobility		
T_3	Vocal cord fixation Moderately advanced local disease		
T_{4a}	Tumor invades through cricoid or thyroid cartilage, and/or invades tissues beyond the larynx Very advanced local disease		
T_{4b}	Tumor invades prevertebral space, encases carotid artery or invades mediastinal structures		
N_0	No cervical lymph nodes positive		
N_1	Single ipsilateral lymph node ≤3 cm		
N_{2a}	Single ipsilateral lymph node >3 cm and ≤6 cm		
N_{2b}	Multiple ipsilateral lymph nodes, each ≤6 cm		
N_{2c}	Bilateral or contralateral lymph nodes, each ≤6 cm		
N_3	Single or multiple lymph nodes >6 cm		
M_0	No distant metastases		
M_1	Distant metastases present		
Stage	**T**	**N**	**M**
I	T_1	N_0	M_0
II	T_2	N_0	M_0
III	T_3	N_0	M_0
	T_{1-3}	N_1	M_0
IVA	T_{4a}	N_{0-2}	M_0
	T_{1-4a}	N_0	M_0
IVB	T_{4b}	any N	M_0
	any T	N_3	M_0
IVC	any T	any N	M_1

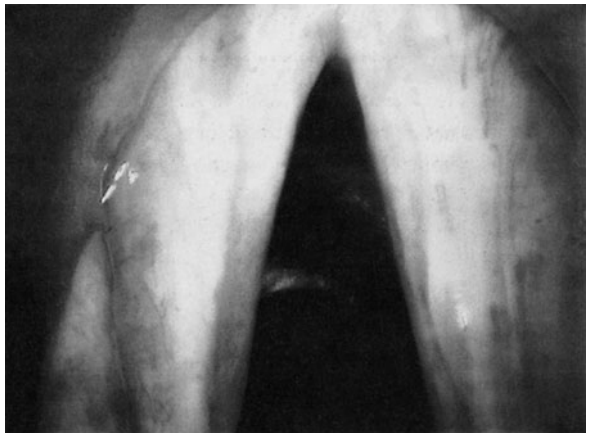
C. Laboratory Findings and Special Tests

SCC of the head and neck can spread to virtually any site of the body, but it is rare in the absence of lung, mediastinal, or liver metastases. Therefore, routine metastatic survey consists of the following tests.

1. Biopsy—Biopsy of a laryngeal lesion is necessary to establish the diagnosis of malignancy. Biopsy of the larynx is best accomplished in the operating room with the patient under general anesthesia and neuromuscular paralysis. Direct laryngoscopy is performed. A variety of laryngoscopes are available designed to enhance visualization of the endolarynx in a range of anatomic and clinical situations. The suspected lesion is mapped and possibly photographed/videotaped. The lesion can be palpated to assess the depth of invasion, and passive mobility of both vocal



A



B

▲ **Figure 31–4.** Stage I, T1 SCC of the left true vocal cord, endoscopic view. **(A)** At diagnosis and **(B)** a complete response, 8 months after the completion of radiation therapy.

cords can be checked. Biopsies of suspected malignant sites are done with cup forceps.

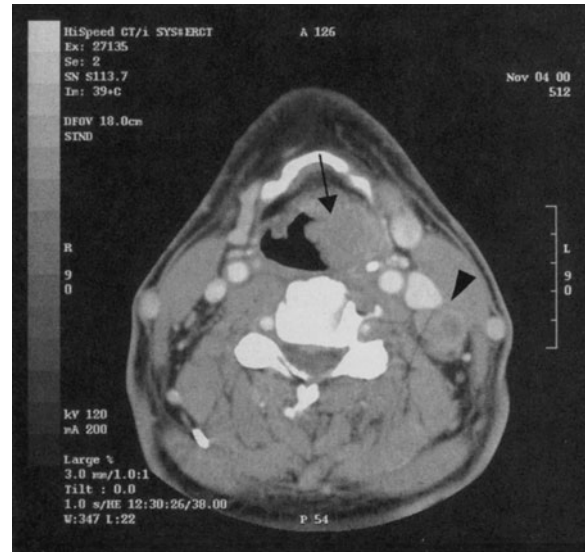
With the patient anesthetized and paralyzed, a thorough neck examination is obtained. Esophagoscopy and bronchoscopy can also be performed at this setting as part of a cancer-staging workup.

For patients who cannot tolerate a general anesthetic, the biopsy of laryngeal lesions can be performed as an office procedure. Under fiber optic guidance, with generous topical anesthesia (typically using lidocaine or cetacaine), a flexible biopsy forceps passed through the fiber optic scope is used.

2. Chest imaging—Cancer of the larynx spreads first to the regional cervical nodes. The next most common site of spread is the lungs. For this reason, patients with head and neck cancer should have a chest X-ray as part of a routine metastatic evaluation. This test should be repeated once or twice yearly to screen for metastases. If there are any significant abnormalities noted on the chest X-ray, a computed tomography (CT) scan of the chest should be performed to confirm the lesions. Bronchoscopy with cytological evaluation of bronchial washings or transbronchial biopsy should be done if there are suspicious lesions. Alternately, thoracoscopy, mediastinoscopy, and biopsy are done if lesions are more amenable to these approaches. Chest and lung lesions may represent either metastases from the larynx primary neoplasm or second primary tumors, because the risk factor of smoking is common to both tumors.

D. Imaging Studies

Radiologic imaging of the larynx and neck is not necessary for an early-stage glottic cancer with a clinically N0 neck. Because the risk of occult nodal disease is high even for early-stage supraglottic cancer, it is sometimes recommended to obtain neck imaging in these cases. If there is any suspicion of impaired vocal cord mobility, a scan should be obtained. Radiologic imaging is generally performed for clinically advanced larynx cancers to aid with staging and treatment planning. CT scanning (Figure 31–5) or magnetic resonance imaging (MRI) is useful in identifying preepiglottic or paraglottic space invasion, laryngeal cartilage erosion, and cervical nodal metastases. Larynx cancers are clinically upstaged as frequently as 25–40% on the basis of CT scanning or MRI. Both imaging modalities are useful to assess



▲ **Figure 31–5.** Contrast CT scan showing bulky left supraglottic tumor (arrow) with ipsilateral lymph node metastasis (arrowhead).

the above characteristics. MRI is more sensitive for soft tissue abnormalities, whereas CT scan is better for bony and cartilaginous defects. The staging accuracy of MRI in laryngeal cancer is thought to be slightly higher because of the greater accuracy in assessing cartilage involvement and paraglottic or preepiglottic extension of tumor. However, CT is still more commonly used for initial staging because of its practical advantages over MRI, such as cost, speed, and availability.

Positron emission tomography (PET) scanning uses fluorescence-tagged glucose and the increased metabolic rate of malignant tissues to identify cancers. Application of PET in the head and neck has focused on (1) identifying occult nodal metastases, (2) distinguishing the recurrence of malignant growth from radionecrosis and other sequelae of prior treatment, and (3) identifying the location of any unknown primary cancer. The role of PET/CT in diagnosing and staging patients with head and neck cancer has been evolving. PET/CT combines the detailed anatomic information of CT with the ability of PET scan to detect subtle lesions. PET/CT can play an important role in the pretreatment period by detecting synchronous or metastatic lesions that may lead to changes in planned procedures or treatment recommendations. In the post-treatment period, PET/CT has high sensitivity and specificity in the detection of recurrence and therefore invaluable in cancer surveillance.

If there is a question of distant metastases, then bone scanning may be of use.

Ultrasound of the neck can be useful in the diagnosis of larynx cancer. In Europe, this noninvasive imaging modality is used to identify cervical metastases and even to characterize laryngeal abnormalities, but it is not typically used in North America for these purposes.

Anzai Y, Carroll WR, Qunit DJ et al. Recurrence of head and neck cancer after surgery or irradiation: Prospective comparison of 2-deoxy-2-[F-18]fluoro-D-glucose PET and MR imaging diagnoses. *Radiology* 1996;200(1):135 [PMID: 8657901]. (Study of patients with recurrent head and neck cancer, demonstrating the improved sensitivity and specificity of PET over MRI and CT scans in detecting the recurrence.)

Blitz AM, Aygun N. Radiologic evaluation of larynx cancer. *Otolaryngol Clinic North Am* 2008;41(4):697 [PMID: 18570954]. (Review of radiographic imaging in laryngeal cancer.)

Chu, EA, Kim YJ. Laryngeal cancer: Diagnosis and preoperative work-up. *Otolaryngol Clinic North Am* 2008;41(4):673 [PMID: 18570953]. (Review of diagnosis and workup of laryngeal cancer.)

Gordin A et al. Fluorodeoxyglucose-positron emission tomography/computed tomography imaging in patients with carcinoma of larynx: Diagnostic accuracy and impact on clinical management. *Laryngoscope*. 2006;116(2):273 [PMID: 1646778]. (Study to assess the value of PET/CT on patients with laryngeal cancer compared with PET or CT alone and the impact that PET/CT had on clinical management.)

McGuirt WF, Greven KM, Keyes JW et al. Laryngeal radionecrosis versus recurrent cancer: A clinical approach. *Ann Otol Rhinol Laryngol*. 1998;107:293 [PMID: 9557763]. (Study showing the usefulness of the PET scan to distinguish recurrent laryngeal cancer from laryngeal radionecrosis.)

Differential Diagnosis

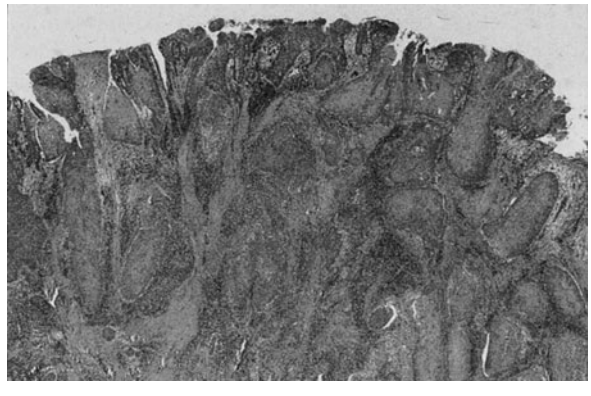
Definitive tissue diagnosis must be obtained before starting treatment for a laryngeal cancer because lesions that appear malignant may, in fact, be benign. These benign conditions include infectious, inflammatory, and granulomatous diseases such as tuberculosis, sarcoidosis, blastomycosis, papillomatosis, and granular cell tumors. The next section provides a discussion of malignant laryngeal lesions.

Histological Types

A. Squamous Cell Carcinoma

SCC represents >90% of larynx cancers and is linked to tobacco and excessive alcohol use. Histologically, the carcinogenesis of SCC is viewed as a continuum of change from normal phenotype, to hyperplasia, to dysplasia, to carcinoma in situ, to invasive carcinoma. Invasive SCC can be well, moderately, or poorly differentiated and is characterized by nests of malignant epithelial cells in a surrounding desmoplastic, inflammatory stroma (Figure 31–6). Varying degrees of mitoses and necrosis are seen. Keratin pearls are a pathognomonic feature seen in well- and moderately differentiated SCC. SCC can invade blood and lymphatic vessels as well as nerves. Immunohistochemical staining is positive for keratin proteins.

Variants of SCC include verrucous carcinoma, spindle cell carcinoma, basaloid SCC, and adenosquamous carcinoma. Verrucous carcinoma, which is characterized grossly by a warty, exophytic tumor that is highly differentiated with bulbous "rete pegs" pushing into the underlying stroma and low metastatic potential, is typically treated surgically because many physicians view this tumor as being radiation-resistant. Spindle cell carcinoma presents as malignant spindle cells seen in the stroma usually predominating over foci of conventional SCC and is often confused with sarcoma. The spindle cells



▲ **Figure 31–6.** Moderately well-differentiated laryngeal SCC. Note nests of tumor extending deep into the stroma.

typically stain positive for keratin on immunohistochemistry. Basaloid SCC presents as compact nests of subepithelial basaloid cells associated with SCC in situ or invasive SCC. Adenosquamous carcinoma is a high-grade malignant neoplasm with features of both SCC with epithelial differentiation and adenocarcinoma with glandular differentiation.

B. Salivary Gland Cancers

Malignant disorders can arise from the minor salivary glands that line the mucosa of the larynx. Adenoid cystic carcinoma (ACC) and mucoepidermoid carcinoma (MEC) are the most common, although other histological types have been reported as well. Women and men are affected equally by ACC of the larynx. The histology resembles that of the major salivary gland counterparts, with cribriform, tubular, and solid architectural patterns for ACC and low-grade cystic patterns to high-grade solid patterns for MEC. The clinical behavior is also similar to that of the corresponding major salivary gland neoplasms. ACC has an indolent clinical course and tendency for perineural spread. Low-grade MEC has a better prognosis than high-grade MEC. Surgery is the preferred treatment for both, with guidelines for adjuvant radiation similar to those for malignant disorders of the major salivary glands.

C. Sarcomas

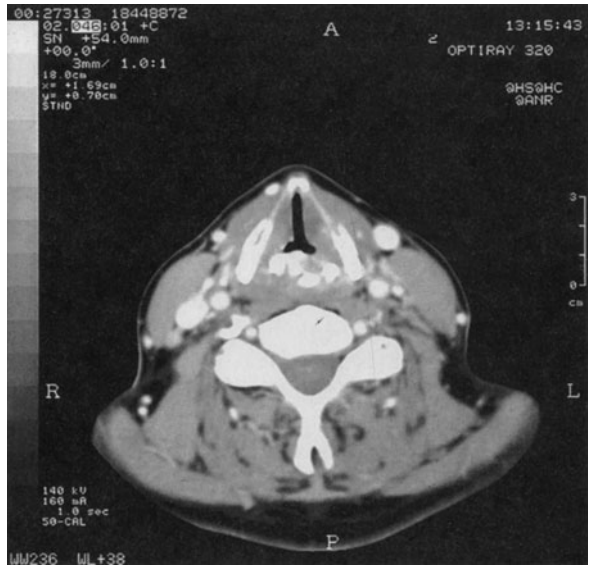
Malignant growths of mesenchymal origin are rarely seen in the larynx. The most common is chondrosarcoma. Chondrosarcoma of the larynx arises most often from the cricoid cartilage and is characterized by a submucosal mass of the posterior glottis with stippled calcification on CT scan (Figure 31–7). The diagnosis can be difficult both because an adequate biopsy may be challenging and because the histological differentiation from a benign chondroma may be difficult. Chondrosarcomas have a nonaggressive clinical behavior, and, for this reason, partial laryngeal surgery with preservation of some laryngeal function is often attempted. Radiation is generally viewed as ineffective in treating laryngeal chondrosarcoma.

Other types of laryngeal sarcoma include malignant fibrous histiocytoma, angiosarcoma, and synovial sarcoma.

D. Other Neoplasms

Other tumors that can occur in the larynx include neuroendocrine tumors such as carcinoid tumors, lymphoma, and metastases from other primary sites. Malignant tumors of the thyroid can invade into the larynx with or without vocal cord paralysis.

Gripp S, Pape H, Schmitt G. Chondrosarcoma of the larynx: The role of radiotherapy revisited—a case report and review of the literature. *Cancer* 1998;82:108 [PMID: 9428486]. (Review of the literature and existing case reports on larynx chondrosarcoma, revisiting the idea of radiation as a treatment for this type of cancer.)



▲ **Figure 31–7.** Contrast CT scan demonstrating calcified stippling in a mass arising from the cricoid cartilage; this finding is characteristic of chondrosarcoma.

Treatment

A. Treatment of Early-Stage Larynx Cancer

Early-stage larynx cancer (Stages I and II) can be treated with either surgery or radiation in single-modality therapy. Current recommendations by the American Society of Clinical Oncology are that all patients with T1 or T2 laryngeal cancer, with rare exceptions, should be treated initially with the intent to preserve the larynx. The advantages of surgery compared with radiation are a shorter treatment period (compared with 6–7 weeks for radiation) and the option of saving radiation for recurrence. Specific surgical procedures used in the treatment of early larynx cancer are discussed in the following section. In addition to the risks inherent in any surgical procedure, surgery can result in a poorer voice quality and, for external surgical approaches, a worse cosmetic outcome.

Specific radiation therapy techniques for larynx cancer are discussed under "Nonsurgical Measures." For early-stage lesions, short-term complications of radiation include odynophagia and laryngeal edema. The long-term complications include a remote possibility of laryngeal fibrosis, radionecrosis, or hypothyroidism. Delayed development of sarcoma (radiation-induced), though possible, is exceedingly rare, with an incidence of 0.03–0.3%.

B. Treatment of Advanced-Stage Larynx Cancer

Advanced-stage larynx cancer (Stages III and IV) was historically treated by dual-modality therapy with surgery

and radiation. For most T3 and T4 tumors, where total laryngectomy is required for the complete removal of the tumor with amply clear margins, organ preservation treatment with combined chemotherapy and radiation therapy is preferred because there is no difference in overall survival and a superior quality of life. Still, extirpative surgery may be used in selected patients, such as those with bone or cartilage destruction in which reasonable organ function is unlikely after conservation therapy. Voice rehabilitation after total laryngectomy is discussed below. For T1, T2, and some T3 lesions, partial laryngectomy procedures with preservation of the voice may be considered (see "Surgical Treatment of Larynx Cancer"). Patient selection is critical with the goal of rendering the patient disease-free with surgery alone because postoperative radiation after partial laryngectomy may result in significant functional impairment. The type of neck dissection chosen is guided by the extent of the neck disease, as discussed below.

Adjuvant radiation should start within 6 weeks of surgery and, on once-daily protocols, lasts 6–7 weeks. The primary site is treated with external-beam irradiation with doses of 55–66 Gy, whereas draining nodal basins typically receive a slightly lower dose, depending on the extent of neck disease. Complications of radiation therapy include those described for radiation given as single-modality treatment for early-stage larynx cancer; however, since the treated area is more extensive, side effects also include mucositis during therapy and chronic xerostomia after treatment. Less common complications include hypothyroidism, radionecrosis, and esophageal stricture.

Organ-preserving protocols have evolved over the past decade. The landmark study of the Veterans Administration Larynx Cancer Study Group randomized 332 patients to receive neoadjuvant chemotherapy followed by radiation, compared with traditional total laryngectomy with postoperative radiation. The study found that two-thirds of patients responded favorably to chemotherapy after just one or two cycles. In two-thirds of these cases, larynges were preserved, and survival was similar to the traditional approach of laryngectomy with postoperative radiation. As a subgroup, patients with larger T4 tumors did not fare as well and, for this reason, organ-preserving protocols sometimes are not offered to patients in this category, particularly if cartilaginous invasion is present. The VA study was followed by a three-arm randomized study comparing induction chemotherapy (cisplatin plus 5-fluorouracil) followed by radiation, concurrent chemoradiation with cisplatin, and once-daily radiation alone in 547 patients. At 2 years, superior organ preservation was achieved with the concurrent chemoradiation group; therefore, this treatment strategy has become the standard of care in most centers. Ongoing studies of combined-modality treatment include radiation with different systemic therapies and systemic therapy with altered radiation schedules, including twice-daily treatment.

C. Treatment of the Neck in Larynx Cancer

A neck without clinically apparent nodal metastases should be treated in larynx cancer if the risk of nodal metastasis exceeds 15% (see Table 31–2). The treatment of both the ipsilateral and contralateral necks should be considered, therefore, for early-stage, primary cancers of the supraglottis in general and for all advanced laryngeal cancers. Neck disease staged as N0 or N1 can be treated with a single modality—surgery or radiation. The choice of surgery or irradiation for elective treatment of the clinically negative neck depends on the treatment chosen for the primary cancer. An elective neck dissection has the advantage over elective irradiation of the ability to stage the neck pathologically, which provides prognostic information and helps in determining whether adjuvant therapy is required. Neck disease staged as N2 or N3 generally requires a combined-modality treatment.

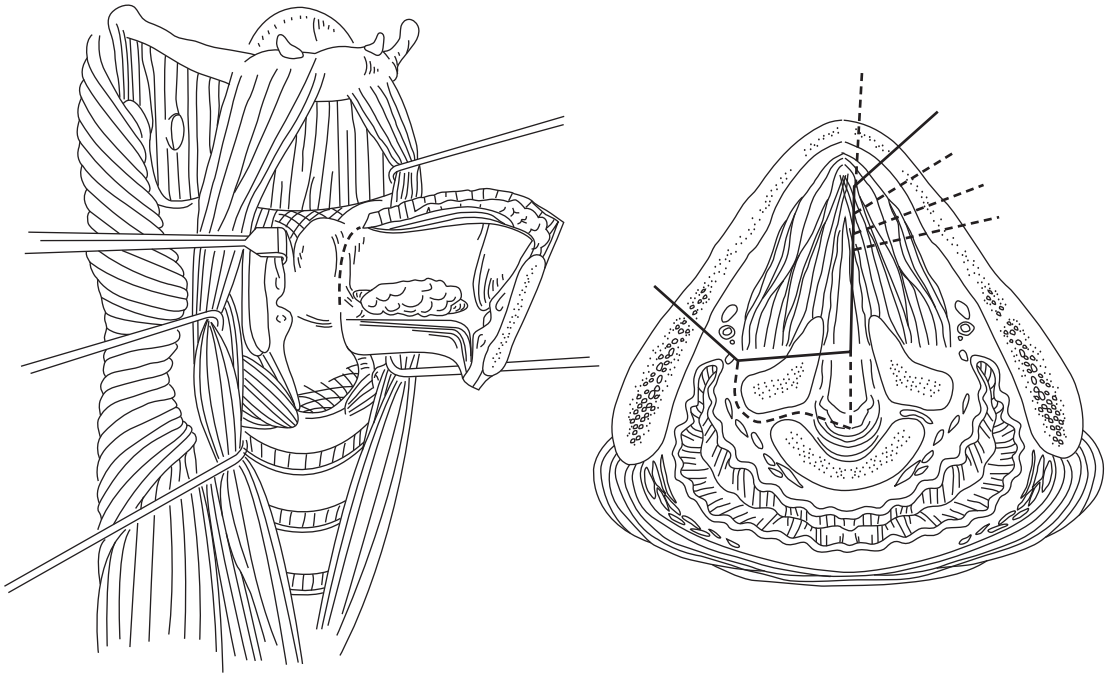
Neck dissection is tailored to the extent of neck disease. Selective neck dissection (preserving the sternocleidomastoid muscle, internal jugular vein, and spinal accessory nerve) can be performed for clinically N0 necks. For N1 necks, dissection is usually limited to levels II–IV, as metastasis to levels I or V is rare in this condition. Radical or extended radical neck dissection, sacrificing the sternocleidomastoid muscle, the internal jugular vein, and the spinal accessory nerve, and addressing neck levels I–V or more, is performed for extensive neck disease with the involvement of vessels, nerves, muscles, or any combination of these structures. A modified radical neck dissection preserves some of these structures, according to feasibility.

D. Surgical Treatment of Larynx Cancer

Surgical options for treating larynx cancer include a variety of partial laryngectomy procedures in addition to total laryngectomy. Understanding the lymphatic drainage patterns of the laryngeal subsites permits the surgeon to resect more closely than the 1- to 2-cm margins that typically are recommended at other head and neck sites. This helps preserve functional voice, respiration, and deglutition in partial laryngectomy procedures.

A preoperative consultation with a speech therapist is appropriate if significant voice or swallowing changes are anticipated. These sessions help educate patients about the speech and swallowing functions of the larynx and prepare the patient for postoperative rehabilitation and therapy.

1. Microlaryngeal surgery—The endoscopic removal of selected larynx cancers can be achieved safely and effectively with use of the operating microscope and microlaryngeal dissection instruments. The carbon dioxide laser, used with direct laryngoscopy and microscope guidance, is also a useful dissection tool, especially for supraglottic lesions. Laser cordectomy has been shown to provide excellent local control and laryngeal preservation of early-stage glottic cancer; it offers low morbidity and excellent retreatment options in



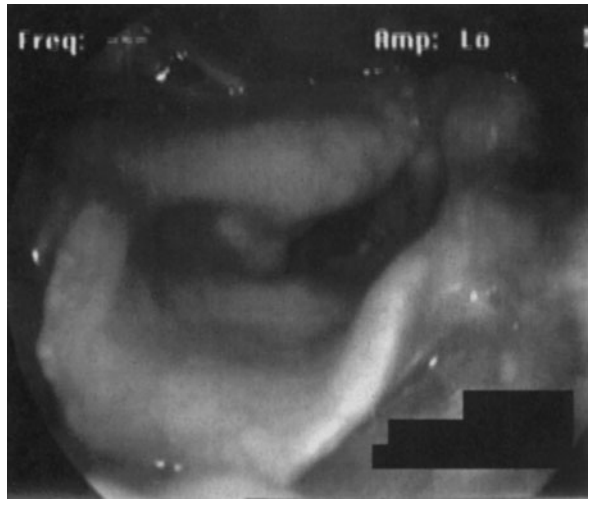
▲ **Figure 31–8.** Schematic of the anatomic resection for a vertical hemilaryngectomy. (Modified and reprinted, with permission, from Myers EN, Suen JY. *Cancer of the Head and Neck,* 3rd ed. WB Saunders, 1996.)

case of local failure. Contraindications for endoscopic laser resection include cases in which the entire tumor cannot be visualized, large tumors requiring too much excision of the functional laryngeal unit, thus decreasing airway protection and leading to aspiration, and cartilage invasion. For supraglottic cancer, contraindications also include bilateral arytenoid involvement and direct extension into the neck.

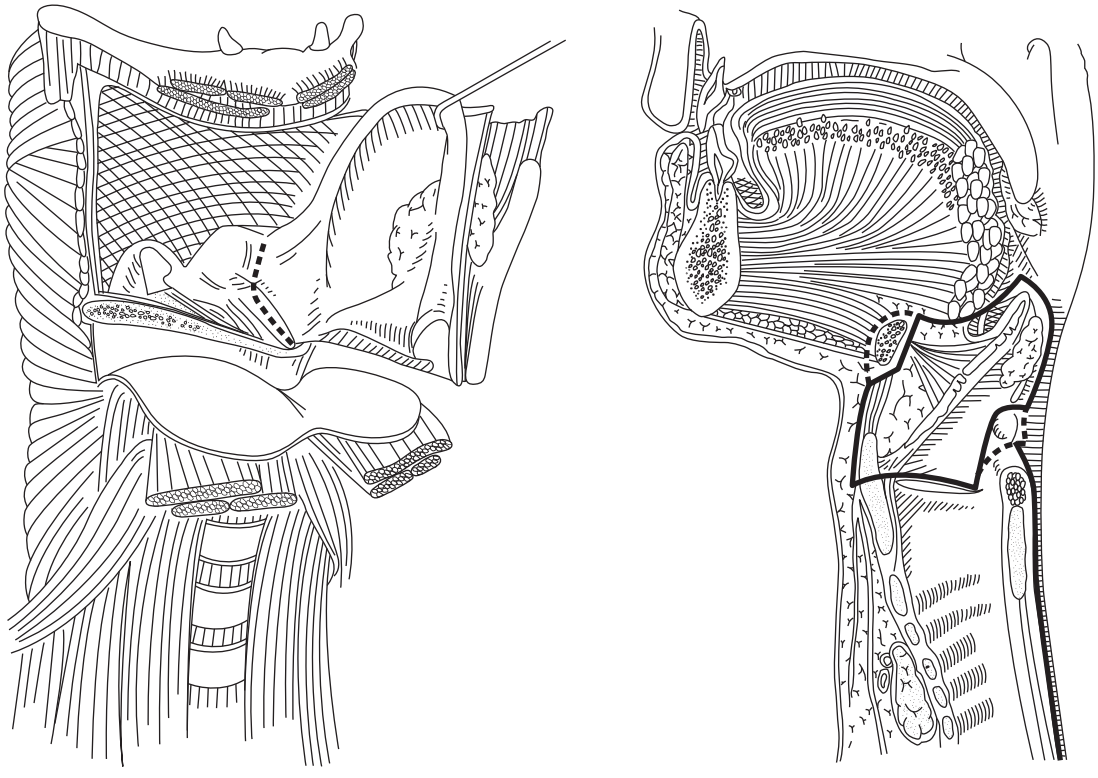
2. Hemilaryngectomy—Hemilaryngectomy is the removal of one vertical half of the larynx (or a part thereof; Figure 31–8). Appropriate tumors for this surgery are those with (1) subglottic extension no more than 1 cm below the true vocal cords; (2) a mobile affected cord; (3) unilateral involvement (involvement of the anterior commissure and anterior extent of the contralateral true cord can, in certain cases, also be treated with an extended vertical hemilaryngectomy); (4) no cartilage invasion; and (5) no extralaryngeal soft tissue involvement.

Vocal cord reconstruction is most often done by transposing a flap of strap muscle or microvascular free flap to provide bulk against which the remaining unaffected vocal cord can vibrate (Figure 31–9). Vertical hemilaryngectomy can be done in appropriate surgical candidates who have failed radiation therapy.

3. Supraglottic laryngectomy—A supraglottic laryngectomy entails removal of the supraglottis or the upper part of the larynx (or a part thereof). This surgery may be considered when the following conditions are met: (1) for tumors with a T stage of T1, T2, or T3 by preepiglottic space involve-



▲ **Figure 31–9.** Vertical right hemilaryngectomy, postoperative endoscopic view. Note the absence of arytenoid, but the presence of the "pseudocord."

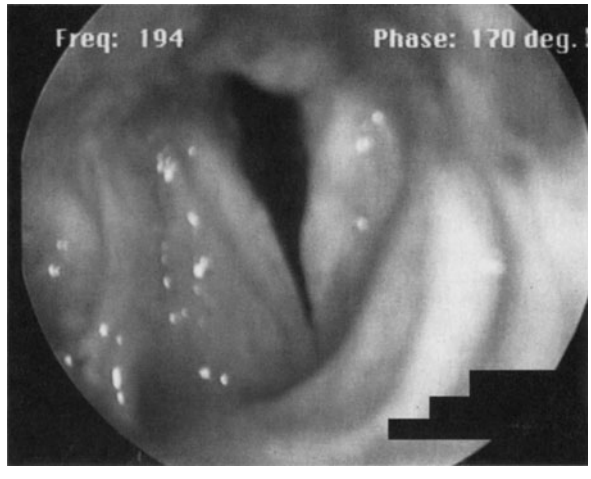


▲ **Figure 31–10.** Schematic of the anatomic resection for a supraglottic laryngectomy. (Modified and reprinted, with permission, from Myers EN, Suen JY. *Cancer of the Head and Neck,* 3rd ed. WB Saunders, 1996.)

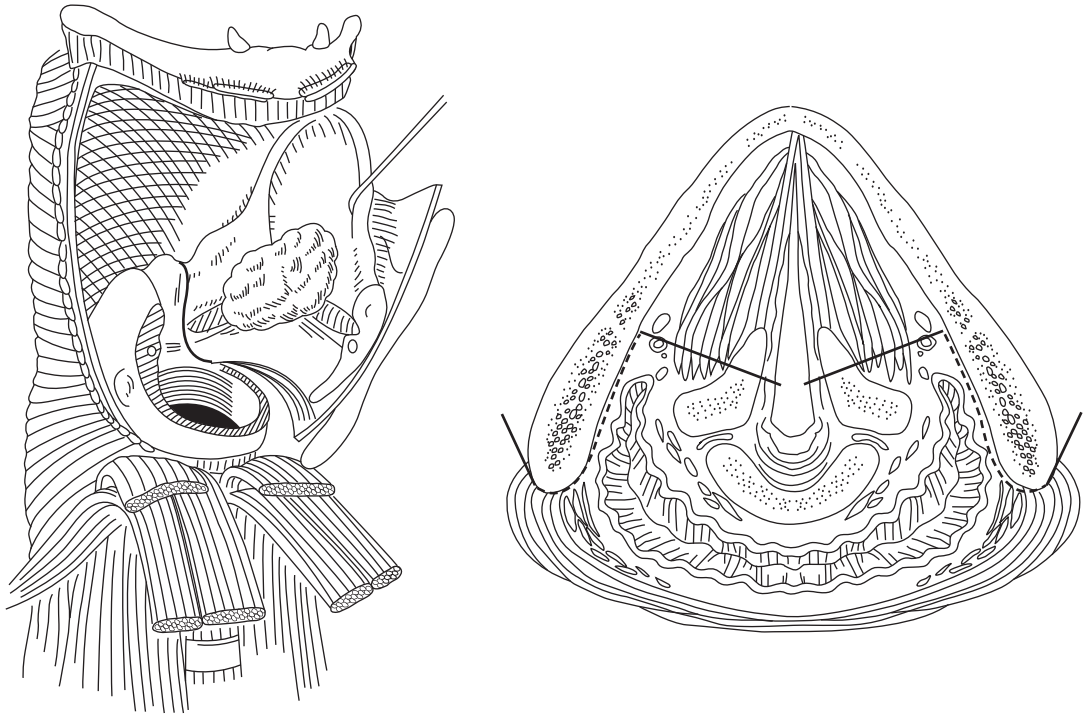
ment only; (2) the vocal cords are mobile; (3) cartilage is not involved; (4) the anterior commissure is not involved; (5) the patient has good pulmonary status/reserve; (6) the base of the tongue is not involved past the circumvallate papillae; (7) the apex of the pyriform sinus is not involved; and (8) the FEV_1 (the forced expiratory volume in the first second) is predicted to be >50%.

A supraglottic laryngectomy can be performed endoscopically using a carbon dioxide laser or with a more standard open, external approach. Endoscopic surgery typically removes just the involved portion of the supraglottis. The traditional supraglottic laryngectomy removes the entire supraglottis from the apex of the laryngeal ventricle, including the false cords, the epiglottis, and the preepiglottic space; the arytenoids and part of the thyroid cartilage are preserved (Figure 31–10). Closure in an open supraglottic laryngectomy is done by collapsing the remaining glottic part of the larynx to the base of tongue (Figure 31–11).

Although the patient's voice is generally normal in quality, some degree of aspiration is an expected side effect of this operation. For this reason, patients with borderline pulmonary function (FEV_1 predicted to be <50%) who cannot



▲ **Figure 31–11.** Supraglottic laryngectomy, postoperative endoscopic view. Note the absence of the epiglottis.



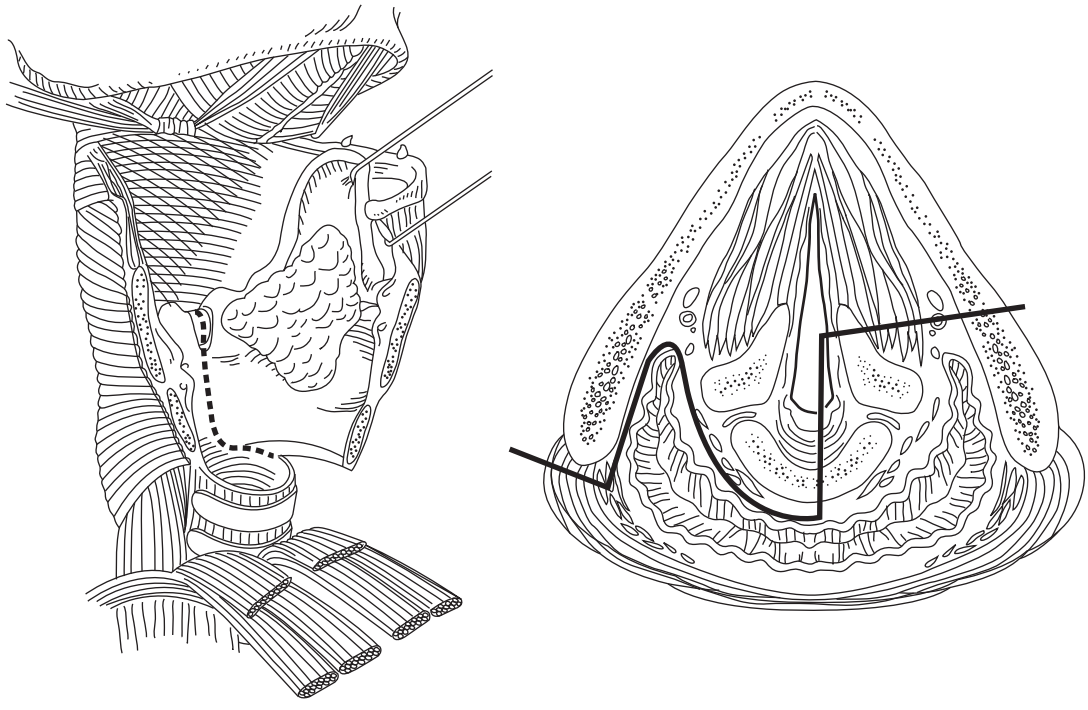
▲ **Figure 31–12.** Schematic of the anatomic resection for a supracricoid laryngectomy. (Modified and reprinted, with permission, from Myers EN, Suen JY. *Cancer of the Head and Neck,* 3rd ed. WB Saunders, 1996.)

tolerate chronic aspiration are generally not considered good candidates for supraglottic laryngectomy. Patients must learn a double-swallow technique called the supraglottic swallow to minimize aspiration with oral intake. Regular visits with a speech therapist are critical to properly learn this technique.

4. Supracricoid laryngectomy—This is a newer surgical technique, which expands on the traditional supraglottic laryngectomy procedure to preserve voice for those with cancers located at the anterior glolttis, including the commissure, or those with more extensive preepiglottic space involvement. The true vocal cords, the supraglottis, and thyroid cartilage are taken, preserving the cricoid and arytenoid cartilages (Figure 31–12). Half of the patients remain dependent on their tracheotomy. Pulmonary function and prior radiation candidacy criteria for supraglottic laryngectomy apply for supracricoid laryngectomy as well. Voice results are reported as adequate. Supraglottic swallow techniques must be used.

5. Near-total laryngectomy—A near-total laryngectomy is a more extended partial laryngectomy procedure in which only one arytenoid is preserved and a tracheoesophageal conduit is constructed for speech (Figure 31–13). Voice is generated by the lungs, but has a more limited range of pitch. Oral intake and swallowing are in the usual fashion, with some aspiration concerns. Patients remain dependent on a tracheotomy for breathing. This procedure is not offered to patients whose radiation treatments have failed, those with poor pulmonary reserve, or those with tumor involvement below the cricoid ring. Candidates are patients with large T3 and T4 lesions with one uninvolved arytenoid, or with unilateral transglottic tumors with cord fixation.

6. Total laryngectomy—A total laryngectomy entails the removal of the entire larynx, including the thyroid and cricoid cartilages, possibly some upper tracheal rings, and the hyoid bone (Figure 31–14). The proximal tracheal stump is anastomosed to an opening at the root of the neck anteriorly in a permanent tracheostoma; this results in the complete anatomic separation of the respiratory and digestive tracts. Indications for total laryngectomy are (1) T3 and T4 cancers not amenable to the above partial laryngectomy procedures or organ preservation therapy with chemoradiation, (2) extensive involvement of thyroid or cricoid cartilage, (3) the direct invasion of surrounding soft tissues of the neck, (4) tongue base involvement beyond the circumvallate papillae, and (5) salvage therapy for failures of organ preservation strategies. Closure is done by reapproximating the pharyngeal mucosa. If a partial or total pharyngectomy is also required because of the size of the tumor, then free flap or regional flap aids the closure and prevents pharyngoesophageal stricture. The ultimate goal is to maintain for the patient the ability to swallow by mouth.



▲ **Figure 31–13.** Schematic of the anatomic resection for a near-total laryngectomy. (Modified and reprinted, with permission, from Myers EN, Suen JY. *Cancer of the Head and Neck,* 3rd ed. WB Saunders, 1996.)

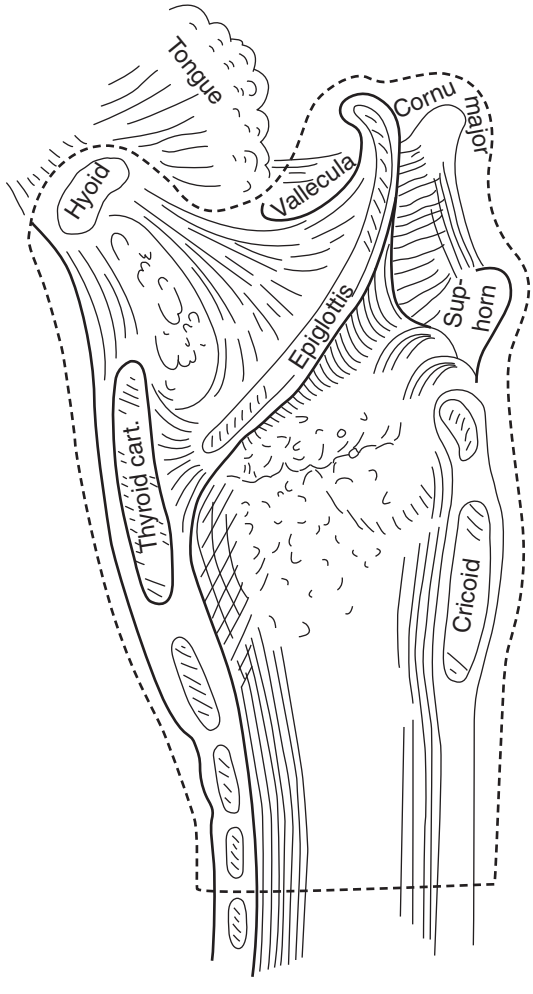
Voice rehabilitation after a total laryngectomy is best accomplished with tracheoesophageal speech, using a tracheostomal device that is a one-way valve directing air into the neopharynx during exhalation when the tracheostoma is occluded (Figure 31–15). The individual accomplishes this with digital occlusion, but foam buttons and hands-free techniques also exist. There are several models of the electrolarynx, which achieves its sound by external vibration. Learning to use the device to optimize comprehensibility is a challenge to most patients; those listening to an individual using an electrolarynx must also be familiar with the sound to understand the speech. Some patients learn pure esophageal speech by forcing air into the esophagus and releasing the air while using the tongue, teeth, cheeks, and lips to produce speech. A speech therapist familiar with postlaryngectomy voice rehabilitation is an essential member of the patient care team for patients undergoing a partial or total laryngectomy.

7. Robotic surgery—More recently, minimally invasive robotic surgery was introduced and currently has increasing applications in the treatment of laryngeal cancer. In many ways, it addresses the shortcomings of both endolaryngeal surgery and open surgical approach. In comparison to transoral laser surgery, the robotic approach allows for en bloc tumor resection as opposed to piecemeal excision with the laser. It can also allow for procedures that are commonly done with an open approach, such as excision of supraglottic or base of tongue lesion through an endoscope. The latter would decrease morbidity associated with an open procedure, thus precluding the need for a tracheostomy.

E. Nonsurgical Measures

1. Photodynamic therapy—Photodynamic therapy is an emerging modality of treating early larynx cancer, as well as cancer arising from other primary mucosal sites of the head and neck. A photosensitizing agent (a chemical preferentially taken up by tumor tissue and sensitive to specific wavelengths of light) is administered intravenously. A laser is then used to activate the photosensitizing agent and induce the destruction of tumor tissue. This treatment has been shown to be effective in treating cancers as deep as 5 mm, with local control and survival rates similar to traditional treatment modalities. The side effects of photodynamic therapy include light sensitivity that can linger for several weeks after the administration of the photosensitizing agent. For this reason, patients must wear sun-protective clothing during this period of time and avoid being outside during the hours of maximal sun intensity.

2. Radiation treatment techniques for larynx cancer—Radiation given as the primary treatment for larynx cancer or as an adjuvant treatment after surgery is most often done



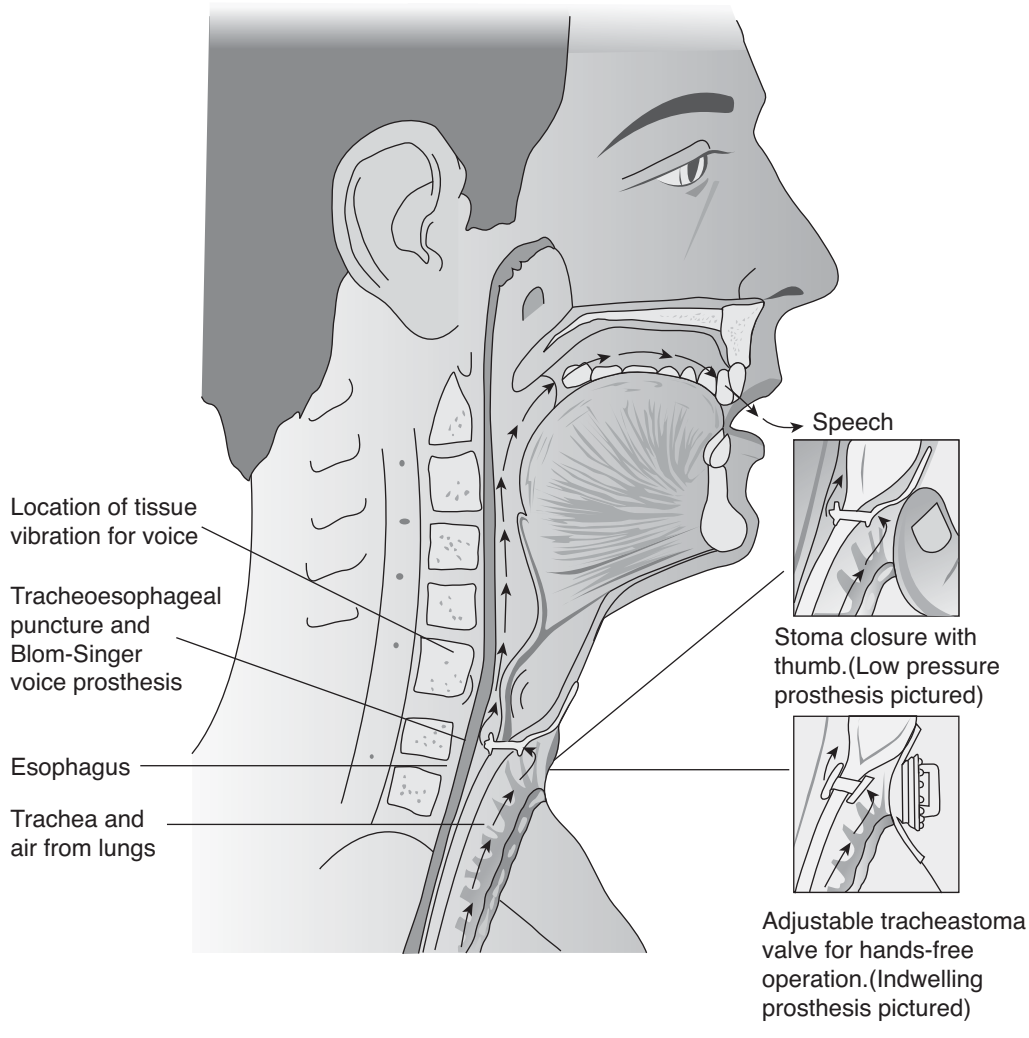
▲ **Figure 31–14.** Schematic of the anatomic resection for a total laryngectomy. (Modified and reprinted, with permission, from Cummings CW, Sessions DG, Weymuller EA, Wood P. *Atlas of Laryngeal Surgery.* CV Mosby, 1984.)

using an external-beam technique; a dose of 6000–7000 cGy is administered to the primary site. When the risk of locoregional nodal metastasis in a clinically negative neck exceeds 15–20%, 5000 cGy is delivered prophylactically to the neck as well. The indications for postoperative adjuvant radiation include advanced-stage disease, close or positive margins, extracapsular spread of tumor in a lymph node, perineural or angiolymphatic spread, subglottic extension, and the involvement of nodes in multiple neck levels (in particular, levels IV or V, or the mediastinum). Although conventional adjuvant radiation treatment consisted of radiation alone, two recent randomized trials have shown improved local control with concurrent radiation and cisplatin for certain risk factors. Patient selection for such treatment continues to be debated, but patients with good performance status and adverse tumor features should be seriously considered for postoperative adjuvant concurrent chemoradiation. As noted previously, newer protocols are using various combinations of radiation with systemic therapies for tumor sensitization and eradication of micrometastatic disease. Altered radiation schedules are also being studied—both with and without systemic agents. Advances in treatment delivery with intensity-modulated radiation therapy have allowed for more accurate tumor dose delivery with greater sparing of normal tissue, including salivary gland preservation with reduced xerostomia. Before undergoing radiation, patients should have a thorough dental examination. When the field will encompass the oral cavity, carious teeth are extracted before starting radiation owing to the radiation-induced dental decay and increased risk of osteoradionecrosis.

Short-term side effects of radiation, lasting up to 6 weeks after the conclusion of therapy, include mucositis, odynophagia, dysphagia, skin and erythema, altered taste, and edema. Common long-term side effects include varying degrees of xerostomia, fibrosis, and edema. Uncommon side effects include hypothyroidism, chondroradionecrosis, and osteoradionecrosis. As noted previously, an exceedingly rare complication is radiation-induced sarcoma.

3. Chemotherapy for larynx cancer—Chemotherapy had not traditionally been part of larynx cancer primary treatment protocols. Starting in the 1980s, organ-preserving protocols using chemotherapy in conjunction with radiation for advanced-stage laryngeal cancer have been compared with standard surgery and radiation treatment. Comparable survival rates have been shown with differing treatment morbidities. In general, lowered rates of distant metastasis are seen, although questionably higher rates of local recurrence are also cited in comparison with surgery and locoregional radiation protocols.

Cisplatin and 5-fluorouracil are the two agents found to be the most effective against larynx cancer. Recently, paclitaxel (Taxol) and docetaxel (Taxotere) have demonstrated activity without the side effects of cisplatin, which include neurotoxicity, ototoxicity, and renal toxicity. Chemotherapy has been given in the neoadjuvant (induction) setting concurrent with radiation and also in the adjuvant setting. Even though successes have been reported for all three approaches, concurrent chemoradiation has generally been deemed the most successful. Trials with neoadjuvant and concurrent intra-arterial chemotherapy have shown excellent local tumor response in selected cases, but with enhanced local toxicity. Cisplatin is the most commonly used agent in concurrent protocols. Agents, such as amifostine, are being used to mitigate side effects and preserve salivary function in the setting of radiation. Chemotherapy may also be used for the palliation of advanced larynx cancer. Once again, cisplatin is the preferred agent, but methotrexate was historically used with some benefit. Chemotherapy is not considered a first-line treatment or standard of care for early-stage (Stages I and II) larynx cancer.



▲ **Figure 31–15.** Tracheoesophageal speech requires a prosthesis and a tracheostoma occlusion. (Reprinted, with permission, from InHealth Technologies, Carpinteria, CA.)

4. Molecular targeted therapy—Recent discoveries in the molecular biology of laryngeal cancer have provided insight into the understanding of the molecular basis of these cancers, which have led to the development of targeted therapeutic strategies aimed at improving clinical outcomes and possibly survival for these patients. Clinical trials are exploring the use of *p53*-engineered recombinant adenoviruses to restore wild-type gene function and the use of epidermal growth factor receptor pathway antagonists. Other molecular-targeted therapies such as antiangiogenic drugs and vaccine-based therapies are also being developed and evaluated for the treatment of laryngeal cancer.

F. Complications of Treatment

The complications of larynx cancer reflect the treatment modality (or modalities) used.

1. Vocal problems—Hoarseness may complicate any treatment of larynx cancer, even the smallest larynx cancer. Voice changes can be as subtle as the loss of vocal range, vocal fatigue, and lowered threshold for bouts of laryngitis. Deepening of the voice or a raspy, rough quality of the voice is common. Failure to achieve tracheoesophageal speech after a total laryngectomy can be due to hypertonicity or stricture of the neopharyng\eal segment, an inappropriately positioned voice prosthesis, problems with digital occlusion of the stoma, or other neurologic impairment.

2. Swallowing problems—After partial laryngectomy procedures, aspiration risk is significant. This can be due to surgical removal or to denervation, in whole or in part, of the protective mechanisms of the larynx. Acute side effects of radiation include mucositis, thick secretions, odynophagia, and edema, which all contribute to swallowing difficulties in the immediate periradiation period. Xerostomia is a long-term side effect of radiation that also contributes to dysphagia. Stricture, stenosis, or fibrosis of the pharyngoesophageal segment as a result of surgical scarring or as a residual effect of radiation can lead to intolerance of solid foods or an inability to take adequate nutrition by mouth.

3. Loss of taste and smell—Radiation can permanently damage taste buds, although this side effect is often transient. After total laryngectomy, anatomic changes result in a lack of airflow through the nose and mouth. This severely changes the patient's sense of smell and, therefore, the sense of taste.

4. Fistula development—A fistula, or connection between the pharynx and skin of the neck, reflects the failure of the pharyngeal surgical closure to seal after laryngectomy. This results in the leakage of saliva and pharyngeal contents (including food) into the neck. When this initial fluid collection ruptures, leakage of mucoid and fluid material occurs onto the skin. Fistulas are more prone to occur in patients who have undergone previous radiation (up to 35% more likely) or surgery, and in those in whom the pharyngeal closure is tight. A fistula is more likely to occur if the nutritional status of the patient is poor (common) and may reflect a residual underlying cancer. Most fistulas close by secondary intention with conservative management, including feeding through a nasogastric or gastrostomy tube. Occasionally, surgical closure with a flap is advisable for vascular protection, for control of infection, or for facilitation of the delivery of indicated postoperative adjuvant therapy.

5. Airway problems—Some patients undergoing partial laryngectomy procedures are left with either an inadequate laryngeal airway or significant aspiration; for these reasons, they remain dependent on tracheotomy tubes. Excessive laryngeal edema can also happen as a sequela of radiation treatment alone. For patients who undergo a total laryngectomy, excessive secretions and crusting mucus can occlude the tracheostoma. Patients who undergo total laryngectomy often have an increased air temperature sensitivity, which manifests by cough; the lack of airway protection may also result in increased risk of aspiration and drowning.

6. Cranial nerve injury—During the surgical dissection for a partial or total laryngectomy with neck dissection, cranial nerves VII (the marginal mandibular branch), IX, X, XI, and XII are encountered and are therefore at risk for potential injury. Injury can be temporary or permanent. Preoperatively, patients need to be counseled about the following potential postoperative complications: asymmetric smile and mouth closure, swallowing difficulties, hoarseness and aspiration, shoulder drop and range-of-motion limitation, and the impairment of tongue mobility. Similarly, patients with aggressive larynx tumors with neck extension or locoregional metastases may present with, or develop, these cranial nerve deficits because of tumor involvement of the nerve.

7. Vascular injuries and events—Stroke is a risk of laryngectomy and neck dissection, but occurs surprisingly infrequently. A long-term sequela of radiation to the neck is acceleration of carotid atherosclerosis, and patients who have undergone radiation to the neck have a greater risk for stroke because of this.

In advanced tumors with necrosis and the resulting exposure of the carotid artery or the internal jugular vein, rupture (a carotid or jugular "blowout") is a risk. In cases of sentinel bleeds, angiographic embolization or stenting can prevent or stave off further bleeding. Flap coverage with vascularized tissue, when feasible, can protect against further bleeding. For patients who do experience a carotid blowout, the incidence of major debilitating stroke is >50% in attempts at surgical salvage. Surgical salvage consists of ligating the carotid artery or more rarely attempting bypass. Major vessel rupture is otherwise a commonly fatal event.

8. Dropped shoulder—Injury to the spinal accessory nerve during neck dissection results in a loss of trapezius muscle function, an inability to abduct the arm past 90°, and downward and inward rotation of the shoulder. These limitations can also occur as a result of primary tumor or neck metastases involving the spinal accessory nerve. Patients complain of a loss of shoulder function and pain. With intensive physical therapy, these deficits and pain can be overcome by increasing the strength of the other muscles of the shoulder girdle.

9. Tissue fibrosis—Because of radiation and surgery, which are augmented by the loss of the function of cranial nerve XI (when it occurs), larynx cancer patients often experience significant fibrosis of neck tissues. This manifests by stiffening, loss of range of motion, and pain. Fibrosis of the larynx and ankylosis of the cricoarytenoid joint have also been observed as a result of radiation treatment, leading to bilateral vocal cord immobility many years after the treatment.

10. Hypothyroidism—A loss of thyroid function can occur as a result of radiation to the lower anterior neck from a thyroidectomy done as part of laryngectomy, devascularization, or as a combined result of both. Hypothyroidism may not become apparent clinically or by serum tests until 6–12 months (or longer) after the completion of treatment for larynx cancer. Severe hypofunction may be responsible for poor healing of flaps and fistulas. For this reason, thyroid function tests should be performed periodically. Replacing the thyroid hormone with appropriately titrated doses of enteral thyroxin is curative, but requires periodic monitoring.

11. Other complications—Other risks of laryngectomy include hematoma and infection.

G. Long-Term Clinical Follow-up

Patients with larynx cancer should be followed up clinically in the same manner in which patients with cancer of the head and neck are generally followed up. After treatment is completed, routine office visits are scheduled at 4-to 6-week intervals. During these visits, a complete head and neck examination is performed, focusing on the primary site for signs of recurrence, but also screening for metachronous primary malignant lesions. So-called "second" primary lesions have an annual incidence of 4–7%. After the first year, visits can extend to every 2 months during the second year, every 3 months during the third and fourth years, and every 6–12 months thereafter. Most recurrences of head and neck cancer occur within the first 2 years after treatment. Individuals are considered to be cured of their index primary after 5 years of disease-free status. The signs and symptoms of recurrence are the same as those of the initial presentation, including hoarseness, dysphagia, otalgia, hemorrhage, cervical adenopathy, and pain. The findings of the physical examination, the evaluation for metastases, and the diagnostic tests are the same for recurrences as they were for the original occurrence.

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Table 31–4. Larynx Cancer: 5-year Survival Rates by Stage.

Stage I >95%
Stage II 85–90%
Stage III 70–80%
Stage IV 50–60%
All Stages 68%

Zhang B, Xu ZG, Tang PZ. Elective neck dissection for laryngeal cancer in the clinically negative neck. *J Surg Oncol*. 2006;93(6):464 [PMID: 16615158]. (Study evaluating the efficacy of a lateral neck dissection in the elective treatment of the clinically negative necks in patients with laryngeal cancer.)

Prognosis

Cure for larynx cancer, defined as the 5-year disease-free survival, is generally better than for other primary site tumors of the upper aerodigestive tract (Tables 31–4 and 31–5). This reflects the prevalence of primary glottic tumors over primary supraglottic tumors and the early stage at which glottic tumors are diagnosed. Persistent hoarseness is one indication for which an individual will seek clinical care usually before the emergence of nodal metastasis. Nonetheless, 5-year survival rates have not improved over the last three decades despite advances in surgical technique, the expansion of treatment options, and decrease in morbidity.

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Table 31–5. Larynx Cancer: 5-year Survival Rates by Site and Stage.

Supraglottis	Glottis	Subglottis
Stage I 53–82%	Stage I 74–100%	All stages 36–42%
Stage II 50–64%	Stage II 64–76%	
Stage III 50–60%	Stage III 50–60%	
Stage IV <50%	Stage IV 30–57%	

Vocal Cord Paralysis

32

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True vocal cord paralysis signifies loss of active movement of the "true" vocal cord, or vocal fold, secondary to disruption of the motor innervation of the larynx. Disruption of innervation may occur along the length of the recurrent laryngeal nerves and the vagi and may include damage to the motor nuclei of the vagus. It should be differentiated from fixation of the vocal cord secondary to direct infiltration of the vocal fold, larynx, or laryngeal muscles. It should also be distinguished from fixation at the cricoarytenoid joint, encountered with rheumatoid arthritis or following traumatic intubation.

The site of disruption of the nerve supply leads to a characteristic pattern in the position of the vocal cords. However, distinguishing between recurrent laryngeal nerve paralysis and vocal cord paralysis secondary to disruption of the vagus nerve can be difficult.

Table 32–1 summarizes the main causes of vocal cord paralysis in adults. Once the cause of the vocal cord paralysis is ascertained, the next stage is to consider the rehabilitation and treatment of the patient depending on his or her symptoms.

ANATOMY

The relevant anatomy of the larynx is best understood in terms of the muscles producing abduction and adduction of the vocal cords and their nerve supply. All the intrinsic laryngeal muscles, except the cricothyroid muscle, which is supplied by the external branch of the superior laryngeal nerve, are supplied by the recurrent laryngeal nerve. The sole abductor of the vocal cords is the posterior cricoarytenoid muscle. Table 32–2 provides a summary of the relevant laryngeal musculature and their innervation.

To understand the causes of vocal cord paralysis, it is important to understand the pathways of the vagus and recurrent laryngeal nerves. The course of the vagi in both sides of the head and neck are identical, but the recurrent laryngeal nerves differ significantly in their course once they leave the vagus.

The nuclei lie in the upper medulla and give rise to 8–10 rootlets that lie between the glossopharyngeal nerve superiorly and the spinal root of the accessory nerve inferiorly. The muscles of the pharynx, upper esophagus, larynx, and palate are all supplied by motor fibers originating in the nucleus ambiguus. Most of these fibers join the vagus at the inferior cervical ganglion below the jugular foramen, from the cranial root of the accessory nerve.

The vagus leaves the cranial cavity via the jugular foramen with the glossopharyngeal and hypoglossal nerves. It then descends vertically in the neck within the carotid sheath, adherent to the internal carotid artery, lying deep between the internal jugular vein and the artery itself.

The right vagus enters the thorax crossing superficially to the right subclavian artery. The right recurrent laryngeal nerve then leaves the vagus, curling underneath the artery to run superiorly in the tracheoesophageal groove and pass under the inferior constrictor of the pharynx, into the larynx.

The left vagus enters the thorax deep to the left brachiocephalic vein, between the carotid and subclavian arteries. The left recurrent laryngeal nerve leaves the vagus as it crosses the aortic arch, and then passes under the ligamentum arteriosum before taking a similar course to the right recurrent laryngeal nerve.

PATIENT EVALUATION

The initial evaluation of any patient presenting with dysphonia must include a systemic voice assessment (see Chapter 29). A thorough history must be taken, noting the onset and duration of the dysphonia. A detailed medical and surgical history is particularly important. The examination must include a full ear, nose, and throat examination as well as a detailed inspection of the vocal cords and larynx (see Chapter 29) to rule out an associated infiltrating lesion. This lesion can produce fixation of the vocal fold, which may be missed with a mirror examination. Although difficult to distinguish clinically, if unilateral or bilateral vocal cord

Table 32–1. Etiology of Vocal Cord Paralysis in Adults.

Type of Paralysis	Etiology
Unilateral recurrent	Neoplasia
Laryngeal	Iatrogenic causes
	Trauma
	Aneurysms
	Idiopathic causes
Bilateral recurrent	Post-thyroid surgery
Laryngeal	Thyroid neoplasia
Unilateral vagal	Iatrogenic causes
	Neoplasia
	Neurologic causes
	Brainstem infarction
	Skull base
	Osteomyelitis
	Idiopathic causes
Bilateral vagal	Neurologic causes

paralysis secondary to high disruption of the vagus nerve can be ascertained after inspecting the vocal cords, a full examination of the other cranial nerves should be instituted.

Laryngeal electromyography may be helpful in distinguishing between denervation of the intrinsic muscles and vocal cord fixation. It may also estimate the prognosis relative to reinnervation.

Koufman JA, Postma GW, Whang CS et al. Diagnostic laryngeal electromyography: The Wake Forest experience 1995–1999. *Otolaryngol Head Neck Surg.* 2001;124:603 [PMID: 11391248]. (Evaluation of laryngeal electromyography in the management of vocal cord paralysis.)

Simpson CB, Fleming DJ. Medical and vocal history in the evaluation of dysphonia. *Otolaryngol Clin North Am* 2000;33:719. [PMID: 10918656]. (Review of history-taking in voice disorders.)

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Table 32–2. Summary of Innervation of the Vocal Cord.

Muscle	Nerve
Adductors (lateral cricoarytenoid, thyroarytenoid, interarytenoids)	Recurrent laryngeal (adductor branch)
Posterior cricoarytenoid	Recurrent laryngeal (abductor branch)
Cricothyroid	External laryngeal

UNILATERAL VOCAL CORD PARALYSIS

UNILATERAL RECURRENT LARYNGEAL PARALYSIS

ESSENTIALS OF DIAGNOSIS

- Dysphonia.
- "Bovine" cough.
- Unilateral paramedian vocal fold paralysis.
- Voice may tire with use.

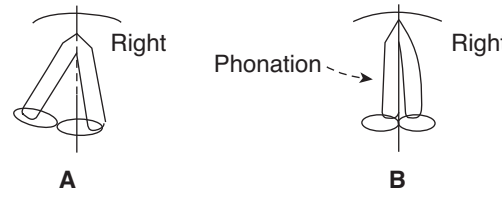
General Considerations

The initial stage in evaluating a unilateral vocal cord paralysis is to establish whether the paralysis is secondary to a recurrent laryngeal nerve injury or to disruption of the vagus nerve. Lesions producing the characteristic paramedian vocal cord palsy are found below the origin of the superior laryngeal nerve. The paralyzed vocal cord is found in the paramedian position owing to the unopposed action of the cricothyroid muscle (Figure 32–1). Left vocal cord paralysis is more common than paralysis of the right vocal cord because of the longer and more convoluted course of the left recurrent laryngeal nerve. The right vocal cord is involved in 3–30% of cases.

Most unilateral vocal cord paralyses are secondary to surgery; therefore, the relative timing of the onset of the dysphonia to any relevant surgery is crucial.

Etiology

The causes of unilateral recurrent laryngeal paralysis can be iatrogenic (eg, following thyroid, esophageal, cervical spine, and thoracic surgery). It can also be caused by a primary and secondary lung carcinoma or a malignant tumor of the esophagus or thyroid. Aneurysms of the aorta or left atrial dilation (Ortner syndrome) and trauma may also contribute to the development of this palsy. The etiology may also be idiopathic.



▲ **Figure 32–1.** Right recurrent laryngeal nerve paralysis (dotted line = midline). **(A)** At rest, the paralyzed cord takes up a paramedian position. **(B)** On phonation.

Clinical Findings

A. Symptoms and Signs

The presenting symptoms associated with the dysphonia as well as the position of the vocal cords are the key to the underlying diagnosis. Patients present with dysphonia; their voices may become weak with use. It is important to question patients regarding respiratory symptoms such as cough, hemoptysis, and dyspnea, particularly in patients who smoke as these symptoms may indicate an underlying malignant chest neoplasm. Signs suggestive of underlying chest malignancy include evidence of clubbing, which is seen in patients with bronchogenic carcinoma, Horner syndrome, and a pleural effusion.

Vocal cord paralysis secondary to recurrent laryngeal nerve paralysis classically produces an immobile vocal cord in the paramedian position. Depending on the time of patient presentation after the development of dysphonia, the other vocal fold may compensate for the immobile one, thus limiting the degree of hoarseness experienced.

B. Imaging Studies

For patients with recurrent laryngeal nerve palsy, accurate imaging of the neck and chest must be performed; the first sign of a malignant chest neoplasm may be recurrent laryngeal nerve palsy. A chest CT should identify an intrathoracic cause. If negative, an MRI of the neck and posterior fossa should be performed (as in practice it is often difficult to distinguish between vagal and recurrent laryngeal nerve palsy). If still negative, an endoscopy including bronchoscopy should be considered.

Treatment

A. Nonsurgical Measures

Expectant treatment is recommended when there is no underlying malignant growth. Most unilateral cord palsies compensate within 6–18 months. Patient age, occupation, and preference as to how aggressively the vocal cord paralysis should be treated should all influence the treatment plan.

B. Surgical Measures

A range of surgical measures is available the aim of which is to allow contact with the opposite cord during phonation and swallowing and to improve the patients' ability to cough. Procedures may be static or dynamic. Dynamic procedures consist of re-innervation or laryngeal pacing with an implantable device; they are performed in relatively few centers worldwide and will not be discussed further. The two principal static measures are injection laryngoplasty and laryngeal framework surgery.

1. Injection laryngoplasty—It involves injecting a material laterally into the vocal fold to displace it medially. An ideal injectable material would lack an antigenic response, have similar viscoelastic properties to the vocal fold, be resistant to resorption or migration, and be easy to prepare and inject with precise control. Substances commonly used include collagen, Vox, calcium hydroxyapatite, polyacrylamide gel, and fat.

Hamilton DW et al. Bioplastique injection laryngoplasty: Voice performance outcome. *J Laryngol Otol*, 2007;121(5):427–435.
Rosen CA et al., Vocal fold augmentation with calcium hydroxyapatite: Twelve month report. *Laryngoscope* 2009;119(5):1033–1041.

2. Laryngeal framework surgery—Laryngeal framework surgery (in the form of medialization thyroplasty) involves the placement of a Silastic implant or Gore-tex lateral to the vocal fold via a window cut in the thyroid cartilage. The Silastic displaces the vocal fold medially, ensuring adequate glottic closure.

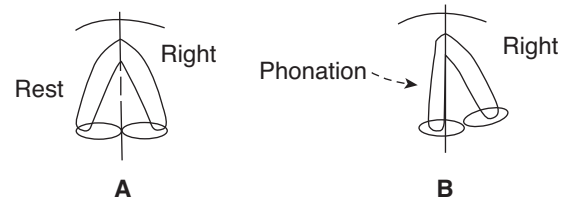
UNILATERAL COMPLETE VAGAL PARALYSIS

ESSENTIALS OF DIAGNOSIS

- Weak, breathy hoarseness.
- Possible history of aspiration.
- Site of injury above the origin of the superior laryngeal nerve.
- Vocal cord in lateralized intermediate position.

General Considerations

During the evaluation of a unilateral high vagal palsy, it is important to establish whether the site of damage to the nerve is at the skull base, the brainstem, or the cerebrum. Because of the inevitable loss of superior laryngeal nerve function, there is a decreased sensation of the larynx above the vocal cords on the affected side and a loss of cricothyroid muscle function. This loss of vagal nerve function leads to the paralyzed cord lying more laterally in the intermediate, or cadaveric, position (Figure 32–2).



▲ **Figure 32–2.** Right vagal nerve paralysis. **(A)** At rest, the paralyzed cord takes up an intermediate position. **(B)** On phonation.

Etiology

The origins of unilateral complete vagal paralysis include (1) iatrogenic causes (eg, skull base surgery), (2) neurologic causes (eg, multiple sclerosis, syringomyelia, and encephalitis), (3) a brainstem infarction (eg, Wallenberg syndrome), (4) a malignant growth (primary or secondary), and (5) inflammation (eg, skull base osteomyelitis).

Clinical Findings

A. Symptoms and Signs

Disruption of the vagus nerve at the skull base or at the motor nucleus of the vagus inevitably results in the loss of unilateral supraglottic sensation; a history of aspiration may therefore be obtained. Compensation of the contralateral vocal cord is often inadequate, and consequently the patient's voice remains weak and breathy.

Lesions of the skull base or brainstem may involve other cranial nerves (eg, the hypoglossal or glossopharyngeal nerves). Unilateral brainstem involvement is uncommon.

B. Laboratory Findings

Depending on the history and pattern of cranial nerve involvement, it may be worthwhile to obtain inflammatory markers such as a C-reactive protein or erythrocyte sedimentation rate (ESR), particularly if the patient has no history of surgery.

C. Imaging Studies

Imaging studies should adequately identify lesions of the skull base. MRI is the imaging modality of choice for the skull base because inflammatory changes on CT scans tend to present late and CT scanning does not image the brainstem satisfactorily.

Isotope bone scans may have use in patients who present with jugular foramen syndrome secondary to skull base osteomyelitis.

Treatment

Injection laryngoplasty is often unsuccessful in cases of complete vagal nerve paralysis because the relatively abducted position of the vocal cord leads to failure of injected materials to adequately displace the cord medially.

Medialization laryngoplasty, using silicone implants, is the optimal treatment method. Laryngoplasty may be combined with arytenoid adduction when the posterior glottic aperture is still not satisfactorily approximated. Most procedures are performed both to prevent aspiration and improve voice quality.

Anderson TD, Mirza N. Immediate percutaneous medialization for acute vocal fold immobility with aspiration. *Laryngoscope.* 2001;111:1318 [PMID: 11568562]. (Efficacy of Gelfoam injection laryngoplasty.)

Carrau RL. Laryngeal framework surgery for the management of aspiration. *Head Neck.* 1999;21:139 [PMID: 10091982]. (Medialization laryngoplasty with silicone, with or without arytenoid adduction.)

Hughes CA. Unilateral true vocal cord paralysis: Cause of right-sided lesions. *Otolaryngol Head Neck Surg.* 2000;122:678 [PMID: 10793345]. (Etiology of right vocal cord palsy.)

Kriskovich MD. Vocal fold paralysis after anterior cervical spine surgery: Incidence, mechanism, and prevention of injury. *Laryngoscope.* 2000;110:1467 [PMID: 10983944]. (Incidence of 2–6%; mechanism due to compression of the nerve during retraction.)

Lo CY. A prospective evaluation of recurrent laryngeal nerve paralysis during thyroidectomy. *Arch Surg* 2000;135:204 [PMID: 10668882]. (0.9% of patients developed permanent unilateral vocal cord palsy.)

Ramadan HH. Outcome and changing cause of unilateral vocal cord paralysis. *Otolaryngol Head Neck Surg.* 1998;118:199 [PMID: 9482553]. (Surgical and neoplastic causes underlying the majority of vocal cord paralyses.)

Zeitels SM. New procedures for paralytic dysphonia: Adduction arytenopexy, Gortex medialization laryngoplasty, and cricothyroid subluxation. *Otolaryngol Clin North Am* 2000;33(4):841–854.

BILATERAL VOCAL CORD PARALYSIS

BILATERAL RECURRENT LARYNGEAL NERVE PARALYSIS

ESSENTIALS OF DIAGNOSIS

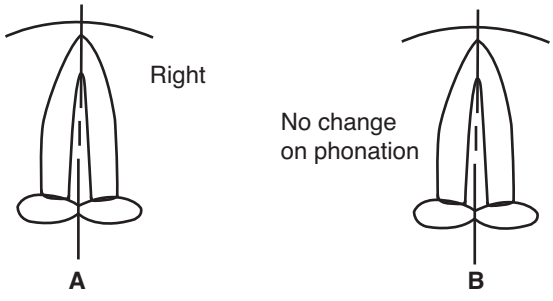
- Often presents with stridor.
- Voice may be normal.
- Usually a history of thyroid surgery.
- Vocal cords fixed in median to paramedian position.

General Considerations

The patient may have a recent history of thyroid surgery—usually total thyroidectomy. Rarely, an advanced malignant thyroid tumor may be an underlying cause. If unrecognized, presentation may be late as normal voice production is possible because of the close approximation of the vocal cords (Figure 32–3).

Clinical Findings

A patient who presents with a bilateral recurrent laryngeal nerve palsy usually does so in an emergency situation, following the development of stridor. The patient may have been well previously, with an apparently normal voice, but developed airway decompensation after an upper respiratory tract infection. Because the vocal folds are adducted, minimal swelling may precipitate stridor.



▲ **Figure 32–3.** Bilateral recurrent laryngeal nerve paralysis (dotted line = midline). **(A)** At rest and **(B)** on phonation.

Treatment

In an emergency situation, tracheostomy is often the only viable option. It is important to discuss with the patient the possible options for long-term treatment if decannulation is to be considered, since any operation to improve the airway may make the voice worse and increase the risk of aspiration. Some patients are happy maintaining their tracheostomy tube on a long-term basis and a fenestrated, cuffless tube is suitable in most cases.

Stitch lateralization of the vocal cord is an effective option during the recovery of nerve function because it prevents the need for a long-term tracheostomy. Partial or full recovery may occur in more than 50% of patients. The main operative procedure currently in practice is laser arytenoidectomy or unilateral or bilateral cordectomy.

Other lateralization procedures exist; however, though improving the airway, they carry the risk of increasing vocal impairment and aspiration.

BILATERAL COMPLETE VAGAL NERVE PARALYSIS

ESSENTIALS OF DIAGNOSIS

- Weak voice.
- History of aspiration and choking.
- Vocal cords in intermediate position.
- Satisfactory glottic aperture at rest.

General Considerations

Bilateral, high vagal, or brainstem involvement is unusual and often secondary to a neurological cause. The complete loss of supraglottic sensation results in a significant risk of aspiration. Vagal paralysis is often accompanied by the involvement of other cranial nerves, typically the glossopharyngeal and hypoglossal nerves.

Etiology

Neurological causes of bilateral complete vagal nerve paralysis include brainstem infarction, multiple sclerosis, and motor neuron disease (eg, amyotrophic lateral sclerosis [ALS]).

Clinical Findings

A. Symptoms and Signs

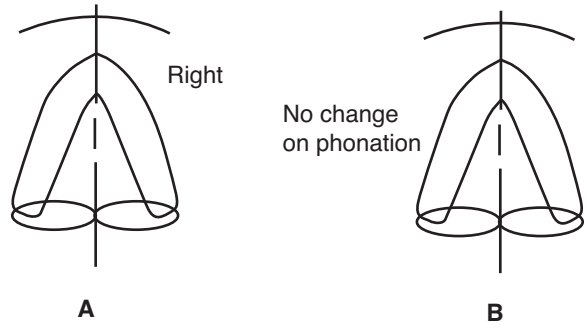
Patients present with either an acute or progressive onset of a weak, breathy voice associated with a history of choking and dysphagia. There may be a history of nasopharyngeal regurgitation. Patients are short of breath on exertion and may develop stridor in the presence of respiratory tract infection. The patient may be dysarthric and have signs of other cranial nerve involvement, such as paralysis of the tongue and loss of a gag reflex. Bilateral vagal nerve paralysis produces immobile vocal cords located in an intermediate position with a widened glottic aperture (Figure 32–4). There may be passive glottic closure on forced inspiration; therefore, it is important to correlate cord movement with the phase of respiration.

B. Imaging Studies

Brainstem disease is best visualized with the aid of MRI scans.

Treatment

Treatment is directed at preventing aspiration and ensuring adequate nutrition. If stridor develops, which is often in the presence of an underlying pneumonia or upper respiratory



▲ **Figure 32–4.** Bilateral vagal nerve paralysis. **(A)** At rest and **(B)** on phonation.

tract infection, then a tracheostomy is usually required. A cuffed tracheostomy tube also helps to diminish aspiration. Long-term enteral nutrition via a percutaneous gastrostomy tube is often necessary. If the vocal cord paralysis is stable, then medialization techniques may be used.

Miyamoto RC, Parikh SR, Gellad W, Licameli GR. Bilateral congenital vocal cord paralysis: A 16-year institutional review. *Otolaryngol Head Neck Surg.* 2005;133:241. ISSN: 0194-5998.

Misiolek M, Ziora D, Namylowski G. Long term results in patients after combined laser total arytenoidectomy with posterior cordectomy for bilateral vocal cord paralysis. *Eur Arch Otolaryngol.* 2007;264:895–900.

Rovo L, Jori J, Brzozha M, Caigner J. Airway complications after thyroid surgery: Minimally invasive management of bilateral recurrent nerve injury. *Laryngoscope*. 2000;110:140 [PMID: 10646730]. (Stitch lateralization as an alternative treatment for bilateral recurrent laryngeal nerve palsy.)

Worley G, Bajaj Y, Hartley B. Laser arytenoidectomy in children with bilateral vocal fold immobility. *Journal of Laryngology and Otology*. 2007;121:25–27.

We would like to acknowledge Rupert Obholzer, MRCS and R Gareth Rowlands FRCS(ORL-HNS) for their contribution to this chapter in the previous editions of CDT.

Stridor in Children

33

Philip D. Yates, MB ChB, FRCS

Stridor is a harsh noise produced by turbulent airflow through a partially obstructed airway. It may be inspiratory, expiratory, or both (biphasic). The term **stertor** is used to describe airway noise originating in the nose, nasopharynx, and oropharynx; therefore, stridor is generally of laryngeal or tracheal origin. As a general rule, **inspiratory stridor** originates from the supraglottis and glottis, **expiratory stridor** from the trachea, and **biphasic stridor** from the subglottis. There is a wide variety of causes of airway obstruction in children (Table 33–1). This chapter describes the more common laryngeal abnormalities that can cause stridor.

LARYNGOMALACIA

ESSENTIALS OF DIAGNOSIS

- Intermittent, positional inspiratory stridor (usually mild).
- Gradual worsening of stridor followed by spontaneous resolution.
- Supraglottic collapse on inspiration.

General Considerations

Laryngomalacia is the most common cause of stridor in infants, and is also the most common congenital laryngeal abnormality, accounting for approximately 60% of cases. Stridor occurs as a result of prolapse of the supraglottic structures into the laryngeal inlet on inspiration. The epiglottis is classically described as being omega shaped and folded in upon itself so that the lateral margins lie close to each other (Figure 33–1). The aryepiglottic folds are tall, foreshortened, and thin, and the arytenoids are large with redundant mucosa. Mucosal edema resulting from repeated vibratory trauma to the supraglottis exacerbates the symptoms.

Although most cases of laryngomalacia have a benign course without any long-term sequelae, the most severe cases, in which significant desaturation occurs, can result in significant morbidity, such as pulmonary hypertension and cor pulmonale.

The incidence of synchronous airway lesions associated with laryngomalacia has been reported in 12–45% of cases, although less than 5% of these cases require intervention.

Clinical Findings

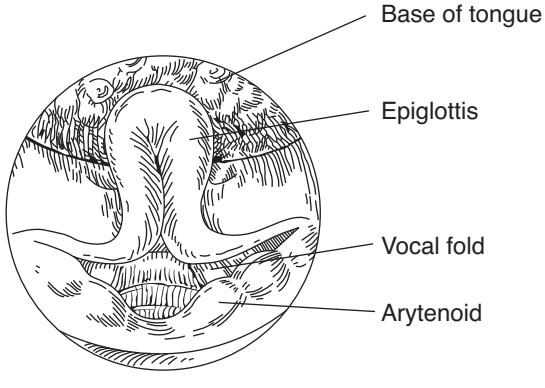
A. Symptoms and Signs

Infants with laryngomalacia usually have no sign of respiratory abnormality at birth. Inspiratory stridor typically develops after a few days or weeks and is initially mild, but over the ensuing months becomes gradually more pronounced, usually peaking at the age of 6–9 months. Spontaneous improvement then occurs and symptoms usually completely resolve by the age of 18 months to 2 years of age. Stridor is not constantly present; rather, it is intermittent and variable in intensity. Typically, symptoms are worse during sleep, stridor being worse when the patient is in the supine position and improved when the patient is prone. Both feeding and exertion tend to result in more pronounced stridor. Although an infant with laryngomalacia usually has a normal cry, stridor may be exacerbated by crying owing to a more forceful inspiratory effort. In most cases, symptoms are mild and self-limiting, but a small proportion of cases have severe stridor, apneic episodes, feeding difficulties, and failure to thrive.

Table 33–1. Causes of Airway Obstruction in Infants and Children.

	Congenital	Acquired
Supralaryngeal	Choanal atresia Craniofacial abnormalities Retrognathia Macroglossia	Adenotonsillar hypertrophy Foreign body Retropharyngeal abscess Ludwig's angina
Laryngeal	Laryngomalacia Laryngeal cysts Laryngeal webs Posterior laryngeal cleft Vocal cord paralysis Cricoarytenoid joint fixation Subglottic hemangioma	Iatrogenic (surgical and intubation) Laryngeal webs Subglottic stenosis Vocal cord paralysis Inflammatory Epiglottitis Laryngotracheobronchitis Hereditary angioedema Neoplasms Respiratory papillomatosis Rhabdomyosarcoma External compression Thyroid Cystic hygroma Foreign bodies Burns (caustic and thermal) External trauma Laryngotracheobronchitis
Tracheal	Tracheobronchomalacia Stenosis Vascular compression Aberrant innominate artery Double aortic arch Pulmonary artery sling Tracheal cysts	Bacterial tracheitis Foreign bodies External compression Thyroid Cystic hygromas Mediastinal tumors

Clinical examination of the patient may reveal no abnormality. If the infant is sleeping or crying, then stridor is more likely to be observed and its associated signs, such as tachypnea and intercostal and subcostal recessions, should be sought. Cyanosis is extremely unusual in laryngomalacia and should raise the suspicion of some other pathology.



▲ **Figure 33–1.** Appearance of the infantile larynx in laryngomalacia.

B. Evaluation

1. Endoscopy—The use of a flexible fiberoptic endoscope under local anesthesia is safe and allows a dynamic assessment of the glottis and supraglottis and avoids the risks associated with general anesthesia.

2. Laryngotracheobronchoscopy—Laryngotracheobronchoscopy is often considered to be an essential study before a definitive diagnosis can be made in order to rule out any synchronous airway pathology.

3. Polysomnography—In severe cases, polysomnography can be performed to detect episodes of hypoxia or hypercapnia. The results of this study can influence the decision to undertake surgical management of the condition.

▶ Treatment

In most patients, laryngomalacia is a self-limiting condition that does not result in any harm to the patient; therefore,

observation is all that is required. In the most severe cases of laryngomalacia, which is encountered in a small percentage of patients, a temporary tracheotomy may be unavoidable.

Surgical intervention is indicated for approximately 10% of patients. The main indications for surgery are severe stridor, apnea, failure to thrive, pulmonary hypertension, and cor pulmonale. A variety of procedures have been described for the treatment of laryngomalacia (referred to as supraglottoplasty), which are largely aimed at reduction of the redundant laryngeal mucosa. These procedures include (1) division of the aryepiglottic folds, (2) excision of a wedge of the aryepiglottic fold with or without trimming the arytenoids or the lateral border of the epiglottis, and (3) suturing of the epiglottis to the base of the tongue. There is disagreement as to whether microdissection or laser surgery is the optimum treatment modality. Physicians who favor laser surgery contend that bleeding is less of a problem compared with microdissection; physicians who favor microdissection maintain that the risk of postoperative scarring is greater with the use of laser.

Complications of supraglottoplasty include bleeding, aspiration, and supraglottic scarring. The risk of supraglottic stenosis is lessened by excising the least amount of supraglottic mucosa to produce an improvement in symptoms. Scarring is particularly problematic in the interarytenoid region; therefore, an island of mucosa must be left in this area.

High rates of reflux have been demonstrated in patients with laryngomalacia, and it has therefore been implicated as a causative factor. However, the relationship remains unproven, hence, the controversy in the antireflux medication for laryngomalacia.

Richter GT, Thompson DM. The surgical management of laryngomalacia. *Otolaryngol Clin North Am.* 2008;41(5):837–64. [PMID: 18775337] (Review article of surgical management.)

LARYNGEAL CYSTS

Laryngeal cysts are a rare cause of stridor in infants. The two main types of laryngeal cysts are ductal and saccular cysts. **Ductal cysts** are more common and are thought to originate from obstruction of the submucous glands. They can arise anywhere in the larynx, but are most commonly found in the supraglottis. **Saccular cysts** arise in the laryngeal ventricle and are usually congenital in infants. Unlike laryngoceles, which usually present in adults, saccular cysts do not communicate with the laryngeal lumen.

The most common symptoms arising from laryngeal cysts are stridor, feeding difficulties, and cyanotic episodes. Laryngeal cysts can usually be managed by endoscopic de-roofing or excision.

VOCAL CORD PARALYSIS

ESSENTIALS OF DIAGNOSIS

(1) Unilateral Vocal Cord Paralysis
- Hoarse or breathy voice/cry.
- ± Mild dyspnea, stridor, or both.
- ± Aspiration.
- Spontaneous improvement or resolution.

(2) Bilateral Vocal Cord Paralysis
- Severe stridor.
- ± Aspiration.
- Usually requires tracheotomy.

General Considerations

Vocal cord paralysis in infants and children can be either congenital or acquired and either unilateral or bilateral. It is the second most common congenital abnormality of the larynx, accounting for approximately 10% of cases. Congenital vocal cord palsy is slightly more common in males, and is more commonly bilateral.

There are many causes of acquired vocal cord palsy (Table 33–2), although most commonly the paralysis is idiopathic. Central nervous system (CNS) abnormalities usually result in bilateral vocal cord palsy. The most common congenital CNS abnormality resulting in vocal cord palsy is the Arnold–Chiari malformation. Acquired CNS causes of vocal cord paralysis are rare in infants and children, as are acquired peripheral neuropathies. Congenital abnormalities of the heart and great vessels may lead to vocal cord palsy, or the paralysis may result from surgery to correct these abnormalities. In this situation, the left side is more commonly affected because of the longer course of the left recurrent laryngeal nerve through the mediastinum. Rarely, esophageal surgery, such as repair of a tracheoesophageal fistula, can result in a bilateral palsy. Other traumatic causes of vocal cord paralysis include birth trauma, intubation, and head injury. Inflammatory conditions such as encephalopathies and Guillain–Barré usually produce bilateral vocal cord paralysis. Neoplastic causes of vocal cord palsy are rare in infants and children. Familial X-linked vocal cord paralysis has been reported, but is extremely rare.

Clinical Findings

A. Symptoms and Signs

The symptoms arising from vocal cord palsy vary from the patient being asymptomatic to having an acute airway

Table 33–2. Etiology of Acquired Vocal Cord Paralysis.

Idiopathic
Central Nervous System
Arnold-Chiari malformation
Hydrocephalus
Encephalocele
Syringomyelia or syringobulbia
Peripheral Nervous System
Myasthenia gravis
Myotonic dystrophy
Charcot-Marie-Tooth disease
Trauma
Surgical
Head injury
Endotracheal intubation
Birth trauma
Neoplasia
Thyroid carcinoma
Inflammatory
Viral
Bacterial
Granulomatous
Cardiovascular Anomalies
Tetralogy of Fallot
Cardiomegaly
Patent ductus arteriosus
Vascular rings

obstruction that requires emergency intervention. Patients with unilateral vocal cord palsy do not usually have signs of airway obstruction. The usual presenting features are a hoarse, breathy voice or cry and a weak cough. Feeding problems and aspiration are more likely to occur if the lesion is proximal to the superior laryngeal nerve since this nerve supplies sensation to the supraglottis. Bilateral vocal cord paralysis tends to have more pronounced symptoms such as stridor, apnea, and cyanosis; however, if the vocal cords lie in the intermediate position, then airway obstruction does not occur and aspiration is the primary problem.

B. Evaluation

If any doubt about the stability of the airway exists, then the patient should be evaluated in the operating room and the airway secured before further investigation is considered.

Although fiberoptic endoscopy can reliably demonstrate vocal cord palsy, the airway needs to be assessed by laryngotracheobronchoscopy for two reasons: (1) the arytenoid cartilage must be palpated to exclude the rare finding of a fixed cricoarytenoid joint; (2) the possibility of synchronous pathology in the airway must be excluded.

If a cause is not apparent, then a magnetic resonance imaging (MRI) scan including the brain, brainstem, neck, and chest (the course of the vagus and recurrent laryngeal nerves) should be performed. In patients in whom aspiration is suspected, a contrast swallow or videofluoroscopy can provide information on deglutition and laryngeal penetration. Functional endoscopy evaluation of swallowing is also used in the pediatric group.

Treatment

The function of the glottis is to protect the lungs from the aspiration of food while providing an adequate airway. A secondary, though important, function is to provide a voice. Management decisions are influenced by the underlying cause, the severity of symptoms, and the likelihood of spontaneous recovery. Spontaneous recovery occurs more frequently in acquired than in congenital vocal cord palsy, and it is also more likely in unilateral than bilateral vocal cord palsy.

A. Unilateral Vocal Cord Paralysis

Most children with unilateral vocal cord paralysis have minimal symptoms because the normal vocal cord adopts a more medial position to compensate for the paralyzed vocal cord. If poor voice quality is persistent, then speech therapy is the preferred treatment. In the rare instance in which the airway is significantly compromised, tracheotomy is indicated. Successful decannulation without the need for further laryngeal surgery is usually possible as the larynx develops.

B. Bilateral Vocal Cord Paralysis

In children with bilateral vocal cord palsy, the vocal cords usually lie in the adducted position, which results in a compromised airway. This circumstance indicates that the majority of cases of bilateral vocal cord palsy will require a tracheotomy to maintain the airway. Once a tracheotomy has been performed, serial endoscopy should be planned to monitor any spontaneous recovery of vocal cord function. It is recommended that irreversible surgical procedures on the larynx are not considered for at least 1 year after a tracheotomy. Some otolaryngologists prefer to wait until the child is old enough to make his or her own decision about further surgery. The aim of surgery for permanent bilateral vocal cord palsy is to produce an airway of sufficient size to allow decannulation without compromising the protective function of the larynx or producing an unacceptable voice quality. Various surgical techniques have been described to accomplish this goal.

Miyamoto RC, Parikh SR, Gellad W, et al. Bilateral congenital vocal cord paralysis: a 16 year institutional review. *Otolaryngol Head Neck Surg*. 2005;133(2):241–245. [PMID: 16087022] (Outcome review of 22 patients treated for bilateral vocal cord palsy.)

Parikh SR. Pediatric unilateral vocal fold immobility. *Otolaryngol Clin North Am*. 2004;37(1):203. [PMID: 15062694] (General review of unilateral vocal cord palsy including the diagnosis and the management.)

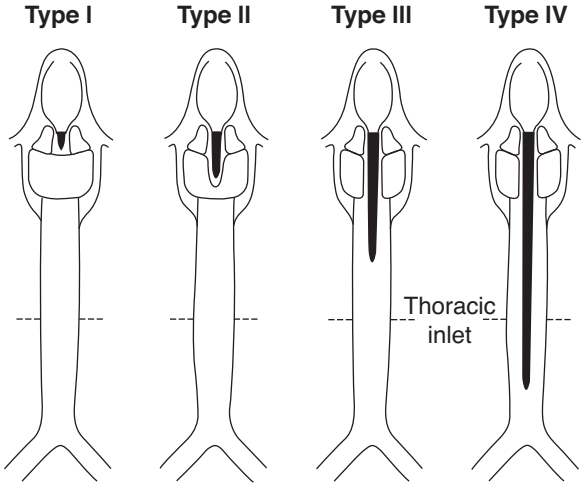
CONGENITAL LARYNGEAL WEBS

Laryngeal webs are thought to arise from a failure of complete recanalization of the larynx in the embryo. Although webbing can occur at all levels in the larynx, it is most commonly seen in the anterior glottis. When webbing is severe, it is often associated with subglottic stenosis. Complete atresia of the larynx is extremely rare and requires immediate tracheotomy at birth.

The most common presenting symptoms are an abnormal cry and stridor. The diagnosis is made at endoscopy, and other airway abnormalities should be excluded. Small, thin webs usually respond to simple incision. More severe webbing may require an excision via a laryngofissure approach, with insertion of a stent.

POSTERIOR LARYNGEAL CLEFTS

A posterior laryngeal cleft is a rare congenital abnormality that occurs as a result of the failure of fusion of the posterior larynx and, in some cases, the trachea. The abnormality is classified according to the extent of the cleft (Figure 33–2). The predominant symptoms are hoarseness and aspiration; stridor is a rare feature. The severity of symptoms varies and depends on the extent of the abnormality. Type I clefts often have minimal symptoms, whereas Type IV clefts produce severe aspiration pneumonia and carry a poor prognosis even if surgical closure is attempted.



▲ **Figure 33–2.** Classification of posterior laryngeal clefts. **Type I:** interarytenoid cleft; superior to the glottis. **Type II:** partial cricoid cleft; extends inferior to the glottis and partially through the posterior lamina of the cricoid. **Type III:** total cricoid cleft, with or without extension into the cervical tracheoesophageal wall. **Type IV:** laryngotracheoesophageal cleft extending beyond the thoracic inlet.

The diagnosis of posterior laryngeal clefts is made by demonstrating penetration of the larynx on contrast swallow, and the presence of a cleft is confirmed at endoscopy. Mild clefts may require no treatment other than the thickening of feeds; however, if aspiration persists, then endoscopic closure should be considered. More extensive clefts require surgical closure.

LARYNGEAL FOREIGN BODIES

Most inhaled foreign bodies pass through the larynx and trachea and become lodged distally. There is often a history of the child having something in the mouth before the onset of symptoms. If a foreign body becomes lodged in the larynx and causes complete obstruction, it will cause sudden death unless removed immediately. If the airway is only partially obstructed, then stridor, hoarseness, and cough are the predominant symptoms. If the object is radiopaque, its site of impaction can be confirmed by x-ray. Removal under general anesthesia is generally required.

SUBGLOTTIC STENOSIS

ESSENTIALS OF DIAGNOSIS

(1) Congenital Subglottic Stenosis

- Stridor at birth, if moderate to severe stenosis.
- Intermittent stridor, associated with respiratory tract infections, if mild stenosis.

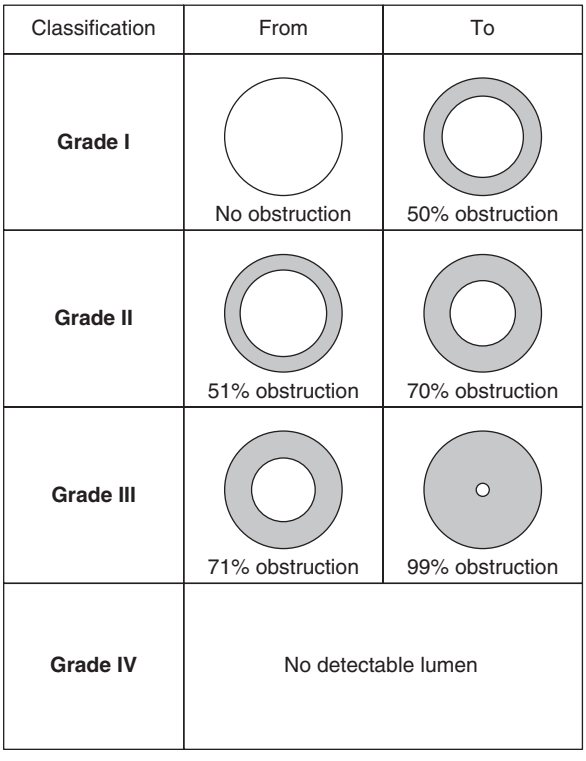
(2) Acquired Subglottic Stenosis

- Commonly as a consequence of prolonged endotracheal intubation.
- Presents with repeated failure of attempted extubation, or with gradual onset of stridor following extubation.

General Considerations

The subglottis is the narrowest portion of the airway in children, and the cricoid cartilage is the only complete cartilaginous ring in the airway. Because airflow in a cylinder is directly proportional to the fourth power of the radius, a slight reduction in the area of the subglottis can lead to significant obstruction.

The Myer–Cotton grading system describes the severity of stenosis according to the percentage of subglottic stenosis present (Figure 33–3). The percentage is calculated by measuring the largest sized endotracheal tube that can be passed through the subglottis and comparing this with the age-appropriate tube size for the child. A subglottic diameter of ≤4 mm in a full-term neonate is considered to be abnormal.



▲ **Figure 33–3.** Myer–Cotton grading system for subglottic stenosis.

Classification of Subglottic Stenosis

Subglottic stenosis can be either congenital or acquired. A diagnosis of congenital stenosis is made when there is absence of any factors that are known to lead to acquired stenosis and there is no previous documentation of a normal airway.

A. Congenital Subglottic Stenosis

Congenital subglottic stenosis is considered to be the third most common congenital abnormality of the larynx. Its true incidence is not known since some patients diagnosed with acquired stenosis after endotracheal intubation may have had a mild preexisting congenital stenosis.

B. Acquired Subglottic Stenosis

Acquired subglottic stenosis is much more common than congenital subglottic stenosis and is generally more severe and difficult to manage. The most common cause of acquired subglottic stenosis in children is endotracheal intubation trauma, accounting for approximately 90% of cases.

Pathogenesis

Subglottic stenosis secondary to endotracheal intubation is a result of pressure necrosis of the subglottic mucosa. The duration of intubation is the most important factor in the development of subglottic stenosis. Edema and ulceration occur followed by secondary infection and perichondritis. Granulation tissue then forms over the areas of perichondritis and the deposition of fibrous tissue results in stenosis. The role of gastroesophageal reflux in the pathogenesis of subglottic stenosis is not clear.

Prevention

The reported incidence of subglottic stenosis in children following endotracheal intubation ranges from 1% to 9%. This rate has fallen because of the introduction of preventive measures by pediatric intensive care units, although the reduction in incidence is somewhat offset by the increased survival of low birth weight infants requiring prolonged intubation. Factors that have reduced the incidence of subglottic stenosis include (1) the use of uncuffed, polyvinylchloride tubes; (2) the use of smaller tubes to reduce pressure on the subglottic mucosa; and (3) nasotracheal intubation, which produces better tube fixation and less frictional trauma.

Clinical Findings

A. Symptoms and Signs

The degree of stenosis dictates the severity of stridor. Severe congenital subglottic stenosis presents at birth with stridor and respiratory distress. Less severe stenosis is likely to present in the first few months of life when increased activity requires increased respiratory efforts. The subglottic edema produced by upper respiratory tract infections often precipitates stridor, which leads to misdiagnosis of recurrent laryngotracheobronchitis. In the case of acquired subglottic stenosis in neonates, the first indication may be a failed trial of extubation. Older children who sustain subglottic trauma may be successfully extubated, but gradually develop symptoms of respiratory distress over a period of weeks, as the fibrosis progresses.

B. Evaluation

Lateral neck and chest x-rays may show a stenosis of the airway in the subglottic region; however, confirmation of the diagnosis requires laryngotracheobronchoscopy under general anesthesia. At this point, staging of the stenosis can be performed.

Treatment

The management of subglottic stenosis is dictated by the type of stenosis, the grade of stenosis, and the age and

general condition of the patient. Surgical reconstruction is indicated when conservative efforts to establish a satisfactory airway are inappropriate or have failed.

A. Observation

In patients with minimal symptoms (Grade I or II), it may be possible to avoid surgical intervention with close observation and repeated endoscopies. This conservative approach ensures that the airway is increasing in dimension with the growth of the child.

B. Tracheotomy

A tracheotomy is frequently performed in patients with symptomatic subglottic stenosis to ensure that the airway is safe until laryngeal reconstruction is planned. It allows time for weight gain and recovery from pulmonary disorders in preterm neonates.

C. Endoscopic Treatment

Endoscopic use of the laser is useful in the treatment of early intubation injuries, particularly for the removal of granulation tissue and mild stenosis. The disadvantage of laser use is that thermal damage can result in scarring and possible worsening of the stenosis in the long term.

D. Anterior Cricoid Split

This procedure is used primarily as an alternative to tracheotomy in premature infants with an acquired subglottic stenosis who have failed multiple extubation attempts. By dividing the cricoid cartilage and the first two tracheal rings anteriorly, the cricoid is able to expand, thereby improving the airway.

E. Laryngotracheal Reconstruction

A variety of surgical techniques aimed at achieving an adequate airway have been described. Following laryngofissure, a cartilage graft can be inserted anteriorly, or both anteriorly and posteriorly. Conventionally, a stent is left in the larynx for a prolonged period until healing occurs; a tracheotomy is also required to maintain airway patency. Once a satisfactory laryngeal airway is achieved, decannulation can be considered. In single-stage laryngotracheal reconstruction cartilage grafts are inserted, but endotracheal intubation is maintained for 7–10 days to stent the larynx, and a tracheotomy is not required. This technique avoids the complication of long-term stenting, but there is an increased potential risk to the airway in the perioperative period.

F. Cricotracheal Resection

In contrast to laryngotracheal reconstruction, which is designed to enlarge the stenosed portion of the larynx, cricotracheal resection excises the stenotic region. This procedure carries a higher rate of success, but a possible favorable outcome must be weighed against the potential complications of recurrent laryngeal nerve damage and dehiscence of the anastomosis.

Eze NN, WyattME, Hartley BEJ. The role of anterior cricoid split in facilitating extubation in infants. *Int J Pediatr Otorhinolaryngol*. 2005;69(6):843–846. [PMID: 15885339] (Retrospective study of outcomes from 33 patients.)

Sandhu K, Monnier P. Cricotracheal resection. *Otolaryngol Clin North Am*. 2008;41(5):981–998. [PMID: 18775346] (Review article.)

White DR, Bravo M, Vijayasekaran S, et al. Laryngotracheoplasty as an alternative to tracheotomy in infants younger than 6 months. *Archives Otolaryngol Head Neck Surg*. 2009;135(5):445–447. [PMID: 19451463] (Comparison of results of laryngotracheoplasty with anterior cricoid split)

SUBGLOTTIC HEMANGIOMAS

ESSENTIALS OF DIAGNOSIS

- Stridor in first 6 months of life.
- Commonly associated with cutaneous hemangioma.
- Progression of symptoms from intermittent to persistent.
- Vascular mass in subglottis.
- Spontaneous resolution over several years.

General Considerations

Hemangiomas can occur in any part of the larynx, but the subglottis is the most common site. Subglottic hemangiomas are typically unilateral, but they can also be circumferential or can arise from multiple sites. They are vascular hamartomas that are most commonly capillary in nature on histologic examination; however, cavernous or mixed types can also occur. Subglottic hemangiomas are rare, accounting for ~1.5% of all congenital laryngeal anomalies. **Cutaneous hemangiomas,** a relatively common congenital abnormality, are found in about half of patients with a subglottic hemangioma and are frequently found in the head and neck region. There is a female preponderance, being twice as common in females.

The natural progression of hemangiomas is from an initial proliferative phase to an involutional phase. The proliferative phase starts soon after birth and usually continues for 12 months, after which gradual involution occurs over a period of years. Most hemangiomas will have resolved by the age of 5 years.

Clinical Findings

A. Symptoms and Signs

Because hemangiomas do not start to proliferate until after birth, they rarely present in the first weeks of life, but 80–90% will have presented by the age of 6 months. Initially, when the lesion is small, inspiratory stridor is intermittently present. At this stage, symptoms may be exacerbated by upper respiratory tract infections, which may lead to an initial diagnosis of recurrent laryngotracheobronchitis. As the lesion enlarges, the stridor becomes biphasic, and dyspnea and cyanosis may occur. The cry is usually normal unless the hemangioma extends onto the vocal folds.

B. Evaluation

The diagnosis of subglottic hemangioma may be suspected from the clinical presentation and reinforced by the finding of an asymmetric narrowing of the subglottis on lateral neck and chest x-rays. However, confirmation of the diagnosis requires laryngotracheobronchoscopy under general anesthesia. The typical finding on endoscopy is a unilateral, sessile, submucosal, compressible vascular lesion in the subglottis. The role of biopsy for histopathologic confirmation of the diagnosis is controversial, since it carries the risk of significant hemorrhage, although biopsy without associated bleeding is widely reported. Biopsy is generally reserved for those in which the diagnosis is uncertain.

In cases of a large cutaneous hemangioma in the neck associated with a hemangioma of the airway, further investigation with MRI is indicated since the lesions may be contiguous.

Treatment

Observation may be appropriate if the lesion is small and the symptoms are minimal. Most patients require a multimodality treatment. The aims of treatment are to overcome the airway obstruction while avoiding complications and long-term sequelae, particularly subglottic stenosis. A variety of treatment modalities are currently in use.

A. Tracheotomy

When tracheotomy is used as the sole treatment, decannulation is the ultimate aim. Decannulation can be attempted only when the airway is no longer compromised (as a result of the increased dimensions of the growing larynx and spontaneous involution of the hemangioma). Tracheotomy, however, is not without complications. Subglottic stenosis, in particular, is a recognized complication of tracheotomy and may require surgical intervention before decannulation can be achieved. If the hemangioma is large, there is a risk of complete airway obstruction if the tracheotomy tube becomes dislodged; therefore, skilled home care is required. There is also a significant effect on speech and language development, and multiple endoscopies are required to assess the stage of the airway. In view of these problems, treatment modalities have been developed to either expedite the possibility of decannulation or to avoid tracheotomy altogether.

B. Steroids

For the treatment of subglottic hemangiomas, steroids can be administered either systemically or by intralesional injection. It is not known how steroids accelerate the involution of hemangiomas, but it may be as a result of estrogen receptor blockade. Systemic steroids need to be used over a prolonged period, which may result in growth retardation, hypertension, and cushingoid appearance. The use of intralesional steroid injection aims to avoid these systemic side effects. However, local edema often results in an initial worsening of the airway, and if tracheotomy is to be avoided, then prolonged intubation may be required until resolution of the edema has occurred. Repeated injections may be required before a satisfactory result is achieved.

C. Laser Therapy

Both the carbon dioxide (CO_2) and potassium titanyl phosphate lasers have been used for the treatment of subglottic hemangioma. The advantage of using the laser is its hemostatic properties. It may be possible to avoid tracheotomy with repeated laser treatment, but equally repeated treatment increases the risk of scarring and subsequent subglottic stenosis.

D. Surgical Excision

The surgical excision of subglottic hemangiomas has been reserved for the most severe cases or cases that do not respond to more conventional therapy. However, with the development of the single-stage laryngotracheoplasty in the management of subglottic stenosis, primary excision is likely to become more commonplace as the need for a tracheotomy is avoided.

E. Interferon

Interferon alfa-2a has antiangiogenic activity and is therefore effective as a treatment for hemangiomas in their proliferative phase. Its use is generally reserved for patients with multiple airway sites or extensive cervical disease with external compression of the airway. The early withdrawal of treatment during the proliferative phase may result in the rapid rebound growth; therefore, treatment must be prolonged. Because of the unknown side effects of long-term treatment in children, interferon remains an option only in the most severe unresponsive cases.

Bajaj Y, Hartley BEJ, Wyatt ME et al. Subglottic haemangioma in children: experience with open surgical excision. *J Laryngol Otol*. 2007;120(12):1033–1037. [PMID: 17052378] (A review of surgical outcomes in 18 patients.)

O-Lee TJ, Messner A. Subglottic hemangioma. *Otolaryngol Clin North Am*. 2008;41(5):903–911. [PMID: 15510009] (Review article.)

RESPIRATORY PAPILLOMATOSIS

ESSENTIALS OF DIAGNOSIS

- Hoarse voice.
- Gradual onset of stridor.
- Recurrent disease requiring multiple surgical procedures.
- Viral etiology.

General Considerations

Although juvenile-onset recurrent respiratory papillomatosis is a rare disease, it is the most common neoplasm of the larynx in children. Diagnosis is most commonly made between the ages of 2 and 5 years, but papillomas can present in any age group. There is no difference in incidence between males and females. The first-born, vaginally delivered child of a teenage mother is associated with an increased chance of developing respiratory papillomatosis.

Papillomatosis is caused by infection with human papillomavirus (HPV), the most commonly identified subtypes being HPV-6 and HPV-11 (HPV-11 is more aggressive and more prone to malignant changes). The same HPV subtypes are responsible for genital warts, and there is a recognized association between maternal genital warts and respiratory papillomatosis. The larynx is the most commonly affected site in respiratory papillomatosis, particularly the glottis, but the mouth, the pharynx, tracheobronchial tree, and the esophagus can all be affected. Pulmonary papillomatosis is rare but carries high morbidity and mortality. The malignant transformation from benign nonkeratinizing squamous papillomas to squamous cell carcinoma can occur in children, but is rarely seen. Malignant transformation most commonly occurs in the distal bronchopulmonary tree, and the prognosis is universally poor.

Juvenile-onset respiratory papillomatosis has a more severe clinical course than that of adult-onset papillomatosis. Characteristically, multiple foci of papilloma recur frequently after treatment and usually require multiple surgical interventions. Spontaneous remission does occur but is unpredictable, and recurrence has been reported after prolonged disease-free periods.

Clinical Findings

A. Symptoms and Signs

Hoarseness, abnormal cry, or both are the most common presenting symptoms of respiratory papillomatosis. If the disease is untreated, then a gradual progression to dyspnea, stridor, and eventually, complete airway obstruction can occur. Stridor and airway obstruction are rarely the first symptoms. Examination may reveal a papilloma in the mouth or pharynx, although this finding is unusual. In a cooperative child, the diagnosis can be made by inspecting the larynx with either a laryngeal mirror or a flexible fiberoptic endoscope.

B. Evaluation

If the diagnosis of respiratory papillomatosis is suspected, then histopathologic confirmation is required. Examination should include tracheo-bronchoscopy to determine whether distal spread has occurred.

Treatment

The primary treatment modality for respiratory papillomatosis is surgery. The aims of treatment are to maintain an adequate airway while avoiding tracheotomy, preserving the voice and controlling the papilloma. The most widely accepted means of surgical ablation of respiratory papilloma is with the CO_2 laser. Because respiratory papillomatosis typically requires multiple procedures to maintain the airway, there is a significant risk of scarring and web formation due to repeated thermal damage caused by the laser. For this reason, it is advisable to leave small amounts of the papilloma in sites where scarring is likely to occur, such as the anterior commissure. Other disadvantages of using the laser include destruction of the papilloma, which both precludes histologic examination and exposes the operating room staff to virus particles in the laser plume. Removal of laryngeal papilloma can be performed using a powered shaver developed for use in the larynx. Although this system reduces the risks associated with the laser, it carries the potential disadvantage of poor hemostatic control. This finding does not appear to be problematic in preliminary reports.

Up to 20% of reported cases of respiratory papillomatosis are severe enough to require tracheotomy, although, if possible, a tracheotomy should be avoided because of the increased risk of distal spread.

Several adjuvant therapies are available, such as intralesional injection of cidofovir. This treatment can be an effective method of treatment, but the risk of inducing malignant transformation has recently been raised. The development of an HPV vaccine gives the potential to prevent further transmission of the disease, but the effectiveness of this will not be known for some years.

Donne AJ, Hampson L, He XT et al. Potential risk factors associated with the use of cidofovir to treat benign human papillomavirus-related disease. *Antivir Ther.* 2009;14(7):939–952. [PMID: 19918098] (Reports the possibility that cidofovir has the potential to induce malignant transformation.)

Gallagher T, Derkay CS. Pharmacotherapy of recurrent respiratory papillomatosis: an expert opinion. *Expert Opin Pharmacother.* 2009;10(4):645–655. [PMID: 19284366] (Review of pharmacotherapies for the treatment of recurrent respiratory papillomatosis.)

INFLAMMATORY CAUSES OF STRIDOR

The major causes of inflammatory stridor in children are laryngotracheobronchitis, epiglottitis, and bacterial tracheitis. The major features of laryngotracheobronchitis and epiglottitis are compared in Table 33–3.

LARYNGOTRACHEOBRONCHITIS (CROUP)

ESSENTIALS OF DIAGNOSIS

- Gradual onset of symptoms.
- Barking cough.
- Stridor.

General Considerations

Laryngotracheobronchitis is the most common infectious cause of airway obstruction in children, usually occurring between the ages of 6 months and 3 years. It is a viral infection most commonly caused by the parainfluenza virus, although numerous other organisms have been reported. Symptoms occur as a result of mucosal edema in the larynx, trachea, and bronchi.

Recurrent episodes of laryngotracheobronchitis should raise the suspicion of underlying abnormalities; therefore, further investigation is indicated.

Table 33–3. A Comparison of The Main Features of Epiglottitis and Laryngotracheobronchitis.

	Epiglottitis	Laryngotracheobronchitis
Microbiology	*Haemophilus influenzae* type B	Parainfluenza virus
Age group	2–6 years	<3 years
Onset	Rapid (hours)	Slow (usually days)
Cough	Absent	Barking cough
Dysphagia	Severe	None
Stridor	Inspiratory	Biphasic
Temperature	Elevated	Elevated
Posture	Sitting forward	Lying back
Drooling	Marked	None
Voice	Muffled	Hoarse
X-ray	Thumbprint sign	Steeple sign

Clinical Findings

A. Symptoms and Signs

Characteristically, the symptoms of laryngotracheobronchitis are gradual in onset and are often preceded by an upper respiratory tract infection. A barking cough is invariably present along with hoarseness and stridor. If stridor is present, it is usually inspiratory in nature, and the onset of biphasic stridor and other signs of respiratory distress are indicative of severe airway obstruction. Symptoms typically last between 3 and 5 days, although the child may be infectious for 2 weeks.

B. Evaluation

Although the diagnosis of laryngotracheobronchitis is mainly based on clinical findings, plain-film x-rays of the neck and chest can be useful. The upper trachea and subglottis may be narrowed (steeple sign) in laryngotracheobronchitis, and other diagnoses, such as foreign body, can be excluded. A blood film reveals a leukocytosis in some cases. If the child has significant symptoms of airway obstruction, then the management should be as described for epiglottitis.

Treatment

Over 85% of cases of laryngotracheobronchitis are mild and can be managed in the community. Parents are typically advised to nurse their child in a humidified room and it seems to be effective anecdotally.

In patients with more severe symptoms, nebulized racemic epinephrine produces a rapid improvement in symptoms by vasoconstriction and reduction in mucosal edema. Heliox has also proved to be beneficial in the acute phase. Both nebulized and systemic steroids have been demonstrated to produce an improvement in the symptoms and the length of time spent in the hospital as well as a decreased need for other interventions such as intubation. Because the beneficial effects of steroids require several hours before onset, the simultaneous administration of racemic epinephrine and steroids results in both immediate and lasting symptom relief. A small number of cases of laryngotracheobronchitis (1.5%) do not respond to medical therapy and airway obstruction worsens. In this situation, endotracheal intubation and ventilation is indicated until the edema resolves.

SUPRAGLOTTITIS (EPIGLOTTITIS)

ESSENTIALS OF DIAGNOSIS

- Rapid progression of symptoms.
- Severe odynophagia with drooling.
- Irritability, fever, toxicity, or any combination of these symptoms.
- Stridor (late sign).

General Considerations

In *epiglottitis*, or more correctly, *supraglottitis*, the cellulitis involves multiple areas of the supraglottis. Typically, acute supraglottitis presents in children between the ages of 2 and 6 years, although any age group, including adults, can be affected. *Haemophilus influenzae* type B (HIB) is the responsible pathogen in most cases, and, as a result of the introduction of the HIB vaccine, the incidence of supraglottitis has been reduced by more than 90%. Although supraglottitis is a rare infection, awareness of the disease is important because of its high mortality rate (if not promptly diagnosed and treated).

Clinical Findings

A. Symptoms and Signs

Symptoms of acute supraglottitis progress rapidly over a matter of hours. The typical features are fever, difficulty in breathing, and severe odynophagia, which results in drooling. The child is usually irritable, sitting or leaning forward, and if the child can speak, the voice is typically muffled. Inspiratory stridor is a late feature occurring when the airway is almost completely obstructed.

B. Evaluation

Once the diagnosis of supraglottitis is suspected, further investigations should not be undertaken since any procedures that induce anxiety in the patient, including intraoral examination and venipuncture, may precipitate complete airway obstruction. In mild cases without respiratory distress, the most useful diagnostic tool is a lateral neck x-ray, which classically demonstrates a swollen epiglottis (the "thumb print" sign) and can help exclude other diagnoses, such as a foreign body or a retropharyngeal abscess. Also, transnasal flexible fiberoptic laryngoscopy can be judiciously used in the evaluation of the stridulous patients with no respiratory distress, based on the patient's age, condition, and cooperation.

Treatment

The management of a child with suspected supraglottitis requires close cooperation between the otolaryngologist, the anesthesiologist, and the pediatrician. The child should be directly transferred to the operating room where equipment for emergency tracheotomy must be available. After inhalational anesthesia, the supraglottis can be inspected and the presence of erythema and edema confirms the diagnosis. The airway is then secured by endotracheal intubation. Once the airway is safe, blood cultures and swabs of the supraglottis can be obtained and an intravenous cannula inserted. Parenteral antibiotic therapy (eg, ceftriaxone or cefotaxime) should then be started. Supraglottitis usually responds rapidly to treatment and extubation is often possible after 48–72 hours.

BACTERIAL TRACHEITIS

Bacterial tracheitis is a rare infection; however, the introduction of the HIB vaccine and the widespread use of corticosteroids in the treatment of laryngotracheobronchitis have resulted in this infection being responsible for a greater proportion of potentially life-threatening airway infections that formerly. It is thought to occur as a secondary bacterial colonization following a viral respiratory tract infection. Involvement of the subglottis and main bronchi is not uncommon. The age at presentation is much more diverse than that seen with croup and has been reported from infancy to adulthood, although the seasonal variation in incidence mirrors that of viral infections of the respiratory tract. The most commonly isolated bacterial pathogen is *Staphylococcus aureus*.

The initial clinical course of bacterial tracheitis is often similar to that seen with croup and is followed by an acute exacerbation of airway obstruction with associated high fever and toxicity. This rapid onset of symptoms is similar to that of supraglottitis, but drooling and dysphagia are absent.

Plain-film x-rays of the neck may demonstrate narrowing of the tracheal lumen, but endoscopy is required to confirm the diagnosis. The typical appearance is a diffusely ulcerated tracheal mucosa with copious purulent secretions partially obstructing the lumen of the trachea. Specimens should be sent for culture at the time of endoscopy, and the tracheal and bronchial secretions should be suctioned. Most patients require endotracheal intubation and ventilation, which secures the airway and allows for repeated tracheal suction. Broad-spectrum parenteral antibiotics should be initiated and adjusted accordingly when the causative organism is identified.

Hopkins A, Lahiri T, Salerno, R et al. Changing epidemiology of life threatening upper airway infections: the reemergence of bacterial tracheitis. *Pediatrics*. 2006;118(4):1418–1421. [PMID: 17015531] (Retrospective analysis of pediatric admissions with potentially life threatening upper airway infections.)

Sobol SE, Zapata, S. Epiglottitis and Croup. *Otolaryngol Clin North Am.* 2008;41(3):551–566. [PMID: 18435998] (Review article.)

We would like to acknowledge Shahram Anari, MD, MRCS for his contribution to this chapter in the previous editions of CDT.

34 Laryngeal Trauma

Andrew H. Murr, MD, FACS, & Milan R. Amin, MD

ESSENTIALS OF DIAGNOSIS

- Hoarseness, neck pain, crepitus, loss of normal midline neck landmarks.
- Fiberoptic examination is a key to the diagnosis; computed tomography scans are extremely helpful.
- Consider concomitant injuries with penetrating trauma.

General Considerations

The larynx serves three important functions: airway protection, regulation of respiration, and phonation. Injury to the larynx resulting from trauma can therefore be devastating. Fortunately, laryngeal trauma is rare and occurs in only a small percentage of trauma victims. Standardized protocols have been developed to help guide the accurate evaluation and identification of injuries requiring operative intervention. Early diagnosis and treatment are critical to prevent dire consequences, including death.

Pathogenesis

A. External Laryngeal Trauma

The relatively low incidence of laryngotracheal injuries results from the natural defenses that the body has to protect the vital structures that allow us to breathe. The relatively high position of the sternum and low position of the mandible along with the thick musculature of the lateral neck allow only a relatively short segment of the airway to be exposed.

Furthermore, there is a naturally protective reflex that causes the head to be flexed downward when startled, allowing for further protection of this region. Injury typically occurs when the body cannot protect this area. This generally occurs in motor or recreational vehicle accidents, assaults (including domestic violence), sports injuries, or strangulation. In motor vehicle accidents, the laryngeal skeleton and/or cricoid cartilage may be shattered between the steering wheel and the cervical spine. Clothesline injuries, although rare, may result classically in cricotracheal separation and bilateral recurrent laryngeal nerve injuries.

The pediatric age group deserves special mention because children have anatomic differences that make the management of laryngeal injuries a distinct entity when compared with the management of similar injuries in adults. Although children are less prone to laryngeal fracture owing to the high position of the larynx in the neck and the increased pliability of the laryngeal cartilage, their diminutive anatomy makes them more vulnerable to life-threatening complications from the injury.

B. Penetrating Neck Trauma

Penetrating trauma to the neck is challenging because up to 30% of patients have multiple structures injured. Penetrating neck trauma usually results from stabbings or gunshot wounds. The severity of a penetrating injury is determined by the mass and velocity of the missile. Therefore, generally, high-velocity, large-caliber bullets will create more damage. However, a variety of bullet types are available that can increase local tissue damage, either by breaking up or exploding on contact or by spiraling in the tissues.

C. Intubation Injury

Because of sophisticated intensive care units, critically ill patients are being sustained longer on ventilatory support with the potential long-term consequences of affected speech and airway patency. Such complications may include scarring of the laryngeal structures, subglottic or tracheal stenosis, formation of granulation tissue, and vocal fold paralysis/paresis. Although the true incidence is unknown, complication rates of 4–19% have been reported after prolonged intubation; therefore, converting an intubated patient to a tracheotomy is often contemplated after 5–7 days. The

benefits of tracheotomy as a management strategy for the prolonged intubation patient include the ability to (1) decrease dead space, (2) improve pulmonary toilet, (3) increase comfort and decrease the need for sedation, (4) ease the process of weaning, and (5) lessen the risk of long-term complications.

Many factors determine the severity of intubation injury. Anatomic variations predispose some patients to a difficult or traumatic intubation. Underlying illness, infection, and reflux laryngitis all may exacerbate the injury. Although glottic edema and superficial ulceration may be seen within just hours of intubation, the use of large-diameter endotracheal tubes, excessive patient movement, repeated self-extubation, overinflated endotracheal tube cuffs, and prolonged intubation increase the risk of long-term damage.

Intubation-related injuries may be reduced by eliminating or controlling the above-listed factors. We routinely ensure that patients are maintained on antireflux medications while intubated. In addition, we attempt to ensure that cuff pressures are kept low. However, as we demonstrated in a recent paper, serial measurement of cuff pressures does not ensure proper pressure maintenance.

Arytenoid dislocation is a special consideration that has been reported as a result of intubation problems. The cause is likely either extreme force applied directly to the arytenoids by a laryngoscope or endotracheal tube or careless extubation with an inflated cuff. The diagnosis is controversial. Some clinicians propose that it is often misdiagnosed and may actually represent the appearance of new onset vocal fold paralysis.

Benjamin B. Prolonged intubation injuries of the larynx: endoscopic diagnosis, classification, and treatment. *Ann Otol Rhinol Laryngol Suppl* 1993;160:1 [PMID: 8470867]. (Management and preservation of the common intubation injury are based on the sequential progression of superficial ulcerations and granulation tissue to various degrees of stenosis.)

Kuttenberger JJ, Hardt N, Schlegel C. Diagnosis and initial management of laryngotracheal injuries associated with facial fractures. *J Cranio-Maxillofac Surg.* 2004;32:80. (The key to proper management of laryngotracheal trauma associated with other injuries is early recognition and evaluation.)

Merritt RM, Bent JP, Porubsky ES. Acute laryngeal trauma in the pediatric patient. *Ann Otol Rhinol Laryngol.* 1998;107(2):104. (Children with laryngeal trauma usually are managed conservatively but also require increased vigilance for airway complications.)

Morris LG, Zoumalan RA, Roccaforte JD, Amin MR. Monitoring tracheal tube cuff pressures in the intensive care unit: A comparison of digital palpation and manometry. *Ann Otol Rhinol Laryngol.* 2007;116(9):639–642 (Despite awareness, the incidence of tracheal tube overinflation remains high. The use of manometry to assess cuff pressures did not reduce the incidence of overinflation.)

Sataloff RT, Bough DB Jr, Spiegel JR. Arytenoids dislocation: Diagnosis and treatment. *Laryngoscope.* 1994;104:1353 [PMID: 7968164]. (Arytenoid dislocation is diagnosed by history and findings on ancillary testing; best results are obtained when reduced early.)

Clinical Findings

A. Symptoms and Signs

1. Patient history—The evaluation of a patient with a suspected laryngeal injury begins with a detailed history (when possible) that specifically addresses the following items: (1) the development of symptoms, (2) the mechanism of injury, and (3) the trajectory of any involved weapons. This information is often difficult to elicit in a patient with multiple traumas because the ability to provide information is compromised by the severity of the injuries. These injuries can include communication deficits caused by concomitant head injuries or illicit substance abuse. Common symptoms include hoarseness, pain, dysphagia, odynophagia, and dyspnea. The failure to elicit these symptoms, however, does not ensure the integrity of the airway. Therefore, a high index of suspicion is mandatory in any patient with neck trauma.

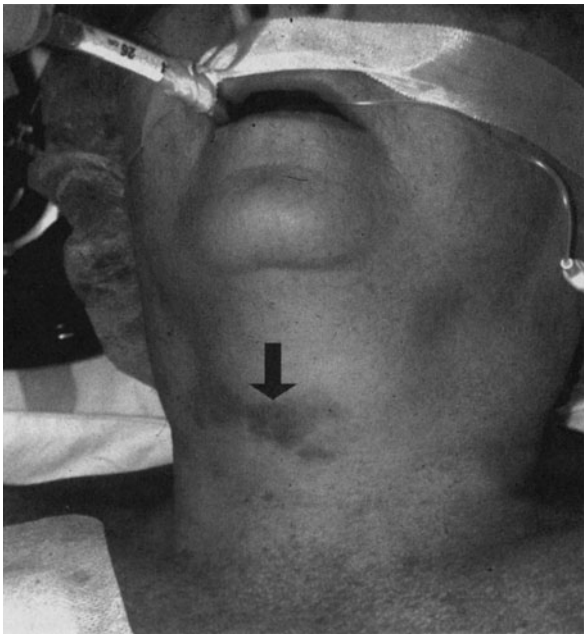
2. Physical examination—The physical examination begins with careful attention to the voice and breathing. The presence of hemoptysis, stridor, or crepitus should alert the physician to a high probability of airway injury. Point tenderness or flattening of the thyroid cartilage prominence is suggestive of an acute laryngeal fracture. Penetrating trauma may involve multiple vital structures such as the esophagus or the carotid neurovascular bundle. An expanding hematoma, a pulse deficit, or the presence of a bruit and thrill all are signs of vascular injury. The prompt diagnosis of these life-threatening injuries requires a methodical investigation. Further evaluation is directed by careful attention to subtle signs and symptoms (Figure 34–1).

One of the most important instruments in diagnosing laryngeal trauma is the fiberoptic nasopharyngoscope. In using this device, the larynx should be evaluated carefully for vocal cord mobility and arytenoid symmetry. Notation should also be made regarding findings of edema, hematoma, soft tissue tears, and exposed cartilage. An attempt should also be made to evaluate the upper trachea by direct examination if the patient tolerates the exam.

B. Imaging Studies

1. Conventional x-rays and soft tissue films—Plain-film x-rays of the chest and soft tissue neck films continue to be essential components in patient evaluation. Any abnormal air surrounding the trachea, mediastinum, or thorax may be the first sign of impending tension pneumothorax and airway embarrassment.

2. Computed tomography (CT)—High-resolution fine-cut CT of the larynx is the best radiographic tool available to evaluate laryngeal trauma. It is especially helpful when the examination is normal but there is a high index of suspicion for occult laryngeal injury. A CT scan is not mandatory in patients with injuries that obviously require operative intervention or in asymptomatic patients with an unremarkable physical examination. However, CT scanning, especially with

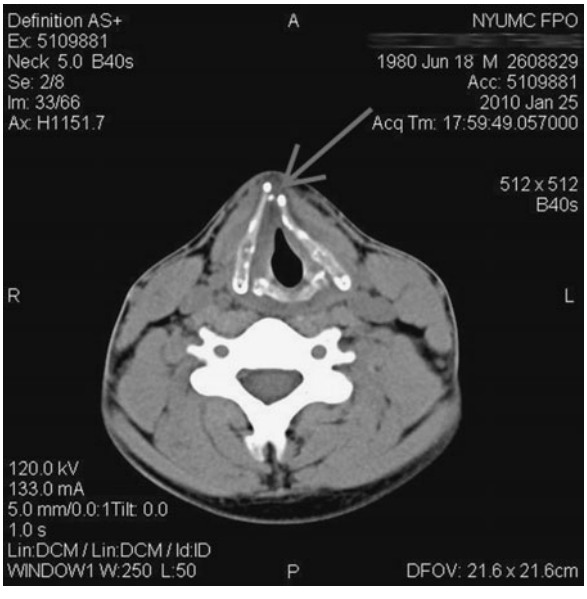


▲ **Figure 34–1.** Anterior neck bruise (see arrow) in a middle-aged woman involved in a motor vehicle accident. (Photo contributed by Andrew N. Goldberg, MD, University of California, San Francisco.)

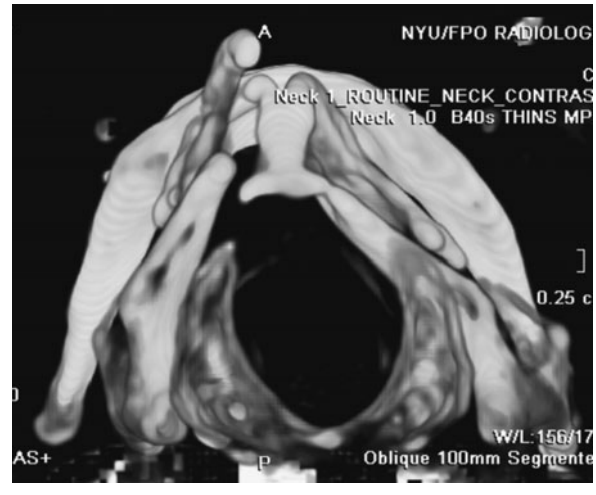
3D reconstruction (Figure 34–2), may be valuable in helping to plan the operative procedure in a patient with a controlled and stable airway.

3. Rigid esophagoscopy and contrast swallow studies— Rigid esophagoscopy or contrast swallow studies are often used to rule out concomitant esophageal perforation in penetrating trauma. When used together, the sensitivity of these tests is approximately 90%. A water-soluble contrast may be preferred to barium because it is less inflammatory to soft tissues, especially if an injury is present or suspected. A negative study then may be repeated with barium, which provides more mucosal detail. A useful adjunct when not dealing with esophageal perforation is flexible esophagoscopy, either in the operating room or at the bedside using a transnasal esophagoscope. These instruments may offer more detail than is available with a barium swallow or rigid esophagoscopy.

4. Angiography—Angiography is often used in the diagnostic evaluation of penetrating neck trauma, especially when the injury involves Zones I and III. (See zone definitions in the section on Definitive Treatment.) Angiography is the gold standard for evaluating vascular injury and is therapeutic when used with interventional neuroradiology embolization. In some centers, duplex ultrasound or noninvasive angiography (CT or magnetic resonance angiography) has replaced conventional angiography for the evaluation of vascular injuries because of its lower cost and risk.



A



B

▲ **Figure 34–2.** CT scan **(A)** revealing a paramedian fracture (see arrow) from an acute blunt laryngeal trauma. This young man presented 1 week after being struck on the left side of the neck with a hockey stick. Note that the 3D reconstruction **(B)** provides valuable information as to the shape of the fracture and demonstrates that the anterior commissure has been displaced.

Kennedy TL, Gilroy PA, Millman B, Greene JS, Pellitteri PK, Harlor M. Strobovideolaryngoscopy in the management of acute laryngeal trauma. *J Voice* 2004;18(1):130. (Videostroboscopy may improve clinical assessment of patients with laryngotracheal injury.)

Miller PR, Fabian TC, Croce MA et al. Prospective screening for blunt cerebrovascular injuries: analysis of diagnostic modalities and outcomes. *Ann Surg.* 2002;236(3):386. (Conventional angiography remains more sensitive than less invasive techniques and is an important part of the diagnostic workup in patients with neck trauma.)

Mokhashi MS, Wildi SM, Glenn TF et al. A prospective, blinded study of diagnostic esophagoscopy with a superthin, standalone, battery-powered esophagoscope. *Am J Gastroenterol.* 2003;98(11):2383. (Ultrathin endoscopy is accurate in detecting esophageal pathologies when compared to traditional esophagoscopy.)

Treatment

A. Emergent Management (For Unstable Patients)

The initial resuscitation begins with following three steps: (1) securing the airway, (2) obtaining hemodynamic stability while controlling the bleeding, and (3) immobilizing the cervical spine. The optimal choice of airway control is often debated. Intubation may be performed safely if the vocal folds are easily seen, there are no visible injuries, and the smallest tube possible is used. However, endotracheal intubation can cause further injury to an already tenuous airway, resulting in an emergent need for airway control. In addition, the extent of injury may not be known prior to attempted direct laryngoscopy. Surgical airway control such as an awake tracheotomy (performed under local anesthetic) or a cricothyroidotomy may often be more prudent in these situations. If a cricothyroidotomy is performed, it should be converted to a formal tracheotomy as soon as possible to prevent long-term sequelae (eg, subglottic stenosis).

In contrast to adults, pediatric patients are unlikely to cooperate with a tracheotomy while awake. In addition, their neck anatomy is often more challenging owing to a high laryngeal position and soft cartilage. Therefore, a pediatric airway is preferably secured with a rigid bronchoscope while maintaining spontaneous respiration before a tracheotomy is performed.

After stabilization of the airway, the patient should be examined and the injury stratified to help guide further management.

B. Definitive Treatment

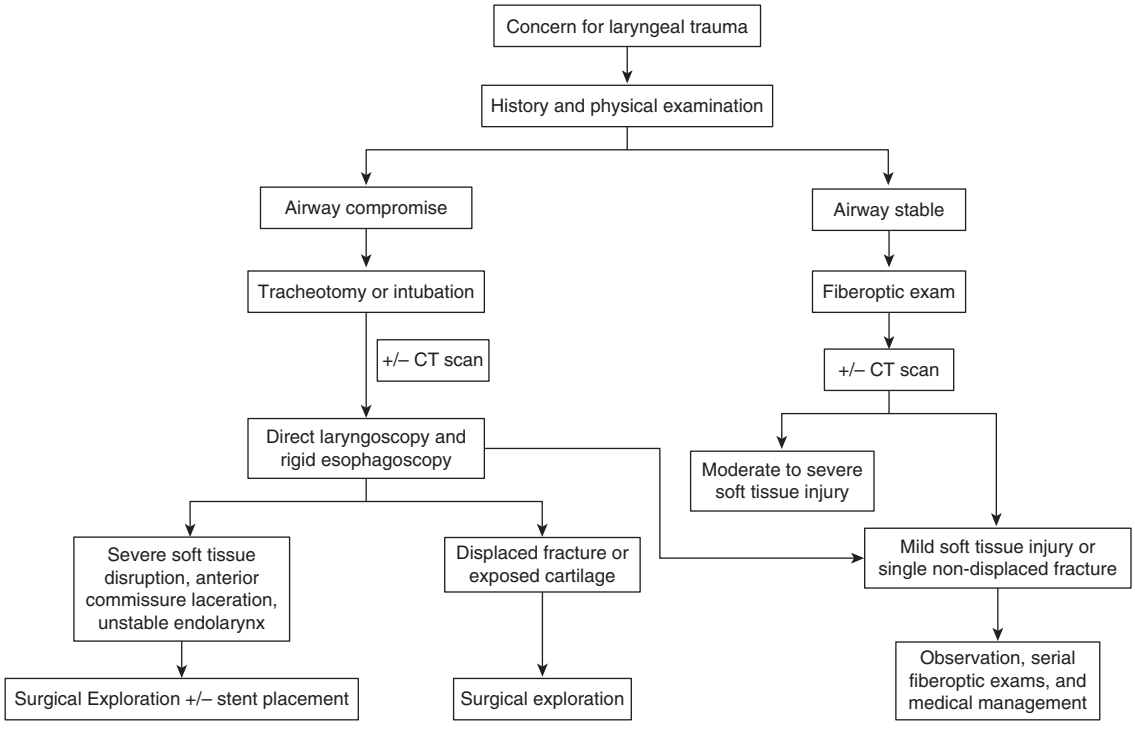
1. External laryngeal trauma—Laryngeal injuries are grouped according to increasing severity (Table 34–1; Figure 34–3). Patients with Group I injuries have minor endolaryngeal hematomas or lacerations. These patients are treated successfully with medical management alone, typically. Group II injuries demonstrate airway compromise, more severe soft tissue injury, or single nondisplaced laryngeal fractures. These patients are usually managed with a tracheotomy followed by direct laryngoscopy and esophagoscopy. If an arytenoid dislocation is discovered, then closed reduction should be attempted. Group III injuries include patients with massive edema, mucosal tears with exposed cartilage, displaced fractures, or vocal cord immobility. Group IV describes the unstable larynx with comminuted fractures. A Group V classification is the most severe type of injury; these patients present with complete laryngotracheal separation. Injuries within Groups III–V require immediate operative repair and may involve the use of stent. The ability to restore the integrity of the larynx impacts a patient's long-term outcome with regard to voice, airway, and the quality of life. It must be noted that this classification system does not account for patients with significant injuries (displaced fractures with altered vocal quality) who have mild or no airway compromise. These patients will often present later with complaints of hoarseness alone. If the injury was relatively recent, repair may be attempted to improve long-term functional outcome.

Table 34–1. Classification of Laryngeal Injury.

Group	Characteristics
I	Minor endolaryngeal hematoma; minimal airway compromise, if any; no detectable fractures
II	Endolaryngeal hematoma or edema associated with compromised airway; minor mucosal lacerations without exposed cartilage; nondisplaced fracture shown on a CT scan
III	Massive endolaryngeal edema with airway obstruction; mucosal tears with exposed cartilage; immobile vocal cord(s)
IV	Same as group III with more than two fracture lines on imaging studies; massive derangement of endolarynx
V	Laryngotracheal separation

Data from Fuhrman GM, Stieg FH, Buerk CA. Blunt laryngeal trauma: classification and management protocol. *J Trauma.* 1990;30:87–92 and Schaefer SD, Brown OE. Selective application of CT in the management of laryngeal trauma. *Laryngoscope.* 1983;93:1473–1475.

A. Nonsurgical measures—Group I and II injuries often heal spontaneously and have excellent outcomes. These injuries are usually managed nonsurgically with humidified air, head of bed elevation, and voice rest. To prevent complications from an undetected or progressive injury, the patient should be closely observed with serial fiberoptic examinations and continuous pulse oximetry for 24–48 h. Antibiotics are often prescribed when there is observable mucosal injury. The use of steroids is controversial. Steroids probably decrease edema if given within the first few hours after injury. The prophylactic treatment of laryngopharyngeal reflux is also recommended to prevent exposure of an injured larynx to acidic gastric contents.



▲ **Figure 34–3.** Treatment algorithm for the acute management of external laryngeal trauma. (Data from Schaefer SD: The acute management of external laryngeal trauma: a 27-year experience. Adapted, with permission, from Schaefer SD. *Arch Otolaryngol Head Neck Surg.* 1992;118:598.)

B. Surgical measures—In more severe injuries, the careful approximation of mucosal tears and the reduction of fracture segments are required to prevent long-term voice disturbance or airway compromise. Findings that tend to lead to a recommendation for surgery include: (1) lacerations involving the anterior commissure, injury to the free edge of the true vocal fold, or the finding of exposed cartilage; (2) displaced or comminuted fractures; (3) vocal fold immobility; or (4) arytenoid dislocation.

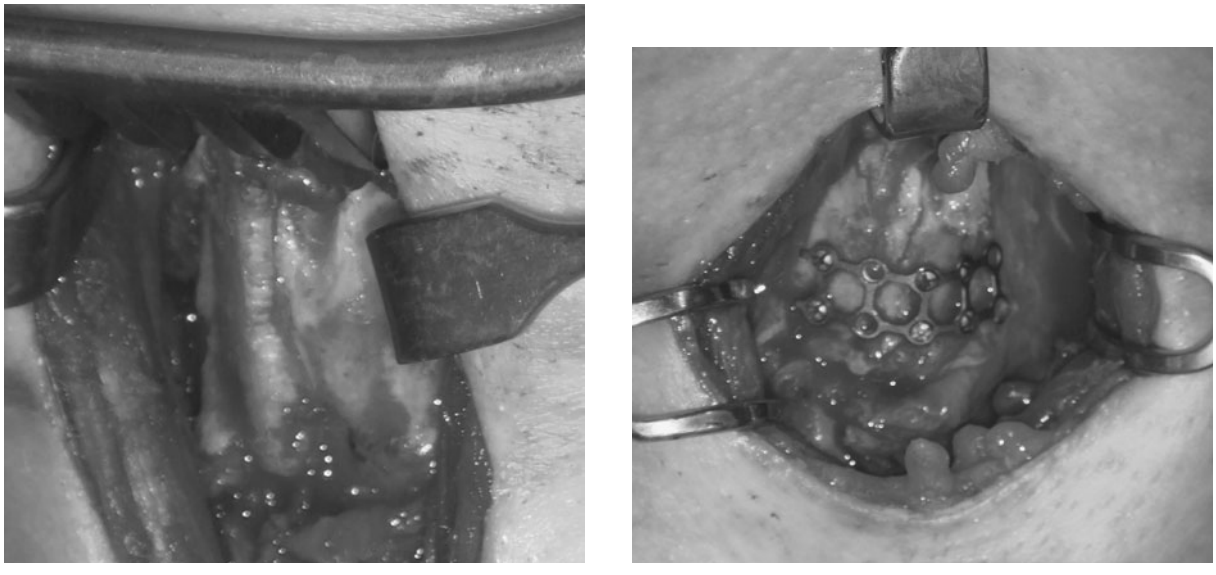
Some data indicate that patients with treatment delays of 48 hours have inferior outcomes when compared with patients whose injuries are repaired soon after the initial trauma. Early intervention is generally preferable since it allows an accurate identification of the injury, less scarring, and superior long-term results.

Fractures can affect the voice by changing the geometry of the larynx and glottal configuration. Therefore, the precise reduction and fixation of even minimally displaced or angulated fractures is often advocated. Fractures traditionally have been repaired with stainless-steel wires or absorbable sutures. Miniplates (titanium or absorbable) provide immediate stability and good results (Figure 34–4) although they are often difficult to place in the cartilaginous framework.

When there is significant disruption of the endolaryngeal soft tissue, a midline thyrotomy to the level of the cricothyroid membrane is performed through a horizontal anterior neck incision. The arytenoids are palpated and reduced if dislocated or avulsed. Only obvious devitalized tissue is débrided. Mucosal lacerations are repaired with primary closure or local flaps to cover any exposed cartilage with the goal of preventing perichondritis, the formation of granulation tissue, and scarring. Grafts are rarely needed.

The use of stents is controversial because of the increased risk of infection and granulation formation. Stents provide structural stability and are indicated in patients with laryngeal instability following inadequate fracture fixation. In the presence of severe soft tissue disruption or lacerations involving the anterior commissure, stents may help prevent synechiae. After 1 or 2 weeks, they are typically removed endoscopically.

2. Penetrating neck trauma—Penetrating neck trauma is classified by the level of injury based on the clinical features and the ease of surgical access: (1) Zone I extends from the sternal notch to the cricoid; (2) Zone II extends from the cricoid to the angle of the mandible; and (3) Zone III extends cranially from the mandible to the skull base. This classification system directs the diagnostic evaluation and treatment.



A B

▲ **Figure 34–4.** Intraoperative photo graphs of the patient from Figure 34–2. The first photograph **(A)** was taken before rigid fixation using a plating system; the second photograph **(B)** was taken after the plate was inserted. Note that the plate is carefully bent to restore the proper anterior commissure angle and location.

With sophisticated ancillary tests and the accurate identification of localizing signs and symptoms, the surgical exploration of penetrating neck trauma is being used increasingly on a selective basis. Immediate operative exploration including triple endoscopy (direct laryngoscopy, bronchoscopy, and esophagoscopy) is used for all patients with hemodynamic instability or airway compromise. The hypopharynx should be closely inspected for injury. Injuries above the level of the arytenoids often heal spontaneously and may be expectantly managed. Lower hypopharyngeal and cervical esophageal injuries require open exploration, primary closure, and drainage due to the higher incidence of salivary leak, infection, and subsequent fistula.

The stable patient is stratified depending on the presence of other signs or symptoms such as expanding hematoma, dysphonia, hemoptysis, hematemesis, or dysphagia. This group of symptoms is explored more selectively.

Injuries crossing into Zones I and III of the neck are more difficult to examine clinically and approach surgically; therefore, imaging—including angiography—is often performed. Zone I injuries are studied with preoperative arteriography and often gastrograffin swallow studies because of the risk of occult injuries reported by some clinicians. Because of difficult surgical access to the vasculature at the base of the skull, patients with Zone III injuries are also studied with arteriography, with the therapeutic option of embolization should an injury be found. Patients with isolated Zone II injuries, however, are usually explored surgically, often without imaging.

The management of asymptomatic patients is controversial. With these patients, some evidence supports observation alone because the physical examination is extremely sensitive in detecting injuries that require operative intervention. In these patients, imaging and adjunctive testing are very helpful in guiding further management.

3. Intubation injury—Intubation injuries may cause a wide variety of acute and chronic conditions. High endotracheal tube cuff pressures may cause progressive hoarseness or airway obstruction from glottic or subglottic edema. Compressive neuropathies caused by direct pressure of the cuff may lead to vocal fold paralysis. Mucosal injury is commonly seen, particularly in the posterior larynx and subglottis and usually results from pressure necrosis due to the presence of the tube and/or cuff or from traumatic intubation. These injuries may progress and lead to granuloma formation, fixation of the cricoarytenoid joint, web formation, or stenosis. The incidence of posterior glottic stenosis increases with the length of intubation and may occur in up to 14% of patients intubated for more than 10 days. Differentiating glottic stenosis from vocal fold paralysis can often be difficult, since both result in partial or complete vocal fold immobility. Typically, the cause of the immobility can be elucidated either by manual assessment of arytenoid mobility or by the use of laryngeal electromyography.

Most cases of granulation tissue formation seen after intubation trauma resolve spontaneously after some time. However, further treatment may be necessary in certain

cases. This treatment typically involves a combination of voice therapy and antireflux medication. This combination reduces the impact of behavioral and local inflammatory factors that are presumed to cause ongoing laryngeal irritation. In certain refractory cases, botulinum toxin injections can be used to forcibly reduce the impact of ongoing phonotrauma. Pulsed-dye or pulsed potassium titanyl phosphate laser treatment has also been successful. Operative removal of the granuloma is rarely necessary except in cases of partial airway obstruction. It should be noted that surgical removal does not obviate the need for voice therapy and antireflux medications. Without controlling these factors, granulomas may recur after surgical excision alone.

The management of stenosis depends on its location and severity. It may be detected weeks or months after extubation, when a patient presents for the evaluation of recent exercise intolerance or stridor. Thin webs that tether the anterior glottis can be surgically divided. A keel may then be placed to prevent the web from reforming between apposed denuded mucosa. Posterior laryngeal stenosis and cricoarytenoid joint fixation are typically treated with repeated dilation through an endoscopic approach. However, occasionally, an open approach through a laryngofissure or the use of a stent is required. Other techniques utilized to treat failures or more severe cases include arytenoidectomy or partial posterior cordotomy.

Subglottic or tracheal stenoses may be initially approached with endoscopic laser incision and dilation. More severe stenoses may require laryngotracheal reconstruction or segmental resection with primary anastomosis. Tracheal segments 4–5 cm in length may be removed if performed with release maneuvers.

In unilateral vocal fold paralysis, patients with persistent dysphonia or significant aspiration—despite therapy—may benefit from vocal fold augmentation with a temporary injection material while awaiting the spontaneous return of function. A medialization laryngoplasty with or without arytenoid adduction or injection augmentation with a more permanent substance is typically recommended if the paralysis is likely to be permanent.

Patients with bilateral vocal fold immobility often present with stridor. Relieving the airway obstruction may require a partial posterior cordectomy, arytenoidectomy, or arytenoid lateralization procedure. In more pressing cases, airway relief is often provided via a tracheostomy.

The finding of arytenoid dislocation is suggested by an uneven vocal cord level seen on laryngoscopy. However, this appearance can also be seen with vocal fold paralysis, which occurs much more commonly. Laryngeal EMG and CT scanning can be used to clarify the diagnosis.

Benninger MS, Gillen JB, Altman JS. Changing etiology of vocal fold immobility. *Laryngoscope.* 1998;108:1346 [PMID: 9738754]. (Vocal fold immobility is most commonly a result of a malignant disorder and surgical trauma, while intubation injuries still account for a significant number of cases.)

Butler AP, Wood BP, O'Rourke AK, Porubsky ES. Acute external laryngeal trauma: experience with 112 patients. *Ann Otol Rhinol Laryngol*. 2005;114:5. (Outcome may be predicted by the initial severity of injury and is improved with earlier intervention.)

Clyne SB, Halum SL, Koufman JA, Postma GN. Pulsed dye laser treatment of laryngeal granulomas. *Ann Otol Rhinol Laryngol.* 2005;114(3):198. (In-office use of the pulsed dye laser is a relatively safe and effective method for treating laryngeal granulomas that do not respond to antireflux therapy and speech therapy.)

De Mello-Filho FV, Carrau RL. Management of laryngeal fractures using internal fixation. *Laryngoscope* 2000;110:2143 [PMID: 11129037]. (Adaptation plating systems are well tolerated and effective, and provide immediate stabilization of laryngeal fractures.)

Gold SM, Gerber ME, Shott SR, Myer CM. Blunt laryngotracheal trauma in children. *Arch Otolaryngol Head Neck Surg* 1997;123(1):83 (Review of pediatric laryngotracheal injuries, which combines the classification systems proposed by Fuhrman et al and Schaefer and Brown for laryngotracheal injuries.)

Schweinfurth JM. Endoscopic treatment of severe tracheal stenosis. *Ann Otol Rhinol Laryngol.* 2006;115(1):30 (Severe and complete tracheal stenoses may be successfully treated endoscopically, which is associated with few complications, low morbidity, a short operative time, and a short length of hospitalization when compared with tracheal resection.)

Sekharan J, Dennis JS, Veldenz HC, Miranda F, Frykberg ER. Continued experience with physical examination alone for evaluation and management of penetrating Zone II neck injuries: Results of 145 cases. *J Vasc Surg* 2000;32:483 [PMID: 10957654]. (Penetrating neck trauma of Zone II may be safely and accurately managed based on the findings of the physical examination of vascular injury.)

Stanley RB Jr, Armstrong WB, Fetterman BL, Shindo ML. Management of external penetrating injuries into the hypopharyngeal-cervical esophageal funnel. *J Trauma.* 1997;42:675 [PMID: 9137257]. (The severity of injuries increases as they descend from the upper hypopharynx to the cervical esophagus, with the former being amenable to expectant treatment.)

Thompson EC, Porter JM, Fernandez LG. Penetrating neck trauma: An overview of management. *J Oral Maxillofac Surg.* 2002;60(8):918. (Review of management of penetrating trauma to the neck.)

Yin SS, Qiu WW, Stucker FJ. Value of electromyography in differential diagnosis of laryngeal joint injuries after intubation. *Ann Otol Rhinol Laryngol.* 1996;105(6):446. (Laryngeal electromyography can help in the diagnosis of cricoarytenoid joint fixation.)

Complications

The initial goal in managing laryngeal trauma is to preserve life; the secondary goal is to prevent long-term sequelae to the voice and airway. Although the injuries to the larynx and trachea can be life altering, it has to be remembered that early aggressive intervention may also lead to long-term complications. In many instances of more minor injury, the best course is conservative observation, particularly with asymptomatic airway stenosis. Complications of more aggressive treatments, such as laryngofissure, laryngotracheal reconstruction, and tracheal resection may include worsening voice, restenosis, airway loss, pneumothorax, infection, vocal fold paralysis, and fistula formation.

Prevention

Seatbelts, traffic safety devices, speed limits, technologic advances in automotive safety (eg, airbags), and neck protective devices used in sports continue to be the mainstay of accident prevention. These safety measures have resulted in a decrease in the incidence of blunt trauma. The adherence to careful intubation techniques, the early identification of patients who require tracheotomy for prolonged intubation, and the development of softer and relatively inert endotracheal tubes have also contributed to a decrease in the incidence of iatrogenic intubation-related injuries.

Prognosis

Postintubation injury occurs more frequently than is brought to clinical attention. Most injuries heal spontaneously and never require further intervention. As more factors that may contribute to these injuries are elucidated, the severity and incidence of complications may be minimized.

Penetrating neck trauma is associated with a 3–6% fatality rate. Management strategies evolve toward the selective exploration of these injuries.

The outcomes of laryngeal trauma in patients managed according to the protocols discussed earlier have been consistently satisfactory. Group I or II injuries heal almost uniformly with excellent results. However, some select injuries (eg, displaced cricoid cartilage, arytenoid subluxation, or recurrent laryngeal nerve injury) carry a more unfavorable prognosis. Study findings indicate that suboptimal results are only seen in patients with more severe injuries.

Biffl WL, Moore EE, Rehse DH, Offner PJ, Franciose RJ, Burch JM. Selective management of penetrating neck trauma based on cervical level of injury. *Am J Surg.* 1997;174:678 [PMID: 9409596]. (Selective management with selective utilization of adjunctive testing in penetrating neck trauma of Zones II and III may be performed safely in asymptomatic patients.)

Schaefer SD. The acute management of external laryngeal trauma: A 27-year experience. *Arch Otolaryngol Head Neck Surg.* 1992;118:598 [PMID: 1637537]. (Lessons learned from the largest series of patients with external laryngeal trauma managed by a consistent protocol.)

We would like to acknowledge Dov C. Bloch for his contribution to this chapter in the previous editions of CDT.

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Congenital Disorders of the Trachea & Esophagus

35

Kelly D. Gonzales, MD & Hanmin Lee, MD

ESOPHAGEAL ATRESIA & TRACHEOESOPHAGEAL FISTULA

ESSENTIALS OF DIAGNOSIS

- Coughing, cyanosis, or vomiting with onset of feeds.
- Association with VACTREL.
- Inability to pass the feeding tube.
- Orogastric tube curled in upper chest or neck on chest -x-ray.
- Intestinal gas indicates esophageal atresia with tracheoesophageal fistula; no gas represents isolated esophageal atresia.

General Considerations

Esophageal atresia and tracheoesophageal fistula (TEF) have a prevalence of 1 in 3000 live births. The male-to-female ratio is equal. Infants with these conditions are often premature, and polyhydramnios is commonly diagnosed prenatally.

Classification

Esophageal atresia and TEF are classified based on the presence of atresia and the relation of the fistula location to the atresia. Older classification methods have been replaced with anatomical descriptions (Figure 35–1). The incidence of these two conditions is found in Table 35–1.

Types of esophageal atresia and tracheoesophageal fistula: (**A**) Type 1, esophageal atresia with distal tracheoesophageal fistula; (**B**) Type 2, esophageal atresia without tracheoesophageal fistula; (**C**) Type 3, TEF without esophageal atresia; (**D**) Type 4, esophageal atresia with proximal and distal tracheoesophageal fistula; and (**E**) Type 5, esophageal atresia with proximal tracheoesophageal fistula.

A. Type 1

Esophageal atresia with a distal TEF is the most common anomaly, comprising 85.4% cases. The lower esophageal segment begins as a fistula that arises from the distal trachea near the carina. The proximal esophageal pouch is found as a blind-ending segment near the thoracic inlet. The blood supply to the superior esophageal segment is via the thyrocervical trunk, whereas branches of the gastric arteries supply the distal esophageal segment.

B. Type 2

Isolated esophageal atresia comprises 7.3% of cases. The lower pouch is usually only 1–2 cm above the diaphragm, whereas the upper pouch ends near the thoracic inlet, creating a long gap between the two ends that can complicate repair. This anomaly does not allow amniotic fluid to pass to the remainder of the developing gut, explaining the finding of polyhydraminos prenatally. However, esophageal atresia with a relatively narrow distal TEF can produce similar findings.

C. Type 3

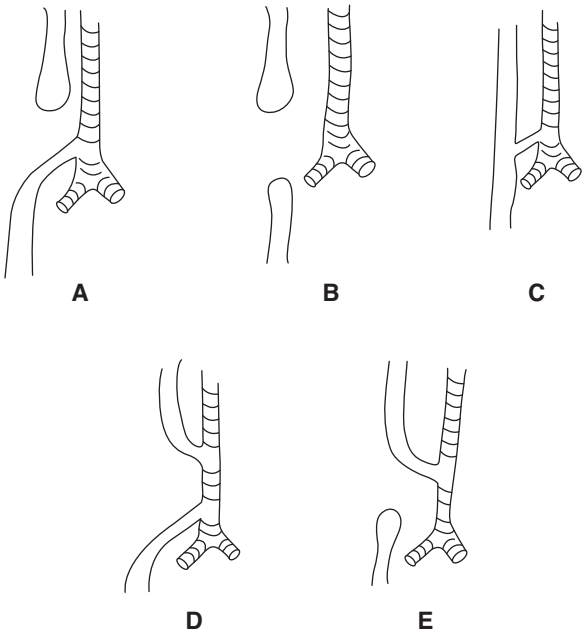
Isolated trasheoesophageal fistula is the third most common anomaly, comprising 2.8% of cases. The location of the fistula is variable, occurring between the cricoid cartilage and carina. More than one fistula can occur. The fistula angles downward from the trachea to the esophagus.

D. Type 4

Esophageal atresia with proximal and distal TEF is less common and comprises 2.1% of cases.

E. Type 5

Esophageal atresia with proximal TEF is the least commonly encountered anomaly, comprising <1% of cases. The fistula angles downward from the trachea to the esophagus. The space between the two esophageal ends is pronounced.



▲ **Figure 35–1.** Types of esophageal atresia and tracheoesophageal fistula. **(A)** Type 1, esophageal atresia with distal tracheoesophageal fistula; **(B)** Type 2, esophageal atresia without tracheoesophageal fistula; **(C)** Type 3, tracheoesophageal fistula without esophageal atresia; **(D)** Type 4, esophageal atresia with proximal and distal tracheoesophageal fistula; and **(E)** Type 5, esophageal atresia with proximal tracheoesophageal fistula.

Pathogenesis

By the 26th day of embryologic development, the dorsal foregut has separated from the ventral trachea. A primary mechanism of esophageal atresia develops by an unknown etiology. Animal models demonstrate a branch of a tracheal trifurcation growing caudally, which connects to the stomach, creating the fistula. Esophageal atresia and tracheoesophageal fistula, seen in association with other embryologic abnormalities, is referred to by the acronym **VACTERL** (**v**ertebral, **a**nal, **c**ardiac, **t**racheo**e**sophageal, **r**enal, and **l**imb abnormalities). Patients with esophageal atresia and tracheoesohpageal fistula have approximately a 50% chance of having one of these associated anomalies, prompting the physician to rule out these other processes. Cardiac anomalies are the most commonly associated defects.

The esophagus of patients with esophageal atresia and TEF has a decreased number of Auerbach plexuses, explaining the neuronal element of altered esophageal motor function and partly explaining the chronic nature of dysmotility seen with these patients.

Pulmonary development may be impeded via two pathways. Firstly, direct pressure on the trachea by a distended proximal esophagus can contribute to tracheomalacia. Secondly, a fistula drains amniotic fluid out of the pulmonary tree. This fluid pressure has been implicated in playing a part in the parenchymal lung development.

Table 35-1. Incidence of Esophageal Atresia and Tracheoesophageal Fistula (TEF).

Atresia with distal TEF	85.4%
Atresia without TEF	7.3%
TEF without atresia	2.8%
Atresia with proximal and distal TEF	2.1%
Atresia with proximal TEF	<1.0%

Cisera CA, Connelly PR, Marmureanu AR, et al. Esophageal atresia with thracheoesophageal fistula: suggested mechanism in faulty organogenesis. *J Pediatr Surg*. 1999;34:204. [PMID: 10022173] (Animal model demonstrating a primary atresia of the esophagus with a secondary phenomenon of tracheoesophageal fistula development.)

Clinical Findings

A. Symptoms and Signs

1. Respiratory symptoms—Patients are often asymptomatic at birth. They can present with excessive drooling because of an inability to swallow. Upon feeding, the infant may cough, choke, regurgitate, or become cyanotic. The prevention of saliva from traveling to the stomach leads to aspiration, which can present as respiratory distress, atelectasis, and pneumonia.

Patients with the rare TEF without esophageal atresia are often diagnosed at a later stage because of a less pronounced symptom complex. Presentation can be subtle, with chronic upper respiratory symptoms and choking, repeated pneumonias, or asthmatic symptoms.

2. Gastrointestinal symptoms—Patients with a distal TEF can have gastric distension resulting from the passage of air from the trachea to the distal esophagus. This situation may result in either gastric reflux into the trachea, causing chemical tracheobronchitis, or compromised respiratory status by abdominal distension and pulmonary compression.

B. Imagning Studies

1. Esophageal catheter and esophagram—Gentle placement of a catheter into the esophagus that will not pass into the stomach is often the first study suggestive of esophageal atresia. The catheter position should be noted on a plain radiograph. A standard barium swallow is not recommended

because of possible spillage into the pulmonary tree. An esophagram may be useful in diagnosing an isolated TEF in an older child.

2. Abdominal x-ray—An abdominal radiograph can suggest which type of anomaly is present. In patients with a fistula connecting the distal esophagus, x-rays show gas in the stomach and small bowel. A gasless abdomen suggests either esophageal atresia without a TEF or a proximal fistula.

C. Special Tests

1. Bronchoscopy and esophagoscopy—With high clinical suspicion and a negative barium study, isolated tracheoesophageal fistulas can be demonstrated with concurrent bronchoscopy and esophagoscopy. Isolated TEF usually presents in an older child.

2. Echocardiogram—An echocardiogram should be performed for two reasons: (1) to rule out the presence of cardiac anomalies and (2) to determine the side of the aortic arch. A left thoracotomy can be considered for a right-sided aortic arch, although some pediatric surgeons still prefer a right thoracotomy even in the presence of a right aortic arch.

3. Abdominal ultrasound—An abdominal ultrasound is performed to image the kidneys to rule out renal anomalies as part of the VACTERL association.

D. Special Examinations

Prenatal sonography can suggest esophageal atresia with the findings of polyhydramnios and no visible stomach. Because of the association of VACTERL, any findings suggestive of these anomalies should promote an evaluation for esophageal atresia and tracheoesophageal fistula. Prenatal MRI may be helpful to further delineate anomalies.

Langer JC, Hussain H, Khan A, et al. Prenatal diagnosis of esophageal atresia using sonography and magnetic resonance imaging. *J Pediatr Surg*. 2001;36:804. [PMID: 11329594] (MRI increases the accuracy of diagnosis of patients suspected of having esophageal atresia on prenatal ultrasound.)

Differential Diagnosis

A. Laryngotracheoesophageal Cleft

Laryngotracheoesophageal cleft is a rare defect related to esophageal atresia and tracheoesophageal fistula. It occurs in the midline between the trachea and the esophagus. The defect can be minimal, or it can extend down past the carina. Symptoms range from chronic cough to respiratory distress. The diagnosis is made by rigid bronchoscopy. Severe cases require operative repair involving a right anterolateral cervical approach with lateral pharyngotomy to expose the defect.

B. Esophageal Stenosis

Esophageal stenosis is a rare congenital anomaly. Anatomically, there can be tracheal elements in the wall of the esophagus or a mucosal web. Patients present later in life with difficulty swallowing solids. The diagnosis is made by barium swallow and esophagoscopy. Dilatation is effective for patients with cartilaginous remnants.

C. Tracheal Stenosis

Congenital tracheal stenosis is a rare disease ranging from an isolated defect to pulmonary agenesis. It is often fatal. The diagnosis is made by bronchoscopy. Individual reports of successful segmental resection or alternative grafts have been noted.

Treatment

A. Pretreatment Risk Evaluation

The **Waterson classification** has been used as a risk evaluation to predict the outcome and determine the surgical timing. Historically, patients in **Category A**, which is defined as birth weight >5.5 pounds, receive prompt surgical correction. A patient in **Category B**, with a birth weight of 4.0–5.5 pounds or an infant who presents with pneumonia and congenital anomaly, generally has short-term delay of surgical intervention. Patients receive a gastrostomy and are stabilized before surgical repair. Very ill infants with significant respiratory compromise due to a wide-open fistula may require ligation of the fistula, stabilization, and then subsequent esophageal reconstruction. A **Category C** classification, which is characterized by a patient birth weight of <4.0 pounds or an infant who presents with severe pneumonia and congenital anomaly, classically receives a staged repair. Infants traditionally had improved outcomes with a staged procedure. However, the addition of total parenteral nutrition to maintain the newborn's nutritional status and the fact that newborn mortality is attributed mostly to associated congenital anomalies have allowed patients in Category C to be treated with a delayed primary closure. In addition, low birth weight may not be an absolute contraindication to early repair. Currently, most children, with the exception of the most ill infants, undergo complete repair; although, increasingly smaller and more ill patients are undergoing complete repair in one stage.

B. Preoperative Care

Before surgery, patients are kept in a head-up position with an oroesophageal tube for continuous suction and frequent pharyngeal aspiration. Broad-spectrum antibiotics are instituted, such as ampicillin and gentamicin. Parenteral nutrition is started if repair is delayed. Associated VACTERL anomalies are ruled out. In patients with a distal fistula, a gastrostomy tube for decompression may be necessary if

patients present with severe abdominal distension and respiratory compromise.

C. Surgical Measures

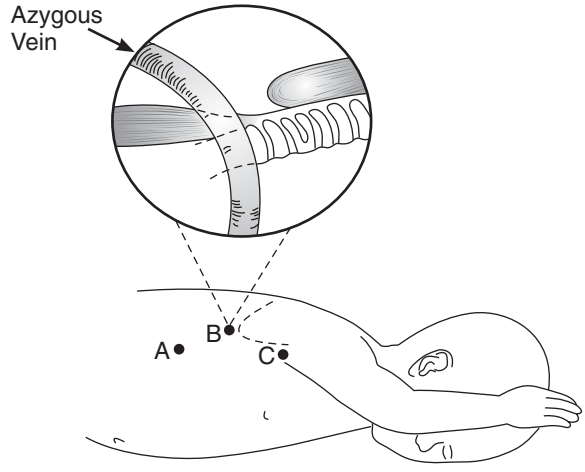
Operative repair is performed through one of two approaches, either a thorocotomy or thoracoscopic approach. In an open repair, a right posterior lateral thoracotomy at the fourth intercostal space is created. A left-sided approach, which is an exception, is often used for an anomalous right-sided aortic arch. The procedure is usually performed extrapleurally. The dissection proceeds posteriorly, with the lung reflected anteriorly. The azygos vein overlies the fistula and is either reflected superiorly or divided. The vagus is identified lying over the two esophageal segments. The fistula is divided and the trachea is closed with interrupted nonabsorbable sutures followed by coverage with adjacent tissue. The proximal esophagus is dissected freely up to the thoracic inlet to provide adequate length.

Care must be taken when dissecting the esophagus from the membranous portion of the trachea, since the two structures are usually adherent. Single-layer, full-thickness interrupted sutures create the anastomosis. A drainage catheter is placed in the retropleural space. Difficult repairs that are due to a long gap between the proximal and distal esophageal ends have been approached by serial stretching of the proximal segment with twice-daily bougie catheter dilations. Intraoperatively, either proximal circumferential or proximal spiral esophagomyotomies can provide the extra length needed. If insufficient length to perform the anastomosis is encountered, a staged repair with a cervical esophagotomy with serial stretching followed by anastomotic construction can be performed. Another method of repairing a long-gap esophageal atresia is lengthening the esophageal ends by placing sutures on the ends of the esophagus, exteriorizing them, and then putting them on tension. The anastomosis is then completed within 10 days.

Alternately, an esophageal replacement can be performed with a colon interposition or gastric tube graft. If a long-gap atresia is expected, particularly with isolated esophageal atresia, then a gastrostomy should be performed initially, with a subsequent esophageal reconstruction or replacement.

Increasingly, repair of esophageal atresia and TEF is being repaired using a thoracoscopic technique. The thoracotomy approach is noted to have significant complications such as scoliosis, chest wall deformity, rib fusion, and thoracic nerve damage. The thoracoscopic approach uses three small incisions which are 3–5 mm in size thus decreasing or eliminating these significant complications of the open procedure.

A thoracoscopic repair usually uses a transpleural approach although extrapleural has been used. Anesthesia obtains left mainstem intubation. The patient is positioned with right side up and slightly prone. Three ports are placed using either 3 or 5 mm sized ports. With left-sided intubation and ventilation, the right lung is collapsed with insufflation of carbon dioxide. The azygous vein is identified and acts as a marker for the inferior pouch (Figure 35–2). Subsequently, the azygous vein is usually divided. The upper pouch is identified with the help of anesthesia by gently moving a suction catheter. With the same care as in the open approach, the fistula and the distal esophageal segment is identified and dissected free circumferentially. The fistula is closed either using a clip or ligation technique. The upper pouch is then dissected carefully until the inferior pouch and proximal pouch can be approximated without undue tension. A single-layer hand-sewen anastomosis is performed. Prior to closure of the anterior anastomosis, a small caliber nasograstric tube is passed under visualization from the nose through the anastomosis site and into the distal esophagus. The nasogastric tube may be left in place for possible tube feeding. Finally, a chest tube is placed through one of the port sites under visualization. The lung is allowed to inflate. The ports are then removed and the remaining two incisions are approximated and sutured closed.



▲ **Figure 35–2.** Three small incisions for the three ports (3–5 mm) are made as indicated by points A, B, and C on the patient. The azygous vein is identified and marks the location of the inferior pouch of the esophageal atresia.

Bax KM, van Der Zee DC. Feasibility of thoracoscopic repair of esophageal atresia with distal fistula. *J Pediatr Surg*. 2002;37:192. [PMID: 11819197] (Case series report on thoracoscopic repair examining outcomes in addition to complications of anastomotic leak and stenosis.)

Foker JE, Linden BC, Boyle EM Jr, Marquardt C. Development of a true primary repair for the full spectrum of esophageal atresia. *Ann Surg*. 1997;226:533. [PMID: 9351721] (Case series report on elongation of esophageal ends using traction with sutures.)

Holcomb GW III, Rothenberg SS, Bax KMA, et al. Thoracoscopic repair of esophageal atresia and tracheoesophageal fistula: a multi-institutional analysis. *Ann Surg*. 2005;242:422–428.

Kimura K, Nishijima E, Tsugawa C, et al. Multistaged extrathoracic esophageal elongation procedure for long-gap esophageal

atresia: experience with 12 patients. *J Pediatr Surg*. 2001;36:1725. [PMID: 11685713] (Case series with follow-up of a multistaged procedure for repair of long-gap esophageal atresia.)
Lugo B, Malhotra A, Guner Y, Nguyen T, Ford H, Nguyen NX. Thoracoscopic versus open repair of tracheoesophageal fistula and esophageal atresia. *J Laparoendosc Adv Surg Tech A*. 2008;18(5):753–756. [PMID 18803521]
MacKinlay GA. Esophageal atresia surgery in the 21st century. *Semin Pediatr Surg*. 2009;18(1):20–22. [PMID 19103417]
Tsao K, Lee H. Extrapleural thoracoscopic repair of esophageal atresia with tracheoesophageal fistula. *Pediatr Surg Int*. 2005;21(4):308–310. [PMID 15789240]

Complications

A. Anastomotic Leak

Anastomotic leak occurs in 10–20% of patients. In a multiinstitutional study, anastomotic leak occurred in 10–20% of patients who underwent open repair compared to 7.6% of patients who underwent thoracoscopic repair. Most reports implicate anastomotic tension and esophagomyotomy as factors increasing the chance for leak. This condition can be diagnosed with saliva in the postoperative chest tube aspirate. Barium swallow diagnoses the location and the extent of the leak. Most small leaks close spontaneously with nonoperative management.

B. Anastomotic Stricture

Anastomotic stricture presents in approximately 25% of open repair versus 4% in thoracoscopic repair. Patients can present with aspiration, malnutrition, and food obstruction. Strictures are diagnosed by barium swallow and usually treated successfully with one or more esophageal dilations. Occasionally, a segmental esophageal resection is required for refractory strictures.

C. Gastroesophageal Reflux Disease (GERD)

Gastroesophageal reflux can contribute to anastomotic stricture. It occurs in about 50% of patients. Intrinsic poor esophageal motility allows for the reflux of gastric acids, leading to aspiration, esophagitis, and scarring. The diagnosis is made by 24-hour esophageal pH monitoring. The treatment is aggressive medical therapy; however, about 30% of patients require antireflux fundoplication.

D. Tracheomalacia

Tracheomalacia is diagnosed by bronchoscopy and is performed at the time of surgical intervention. Some studies report a 25% incidence. This disorder can result from poor development of the cartilaginous rings at the level of the fistula. It should be suspected in any patient with respiratory symptoms. Mild cases usually improve by age 1 or 2; however, severe cases may be treated with aortopexy.

Dutta HK, Gover VP, Dwivedi SN, Bhatnagar V. Manometric evaluation of postoperative patients of esophageal atresia and tracheoesophageal fistula. *Eur J Pediatr Surg*. 2001;11:371. [PMID: 11807665] (Manometry of patients who receive repair for the esophageal atresia and tracheoesophageal fistula demonstrating altered pressure and contractility profile of the esophagus.)

Prognosis

Esophageal atresia is lethal if not corrected. Patients with the VACTERL association have a poorer prognosis owing to the presence of the other anomalies. In fact, the mortality risk is greater for the associated anomalies than for esophageal atresia and tracheoesohageal fistula. The current survival rate of postsurgical repair is reported to be >90%.

Driver CP, Shankar KR, Jones MO, et al. Phenotypic presentation and outcome of esophageal atresia in the era of the Spitz classification. *J Pediatr Surg*. 2001;36:1419. [PMID: 11528619] (Cohort study over a 12-year period. Patients with increasing incidence of cardiac anomalies.)

36 Benign & Malignant Disorders of the Esophagus

Alexander Langerman, MD & Marco G. Patti, MD

ANATOMY

The esophagus is a muscular tube that extends from the level of the sixth cervical vertebra to the 11th thoracic vertebra, spanning three anatomic regions. The cervical esophagus lies left of the midline and posterior to the larynx and trachea. This portion receives its blood supply from branches of the inferior thyroid arteries and drains into the inferior thyroid veins. The upper portion of the thoracic esophagus passes behind the tracheal bifurcation and the left mainstem bronchus. The lower portion of the thoracic esophagus passes behind the left atrium and then enters the abdomen through the esophageal hiatus of the diaphragm.

The thoracic esophagus is supplied by the bronchial arteries (upper portion) and the branches of the thoracic aorta (midportion) and drains into the hemiazygos and azygos veins. The abdominal esophagus ends at the level of the junction with the stomach. The lowermost thoracic esophagus and the abdominal esophagus are nourished by the branches of the left gastric and inferior phrenic arteries and drain into the left gastric veins. Abundant lymphatics form a dense submucosal plexus. Lymph from the upper esophagus drains mostly in the cervical and paratracheal lymph nodes, whereas the lower thoracic and abdominal esophagus drains preferentially into the retrocardiac and celiac nodes.

The architecture of the esophageal wall consists of three layers. The mucosa is made of squamous epithelium overlying a lamina propria and a muscularis mucosa. The submucosa is made of elastic and fibrous tissue and is the strongest layer of the esophageal wall. The esophageal muscle is composed of an inner circular and outer longitudinal layer. The upper third of the esophageal musculature consists of skeletal muscle and the lower two thirds consist of smooth muscle. The upper esophageal sphincter (UES) is formed by the cricopharyngeus muscle along with the inferior constrictors of the pharynx and fibers of the esophageal wall. The lower esophageal sphincter (LES) is not a distinct anatomic structure. Unlike the remainder of the gastrointestinal tract, the esophagus does not have a serosal layer.

PHYSIOLOGY

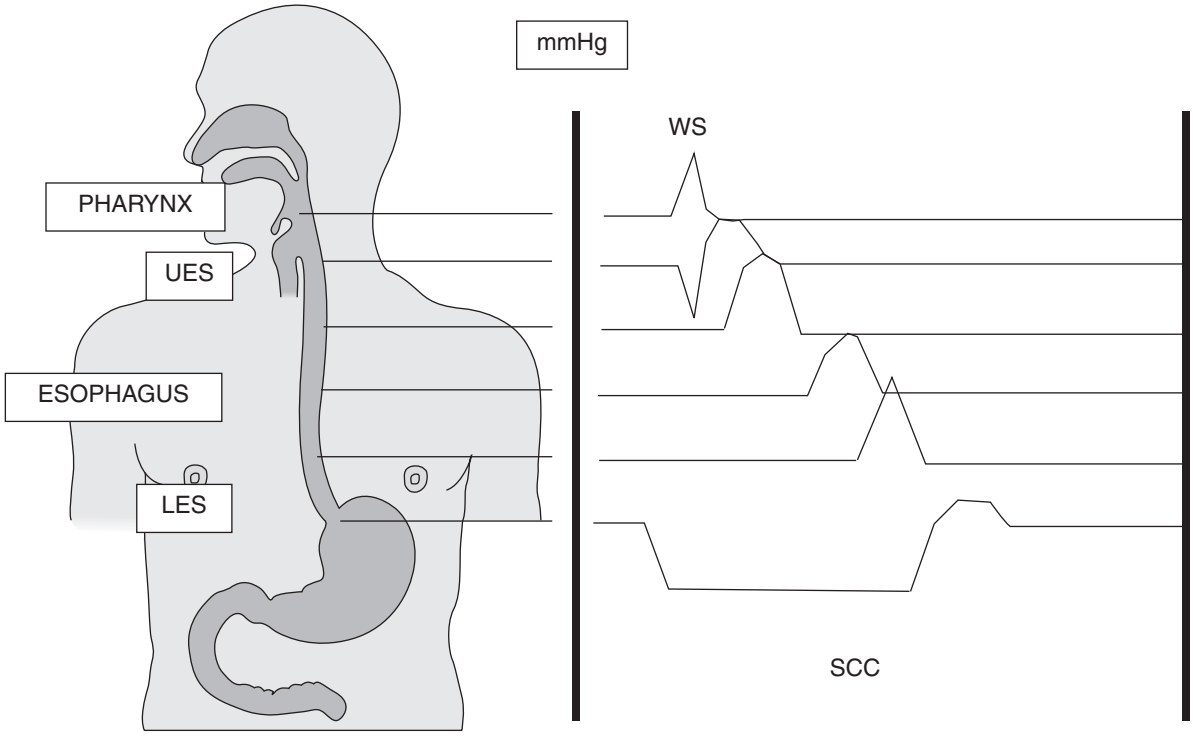
The coordinated activity of the UES, the esophageal body, and the LES is responsible for the motor function of the esophagus.

UPPER ESOPHAGEAL SPHINCTER

The UES receives motor innervation directly from the brain (ie, the nucleus ambiguus). Contributions from the inferior pharyngeal constrictor, cricopharyngeus, and cervical esophageal form this muscular sphincter, with the primary contributor being the cricopharyngeus. The sphincter is continuously in a state of tonic contraction, with a resting pressure of approximately 60–100 mm Hg. The sphincter prevents both the passage of air from the pharynx into the esophagus and the reflux of esophageal contents into the pharynx. During swallowing, a food bolus is moved by the tongue into the pharynx, which contracts while the UES relaxes. Supra- and infrahyoid musculature contribute to pulling the laryngotracheal apparatus away from the spinal column and further dilating the UES. After the food bolus has reached the esophagus, the UES regains its resting tone (Figure 36–1).

ESOPHAGEAL BODY

When food passes through the UES, a contraction is initiated in the upper esophagus, which progresses distally toward the stomach. The wave initiated by swallowing is referred to as *primary peristalsis.* It travels at a speed of 3–4 cm/s and reaches peak amplitudes of 60–140 mm Hg in the distal esophagus.



▲ **Figure 36–1.** The swallowing process. LES, lower esophageal sphincter; SCC, squamous cell carcinoma; UES, upper esophageal sphincter; WS, wet swallow.

LOWER ESOPHAGEAL SPHINCTER

The LES measures 3–4 cm in length and is tonic, with resting pressure ranges between 15 and 24 mm Hg. At the time of swallowing, the LES relaxes for 5–10 s to allow the food bolus to enter the stomach, and then it regains its resting tone (see Figure 36–1). The LES relaxation is mediated by vasoactive intestinal polypeptide and nitric oxide, both nonadrenergic and noncholinergic neurotransmitters. The resting tone depends mainly on intrinsic myogenic activity. The LES has a tendency to relax periodically at times, independent from swallowing. These periodic relaxations are called *transient LES relaxations* to distinguish them from relaxations triggered by swallows. The cause of these transient relaxations is not known, but gastric distention probably plays a role.

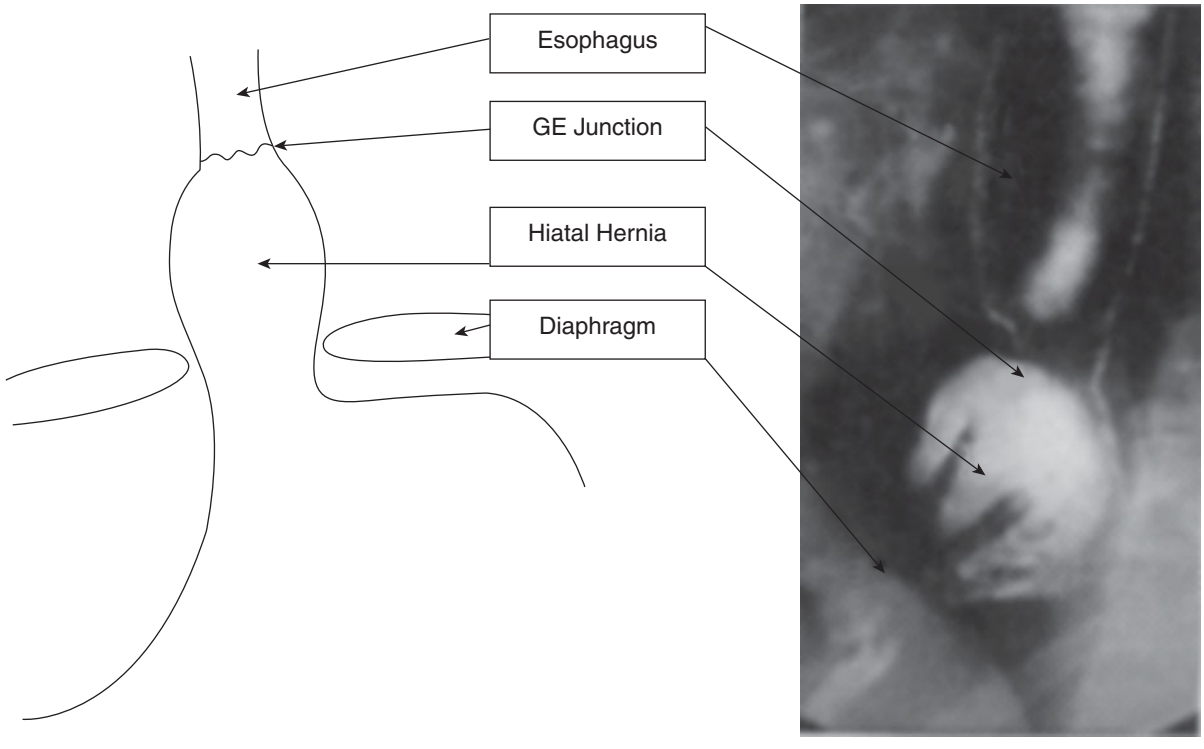
Transient LES relaxations account for the small amount of physiologic gastroesophageal reflux present in any individual and are also the most common cause of reflux in patients with gastroesophageal reflux disease (GERD). A decrease in the length or the pressure (or both) of the LES is responsible for abnormal reflux in the remaining patients. Overall, it is thought that although transient LES relaxation is the most common mechanism of reflux in patients with either absent or mild esophagitis, the prevalence of a mechanically defective sphincter (ie, hypotensive, short, or both) increases in patients with more severe esophagitis. The crus of the esophageal hiatus of the diaphragm contributes to the resting pressure of the LES. The pinchcock action of the diaphragm is particularly important because it protects against reflux caused by sudden increases of intraabdominal pressure, such as with coughing or bending. This synergistic action of the diaphragm is lost when a sliding hiatal hernia is present, since the gastroesophageal junction is displaced above the diaphragm (Figure 36–2).

Lang IM, Shaker R. An overview of the upper esophageal sphincter. *Curr Gastroenterol Rep*. 2000;2:185–190. [PMID:10957928] (Review of the anatomy and physiology of the upper esophageal sphincter.)

Mittal RK, Balaban DH. The esophagogastric junction. *N Engl J Med*. 1997;336:924. [PMID: 9070474] (Review of the anatomy and physiology of the esophagogastric junction.)

Paterson WG, Zhang Y. The lower esophageal sphincter. *Clin Invest Med*. 2002;25:47–53. [PMID:12030254] (Review of the anatomy and physiology of the lower esophageal sphincter.)

Patti MG, Gantert W, Way LW. Surgery of the esophagus: anatomy and physiology. *Surg Clin North Am*. 1997;77:959. [PMID: 9347826] (Review of the esophageal anatomy and physiology.)



▲ **Figure 36–2.** Hiatal hernia.

BENIGN DISORDERS OF THE ESOPHAGUS

ACHALASIA

ESSENTIALS OF DIAGNOSIS

- Dysphagia
- Regurgitation
- Radiologic evidence of distal esophageal narrowing
- Absence of esophageal peristalsis on manometry.

General Considerations

Esophageal achalasia is a primary esophageal motility disorder characterized by the absence of esophageal peristalsis and increased pressure of the LES, which fails to relax completely in response to swallowing. The disease is rare, with an incidence of about 1 in 100,000 individuals. It affects men more than women, and it can occur at any age.

Pathogenesis

The cause of esophageal achalasia is unknown. A degeneration of the myenteric plexus of Auerbach has been documented, with loss of the postganglionic inhibitory neurons. These neurons contain nitric oxide and vasoactive intestinal polypeptide, which mediate LES relaxation. Because the postganglionic cholinergic neurons are spared, there is unopposed cholinergic stimulation that can result in increased LES resting pressure and insufficient relaxation. However, it is primarily decreased esophageal motility and incomplete relaxation that characterizes achalasia, as not all patients have a hypertensive LES.

Clinical Findings

A. Symptoms and Signs

Dysphagia, for solids and liquids, is the most common symptom, occurring in over 90% of patients. Most patients adapt to this symptom by changing their diet and are able to maintain a stable weight, whereas others experience a progressive increase in dysphagia that eventually leads to weight

loss. Regurgitation is the second most common symptom and it is present in about 75% of patients. It occurs more often in the supine position and may lead to the aspiration of undigested food. Heartburn is present in about 50% of patients, and it is caused by stasis and fermentation of undigested food in the distal esophagus. Chest pain also occurs in 40% of patients. The symptoms of heartburn and chest pain can erroneously be attributed to GRED if proper studies are not performed.

B. Imaging Studies

In evaluating a patient with dysphagia, a barium swallow should be the first test performed. It usually shows a narrowing at the level of the gastroesophageal junction (Figure 36–3A). A dilated, sigmoid esophagus may be present in patients with long-standing achalasia (Figure 36–3B). An endoscopy should be performed to rule out a tumor of the esophagogastric junction and gastroduodenal pathology.

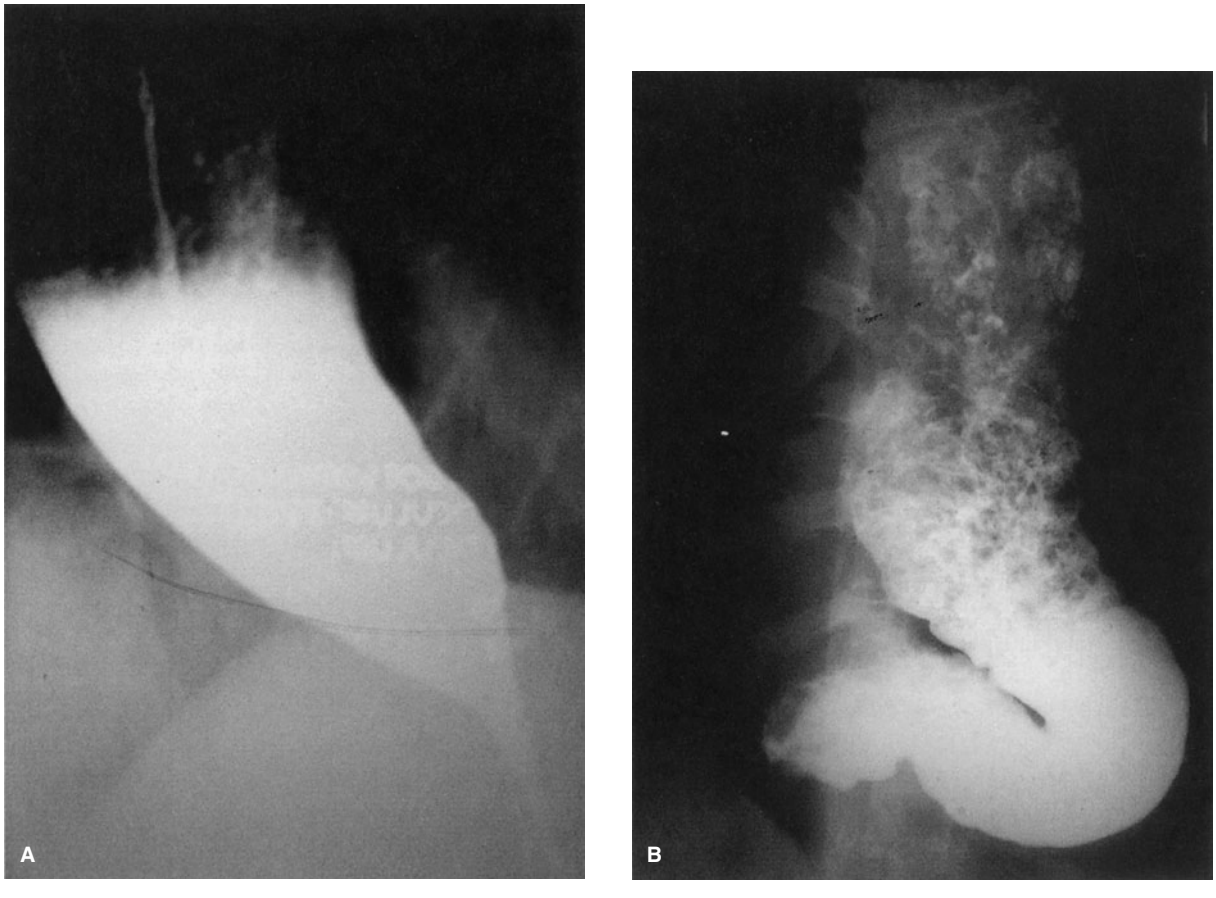
C. Special Tests

1. Esophageal manometry—Esophageal manometry is the key test for establishing the diagnosis of esophageal achalasia. The classic manometric findings are (1) absence of esophageal peristalsis and (2) a hypertensive LES that relaxes only partially in response to swallowing.

2. Ambulatory pH monitoring—In patients who have undergone pneumatic dilatation or a myotomy, ambulatory pH monitoring should always be performed to rule out abnormal gastroesophageal reflux; if present, it should be treated with acid-reducing medications.

Differential Diagnosis

Benign strictures caused by gastroesophageal reflux, eosinophilic esophagitis, and esophageal carcinoma may mimic the clinical presentation of achalasia. Sometimes an infiltrating tumor of the cardia can mimic not only the clinical and



▲ **Figure 36–3.** Achalasia. **(A)** "Bird-beak." **(B)** Dilated and sigmoid esophagus.

radiologic presentation of achalasia, but also the manometric profile. This condition is known as **secondary achalasia** or **pseudoachalasia** and should be suspected in patients older than 60 years of age who present with a recent onset of dysphagia and excessive weight loss. An endoscopic ultrasound or a computed tomography (CT) scan can help to establish the diagnosis.

Complications

The aspiration of retained and undigested food can cause repeated episodes of pneumonia. Achalasia is also a risk factor for esophageal cancer. Squamous cell carcinoma is probably due to the continuous irritation of the mucosa by the retained and fermenting food. However, adenocarcinoma can occur in patients who develop gastroesophageal reflux after either pneumatic dilatation or myotomy.

Treatment

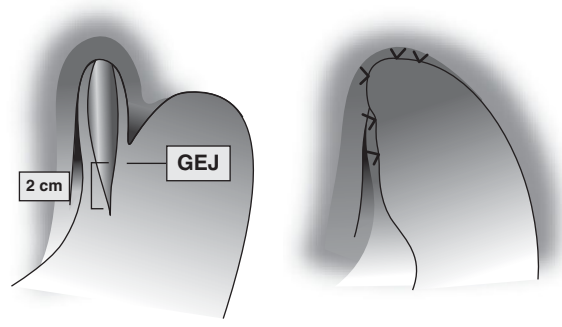
Therapy is palliative and is directed toward relieving symptoms by decreasing the outflow resistance caused by the dysfunctional LES. Because peristalsis is absent, gravity becomes the key factor that allows the emptying of food from the esophagus into the stomach. Several treatment modalities are available to achieve this goal.

A. Nonsurgical Measures

1. Calcium channel blockers—Calcium channel blockers are used to decrease LES pressure. However, only 10% of patients benefit from this treatment. It should be used primarily in elderly patients who have contraindications to either pneumatic dilatation or surgery.

2. Endoscopy—An intrasphincteric injection of botulinum toxin is used to block the release of acetylcholine at the level of the LES, therefore restoring the balance between excitatory and inhibitory neurotransmitters. This treatment, however, is of limited value since only 30% of treated patients still experience a relief of dysphagia 2.5 years later. It should be used primarily in elderly patients who are poor candidates for dilatation or surgery.

3. Pneumatic dilatation—Pneumatic dilatation has been the main form of treatment for many years. The initial success rate is between 70% and 80%, but it decreases to 50% 10 years later, even after multiple dilatations. The perforation rate is approximately 5%. If a perforation occurs, patients are taken emergently to the operating room, where closure of the perforation and a myotomy are performed through a left thoracotomy. The incidence of abnormal gastroesophageal reflux is about 25%. Patients who fail pneumatic dilatation are usually treated by a Heller myotomy.



▲ **Figure 36–4.** Heller myotomy **(left)** and Dor fundoplication **(right)**. GEJ, gastroesophageal junction.

B. Surgical Measures

A laparoscopic Heller myotomy and partial fundoplication is the procedure of choice for esophageal achalasia. The operation consists of a controlled division of the muscle fibers (ie, a myotomy) of the lower esophagus (5 cm) and proximal stomach (2 cm), followed by a partial fundoplication to prevent reflux (Figure 36–4). Patients remain in the hospital for 24–48 h, and return to regular activities in about 2 weeks. The operation effectively relieves symptoms in 85–95% of patients, and the incidence of postoperative reflux is between 10% and 15%. Because of the excellent results, short hospital stay, and fast recovery time, a laparoscopic Heller myotomy and partial fundoplication is considered today to be the primary treatment modality for esophageal achalasia.

Prognosis

A laparoscopic Heller myotomy allows for the excellent relief of symptoms in the majority of patients and should be preferred to pneumatic dilatation whenever surgical expertise is available. Botulinum toxin and medications should be used only in patients who are not candidates for pneumatic dilatation or laparoscopic Heller myotomy. Periodic follow-up by endoscopy is recommended to rule out the development of esophageal cancer.

Campos GM, Vittinghoff E, Rabl C et al. Endoscopic and surgical treatments for achalasia: A systematic review and meta-analysis. *Ann Surg*. 2009;249:45–57. [PMID:19106675] (Pneumatic dilatation is superior to botulinum toxin for the treatment of achalasia. Laparoscopic myotomy with fundoplication is most effective and the procedure of choice.)

Fisichella PM, Raz D, Palazzo F et al. Clinical, radiological, and manometric profile in 145 patients with untreated achalasia. *World J Surg*. 2008;32:1974–1979. [PMID:18575930] (Large series demonstrating a high frequency of heartburn in achalasic patients unrelated to refux status. Additionally, hypertensive LES was found to be less significant in the pathogenesis of the disease.)

Khajanchee YS, Kanneganti S, Leatherwood A et al. Laparoscopic Heller myotomy with Toupet fundoplication: Outcomes predictors in 121 consecutive patients. *Arch Surg*. 2005;140:827. (Heller myotomy relieves symptoms in more than 90% of patients.)

Moonka R, Patti MG, Feo CV et al. Clinical presentation and evaluation of malignant pseudoachalasia. *J Gastrointest Surg*. 1999;3:456. [PMID: 10482700] (Esophageal tumors can mimic the clinical and manometric picture of achalasia.)

Patti MG, Fisichella PM. Laparoscopic Heller myotomy and Dor fundoplication for esophageal achalasia. How I do it. *J Gastrointest Surg*. 2008;12:764–766 [PMID:17957436]. (Provides description of the operative procedure and perioperative management.)

Patti MG, Gorodner MV, Galvani C et al. Spectrum of esophageal motility disorders: Implications for diagnosis and treatment. *Arch Surg*. 2005;140:442. (Largest published series of diagnosis and treatment of esophageal motility disorders.)

Patti MG, Molena D, Fisichella PM et al. Laparoscopic Heller myotomy and Dor fundoplication for achalasia. *Arch Surg*. 2001;136:870. [PMID: 11485521] (Heller myotomy relieves symptoms in more than 90% of patients.)

West RL, Hirsch DP, Bartelsman JF et al. Long-term results of pneumatic dilatation in achalasia followed more than 5 years. *Am J Gastroenterol*. 2002;97:1346. [PMID: 12094848] (Long-term follow-up of patients after pneumatic dilatation.)

ESOPHAGEAL DIVERTICULA

Diverticula of the esophagus are mainly located above the LES (epiphrenic diverticulum) or the UES (pharyngoesophageal—or Zenker—diverticulum). They are both caused by abnormalities involving the LES or the UES, which result in protrusion of the mucosa and submucosa through the muscular layers.

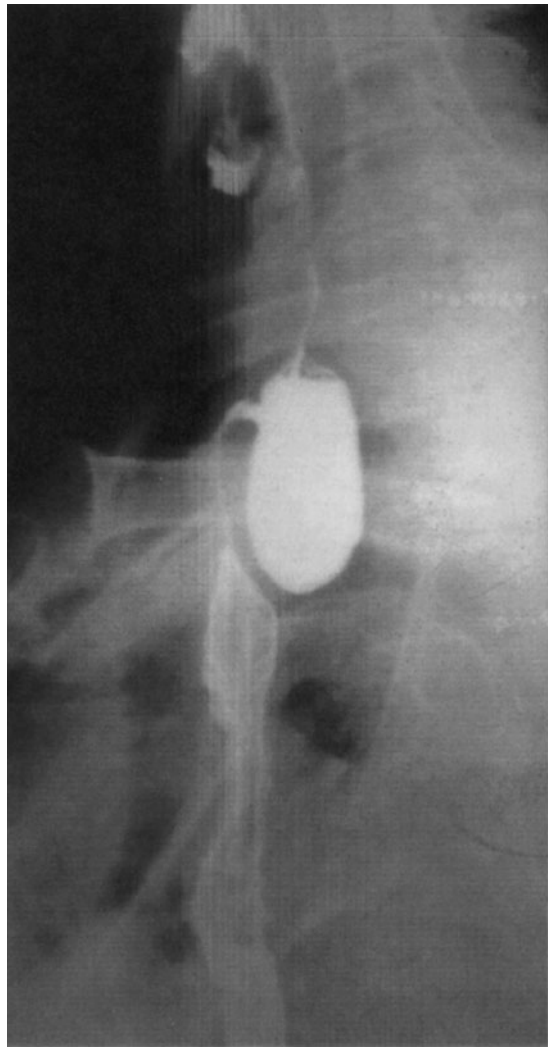
PHARYNGOESOPHAGEAL DIVERTICULUM (ZENKER DIVERTICULUM)

ESSENTIALS OF DIAGNOSIS

- Dysphagia
- Regurgitation of undigested food (with risk of aspiration)
- Gurgling sounds in the neck
- Halitosis.

General Considerations

Zenker diverticulum originates from the posterior wall of the esophagus in a triangular area of weakness, limited inferiorly by the cricopharyngeus muscle and superiorly by the inferior constrictor muscles (ie, the Killian triangle). As the diverticulum enlarges, it tends to deviate from the midline, mostly to the left (Figure 36–5).



▲ **Figure 36–5.** Zenker diverticulum.

Pathogenesis

Zenker diverticulum results from either a lack of coordination between the pharyngeal contraction and the opening of the UES or a hypertensive UES (including cricopharyngeal spasm). Because of the increased intraluminal pressure, there is progressive herniation of mucosa and submucosa through the Killian triangle.

Clinical Findings

A. Symptoms and Signs

Dysphagia is the most common symptom. The regurgitation of undigested food from the diverticulum often occurs and

can lead to aspiration both into the tracheobronchial tree and pneumonia. Patients frequently have halitosis and can hear gurgling sounds in the neck. About 30–50% of patients have associated GERD.

B. Imaging Studies

A barium swallow can clearly show the position and size of the diverticulum. It can also show a hiatal hernia.

C. Special Tests

Esophageal manometry can demonstrate a lack of coordination between the pharynx and the cricopharyngeus muscle, as well as a hypertensive UES. In addition, it can show a hypotensive LES and abnormal esophageal peristalsis. Ambulatory pH monitoring can determine whether abnormal esophageal acid exposure is present.

Differential Diagnosis

The differential diagnosis of Zenker diverticulum includes esophageal stricture, achalasia, esophageal cancer, and pneumonia. A sudden increase in pain and dysphagia symptoms or hematemesis in a patient with an existing Zenker diverticulum should raise suspicion for a squamous cell carcinoma arising within the diverticulum, which is a rare but reported event. Other diverticula can occur in the pharyngeal (pharyngeal pouch) and upper esophageal (Killiam–Jamieson diverticulum) areas and should be distinguished because the treatment is different.

Treatment

The classic treatment consists of excision of the diverticulum and myotomy of the cricopharyngeus muscle, including the upper 3 cm of the posterior esophageal wall through a cervical incision. For small diverticula (ie, <2 cm), myotomy alone is sufficient.

In more recent years, transoral endoscopic management has gained popularity, using either rigid or flexible endoscopy. The wall of the diverticulum and the cricopharyngeus muscle is divided with a stapling device, electrocautery, or laser. Use of a stapling device has been preferred for diverticula between 3 and 6 cm because it effectively seals the cut edges of the wound as it divides the sac. The stapling device is mechanically limited in short segment (<3 cm) diverticula due to inability to advance the staple line to the end of the sac and thus incomplete division of the party wall, and this can also result in recurrence in patients with longer sacs. Division of short- and long-segment diverticula can be performed with CO_2 laser or electrocautery, with some authors advocating mucosal closure with an endoscopic suturing device following division. Endoscopic injection of botulinum toxin into the cricopharyngeus has also been used with some success for small diverticula.

If GERD is present, it should be treated aggressively with either proton pump inhibitors or fundoplication in order to avoid aspiration into the tracheobronchial tree.

Prognosis

The prognosis is excellent in about 90% of cases.

Aly A, Devitt PG, Jamieson GG. Evolution of surgical treatment for pharyngeal pouch. *Br J Surg*. 2004;91:657. [PMID: 15164432] (Review article describing the evolution of treatment of Zenker's diverticulum.)

Ferreira LEVVC, Simmons DT, Baron TH. Zenker's diverticula: pathophysiology, clinical presentation, and flexible endoscopic management. *Dis Esophagus*. 2008;21:1–8 [PMID:18197932] (Review of literature on flexible endoscopic management of Zenker diverticula.)

Mortensen M, Schaberg MR, Genden EM, Woo P. Transoral resection of short segment Zenker's diverticulum and cricopharyngeal myotomy: an alternative minimally invasive approach. *Laryngoscope*. 2010;120:17–22. [PMID: 19877194] (Description of methods for transoral cricopharyngeal myotomy and sac division.)

Counter PR, Hilton ML, Baldwin DL. Long-term follow-up of endoscopic stapled diverticulotomy. *Ann R Coll Surg Engl*. 2002;84:89. [PMID: 11995771] (Endoscopic, stapled diverticulotomy.)

Smith SR, Gendene M, Urken ML. Endoscopic stapling technique for the treatment of Zenker diverticulum vs standard open-neck technique: a direct comparison and charge analysis. *Arch Otolaryngol Head Neck Surg*.. 2002;128:141. [PMID: 11843721] (Endoscopic stapled diverticulotomy is more cost effective than open surgery.)

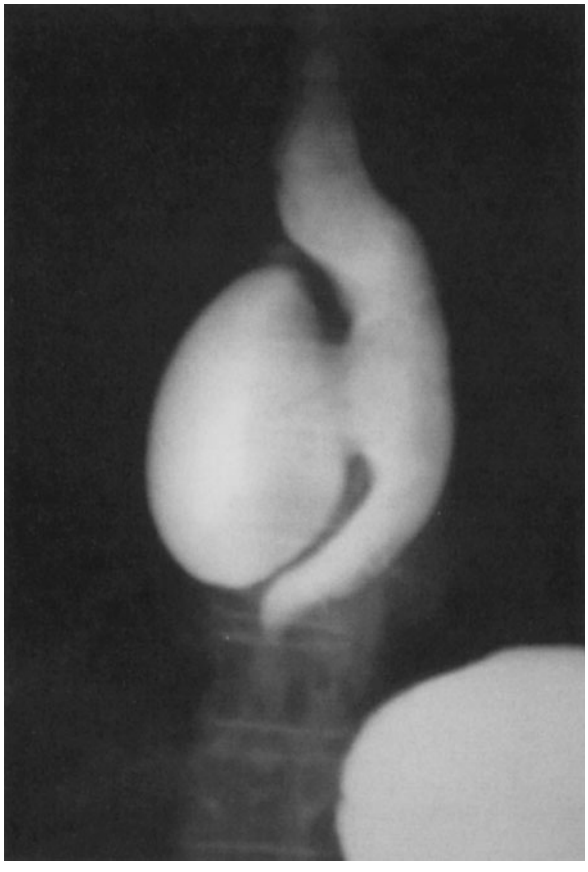
EPIPHRENIC DIVERTICULUM

ESSENTIALS OF DIAGNOSIS

- Dysphagia
- Regurgitation
- Diverticulum evident on barium swallow
- Esophageal motility disorder shown by esophageal manometry.

General Considerations

Epiphrenic diverticula are located just above the diaphragm (Figure 36–6). The diverticulum is not a primary anatomic abnormality but rather the consequence of an underlying motility disorder of the esophagus; achalasia is the most common, followed by diffuse esophageal spasm. The disorder causes an outflow obstruction at the level of the gastroesophageal junction, with a consequent increase in intraluminal



▲ **Figure 36–6.** Epiphrenic diverticulum.

pressure as well as progressive herniation of mucosa and submucosa through the esophageal muscle wall.

Clinical Findings

A. Symptoms and Signs

The symptoms experienced by patients with epiphrenic diverticulum are in part due to the underlying motility disorder (eg, dysphagia or chest pain) and in part due to the diverticulum per se (ie, regurgitation with the risk of aspiration). Some diverticula, however, can be asymptomatic.

B. Imaging Studies

A chest radiograph can show an air-fluid level in the posterior mediastinum. A barium swallow clearly shows the position and size of the diverticulum (see Figure 36–6).

C. Special Tests

In most cases, esophageal manometry identifies the underlying motility disorder.

Differential Diagnosis

A paraesophageal hernia can be confused with an epiphrenic diverticulum. Barium swallow and endoscopy help in establishing the diagnosis.

Treatment

The treatment is surgical and the laparoscopic approach is currently preferred. This procedure consists of (1) resection of the diverticulum, (2) a long myotomy, and (3) a partial fundoplication to prevent gastroesophageal reflux. The myotomy is performed on the side of the esophagus opposite to where the diverticulum is located. It should extend proximally to the upper border of the neck of the diverticulum and distally for 2 cm onto the gastric wall; a partial fundoplication is then performed.

Prognosis

A laparoscopic diverticulectomy, with myotomy and fundoplication, is successful in 80–90% of cases.

Kilic A, Schuchert MJ, Awais O et al. Surgical management of epiphrenic diverticula in the minimally invasive era. *JLS*. 2009;13:160–164. [PMID:19660209] (Laparoscopic treatment of epiphrenic diverticula results in reduced morbidity compared to open treatment with similar symptom relief.)

Klaus A, Hinder RA, Swain J, Achem SR. Management of epiphrenic diverticula. *J Gastrointest Surg*. 2003;7:906. [PMID: 14592666] (Laparoscopic treatment of epiphrenic diverticula.)

Nehra D, Fumagulli W, Bona S et al. Physiologic basis for the treatment of epiphrenic diverticulum. *Ann Surg*. 2002;235:346. [PMID: 11882756] (A physiologic approach to the treatment of epiphrenic diverticulum.)

Tedesco P, Fisichella PM, Way LW et al. Cause and treatment of epiphrenic diverticula. *Am J Surg*. 2005;190(6):891.

EOSINOPHILIC ESOPHAGITIS

ESSENTIALS OF DIAGNOSIS

- Dysphagia
- Recurrent food impactions
- Heartburn
- Esophagitis on endoscopy with absence of reflux on pH monitoring
- Eosinophilic infiltration on biopsy.

General Considerations

Eosinophilic esophagitis (EE) is an uncommon but increasingly recognized and reported disease entity involving esophagitis in the setting of absent or controlled reflux. These patients tend

to have a history of atopy and can present with dysphagia and recurrent food impactions. Currently it is a diagnosis of exclusion but diagnostic criteria are being developed.

Pathogenesis

This disease is not yet well understood. However, a strong association with hypersensitivity reactions to airborn alloantigens and particularly food has been found, suggesting a role for antigen-driven eosinophilic infiltration of the esophagus. This is supported by reports of success with food elimination strategies in reducing symptoms. Eosinophilic infiltration is thought to lead to smooth muscle dysfunction and resulting motor disturbances.

Clinical Findings

A. Symptoms and Signs

Dysphagia is the most common presenting sign, occurring in >90% of patients with EE. Patients can also present with recurrent food impaction, and in the setting of unimpressive endoscopy this should raise suspicion for EE. Heartburn is present in approximately a quarter of patients. Due to the association with atopy, a personal and family history of atopic diseases and reactions should be sought.

B. Imaging Studies

1. Endoscopy—Findings consistent with but not pathognomonic for EE include: (1) concentric rings or "trachealization" of the esophagus; (2) longitudinal furrows; (3) friability and esophageal inflammation; (4) multicentric white patches; (5) narrowing or strictures; (6) absence of hiatal hernia or other findings more strongly suggestive of GERD. Biopsies should be performed of any suspicious areas, but should also be performed in any patient with symptoms and history suggestive of EE even in the setting of normal endoscopic findings.

C. Specials Tests

1. Mucosal Biopsy—An elevated level of eosinophils (>15/high-power field) has been proposed as a diagnostic criteria for EE. This finding can also be seen in GERD, though usually to a lesser degree. This is particularly true for patients who are currently on antireflux therapy, in whom high levels of esoinophils in the setting of refractory esophagitis should raise suspicion for EE. Patients with EE also tend to have elevated esosinophils in all areas of the esophagus, as compared to typically only the distal esophagus with GERD.

2. Alloantigen Testing—Skin prick testing has been used to identify food triggers in patients with suspected EE with some success. However not all sensitivities can be identified in this manner. Food elimination testing is the mainstay of food sensitivity testing but requires close partnership between the patient and physician and careful monitoring of food content and symptoms. Consultation with a dietician can be useful in the development of food elimination strategies.

Differential Diagnosis

It is important to rule out GERD and achalasia by esophageal manometry and pH monitoring tests. Other esophageal motility disorders and benign and malignant strictures can present in a similar way.

Treatment

Current therapy for EE consists of identification of food triggers and avoidance. This can be difficult because many patients are sensitized to multiple food allergens. Topical glutocorticoids has been successful in controlling symptoms and reducing inflammation in some patients. Acid reduction therapy should be considered if reflux is present to decrease irritation of the inflamed esophageal lining.

Prognosis

Despite food avoidance and pharmacotherapy demonstrating effectiveness in some patients, eosinophilic esophagitis remains a difficult disease to treat, with relapses in symptoms occurring in the majority of patients even after successful therapy.

Dellon ES, Gibbs WB, Fritchie KJ et al. Clinical, endoscopic, and histologic findings distinguish eosinophilic esophagitis from gastroesophageal reflux disease. *Clinical Gastroenterol Hepatol*. 2009;7:1305–1313. [PMID: 19733260] (Proposed criteria for distinguishing between EE and GERD.)

Hong S, Vogel NM. Food allergy and eosinophilic esophagitis: learning what to avoid. *Cleve Clin J Med*. 2010;77:51–59. [PMID:200048030] (Overview of food allergy testing and treatment of EE.)

Rothenberg ME. Biology and treatment of eosinophilic esophagitis. *Gastroenterol*. 2009;137:1238–1249. [PMID:19596009] (Current scientific understanding of the pathogenesis of EE and treatment strategies.)

Schopfer AM, Gonsalves N, Bussmann C et al. Esophageal dilation in eosinophilic esophagitis: effectiveness, safety, and impact on underlying inflammation. *Am J Gastroenterol*. advance online publication 24 November 2009. [PMID: 19935783] (Dilation in patients with EE can be carried out safely.)

GASTROESOPHAGEAL REFLUX DISEASE

ESSENTIALS OF DIAGNOSIS

- Heartburn
- Regurgitation
- Sliding hiatal hernia on barium swallow
- Esophagitis on endoscopy
- Abnormal esophageal exposure on ambulatory pH monitoring.

General Considerations

GERD is the most common upper gastrointestinal disorder in the Western world and accounts for approximately 75% of esophageal diseases. Heartburn, usually considered synonymous with the presence of abnormal gastroesophageal reflux, is experienced by 20–40% of the adult population of Western countries. The incidence of reflux symptoms increases with age, and both sexes seem to be equally affected. Symptoms are more common during pregnancy, probably because of hormonal effects on the LES and the increased intraabdominal pressure of the enlarging uterus.

Pathogenesis

GERD is caused by the abnormal retrograde flow of gastric contents into the esophagus, resulting in symptoms, mucosal damage, or both. A defective LES is the most common cause of GERD. Transient LES relaxations account for most reflux episodes in patients either without mucosal damage or with mild esophagitis, whereas a short and hypotensive LES is more frequently found in patients with more severe esophagitis. In 40–60% of patients with GERD, abnormalities of esophageal peristalsis are also present. Because esophageal peristalsis is the main determinant of esophageal acid clearance (ie, the ability of the esophagus to clear gastric contents refluxed through the LES), patients with abnormal esophageal peristalsis have more severe reflux and slower clearance. Therefore, these patients often have more severe mucosal injury and more frequent atypical symptoms such as cough or hoarseness. A hiatal hernia also contributes to the incompetence of the gastroesophageal junction by altering the anatomic relationship between the LES and the esophageal crus. In patients with large hiatal hernias, the LES is usually shorter and weaker and the amount of reflux is greater.

Clinical Findings

A. Symptoms and Signs

Heartburn, regurgitation, and dysphagia are considered typical symptoms of GERD. However, a clinical diagnosis of GERD, based on typical symptoms such as heartburn and regurgitation, is correct in only 70% of patients when compared with the results of pH monitoring. A good response to therapy with proton pump inhibitors is instead a better predictor of the presence of abnormal reflux. In addition to the typical symptoms, patients with GERD can present with atypical symptoms such as cough, wheezing, chest pain, hoarseness, and dental erosions. These symptoms represent extraesophageal presentations of the disease, including respiratory disorders such as asthma, as well as ear, nose, and throat abnormalities such as laryngitis (Table 36–1). Two mechanisms have been postulated for GERD-induced respiratory symptoms: (1) a vagal reflux arc resulting in bronchoconstriction and (2) microaspiration into the tracheobronchial tree.

Table 36–1. Typical and Atypical Symptoms of GERD.

Typical symptoms
Heartburn
Regurgitation
Dysphagia
Atypical symptoms
Hoarseness
Chronic laryngitis and sore throat
Globus sensation
Otitis media
Dental erosions
Noncardiac chest pain
Chronic cough
Aspiration pneumonia
Asthma

Ear, nose, and throat symptoms such as hoarseness, globus sensation, or dental erosions are thought to be secondary to the upward extent of the acid with direct damage. This phenomenon has been termed laryngopharyngeal reflux.

B. Imaging Studies

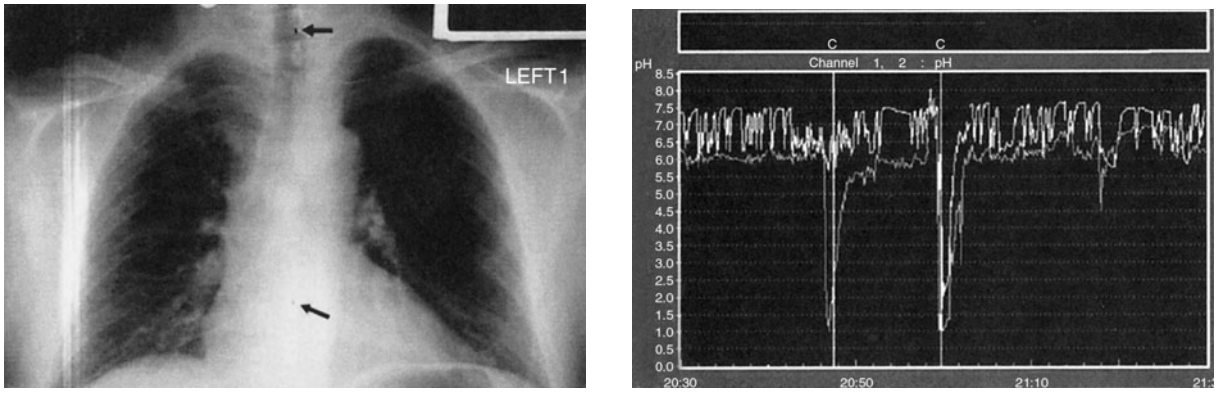
1. Barium swallow—A barium swallow provides information about the presence and size of a hiatal hernia, the presence and length of a stricture, and the length of the esophagus. This test, however, is not diagnostic of GERD since a hiatal hernia or reflux of barium can be present in patients who do not have GERD.

2. Endoscopy—The value of endoscopy is mostly limited to the detection of the complications of GERD (eg, esophagitis, Barrett esophagus, and stricture) and to the exclusion of other pathology (esophageal, gastric, or duodenal). The value of endoscopy in diagnosing GERD is limited because only 50% of patients with GERD have esophagitis. In addition, there is major interobserver variation among endoscopists for the low grades of esophagitis.

C. Specials Tests

1. Esophageal manometry—Esophageal manometry provides information about the LES, including the resting pressure, length, and relaxation, as well as about the quality of esophageal peristalsis. In about 40% of patients with GERD, the pressure of the LES and the peristalsis are normal. In addition, manometry is essential for proper placement of the pH probe for ambulatory pH monitoring (5 cm above the upper border of the LES).

2. Ambulatory pH monitoring—Ambulatory pH monitoring is the most reliable test in the diagnosis of GERD, with a sensitivity and specificity of about 92%. Acid-suppressing medications must be stopped 3 days (eg, H_2-blocking agents) to 14 days (eg, proton pump inhibitors) prior to the study.



A B

▲ **Figure 36–7.** Ambulatory pH monitoring. **(A)** Two sensors located 5 and 20 cm above the lower esophageal sphincter. **(B)** Correlation between episodes of reflux and cough (c).

Diet and exercise are unrestricted during the test in order to mimic a typical day of the patient's life. This test should always be performed (1) in patients who do not respond to medical therapy; (2) in patients who relapse after the discontinuation of medical therapy; (3) before antireflux surgery; (4) when atypical symptoms are present. In patients with atypical symptoms a pH probe with two sensors (5 and 20 cm above the LES) is used to determine the upward extent of the reflux. The tracing should be analyzed for a temporal correlation between symptoms and episodes of reflux (Figure 36–7).

Differential Diagnosis

Irritable bowel syndrome, achalasia, eosinophilic esophagitis, cholelithiasis, and coronary artery disease can present with heartburn. Esophageal manometry and pH monitoring are essential to determine with certainty whether GERD is present.

Complications

Esophagitis is the most common complication. Barrett esophagus (ie, metaplastic changes from squamous to columnar epithelium) is found in about 12% of patients with reflux documented by pH monitoring. This complication may lead to the development of adenocarcinoma. Asthma, aspiration pneumonia, laryngitis, chronic sinusitis, and dental erosions can also occur.

Treatment

A. Nonsurgical Measures

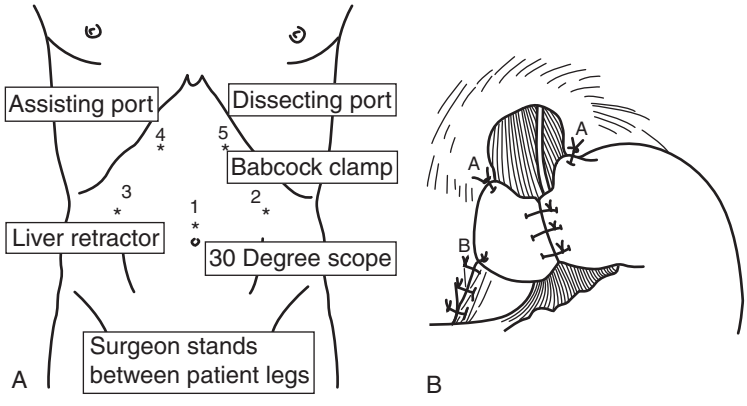
1. Lifestyle modifications—Patients should eat frequent, small meals during the day to avoid gastric distention. They should also avoid fatty foods, spicy foods, and chocolate, because these foods lower the LES pressure. The last meal of the day should be no less than 2 h before going to bed. To increase the effect of gravity, the head of the bed should be elevated over 4- to 6-inch blocks. Patients should also be counseled to lose weight if obese.

2. Other nonsurgical measures—Antacids are useful for patients with mild intermittent heartburn. Acid-suppressing medications are the mainstay of medical therapy. H_2 blocking agents are usually prescribed for patients with mild symptoms or mild esophagitis. Proton pump inhibitors are superior to H_2 blocking agents because they exert a more profound control of acid secretion—healing of the esophagitis occurs in 80–90% of these patients. However, both the symptoms and esophagitis tend to recur in most patients after therapy is discontinued so that most patients need chronic maintenance therapy. In addition, about 50% of patients on maintenance proton pump inhibitors require increasing doses to maintain healing of the esophagitis. Medical therapy is largely ineffective for the treatment of the extraesophageal manifestations of GERD due to the upward extension of the gastric contents. In these patients, acid-suppressing medications only alter the pH of the gastric refluxate, but reflux and aspiration still occur because of an incompetent LES and an ineffective esophageal peristalsis.

Recent concern has been raised about potential adverse effects of long-term therapy with proton-pump inhibitors, in particular calcium malabsorption leading to osteoporosis, increased risk of gastrointestinal infections and pneumonia. Overall the safety profile of proton pump inhibitors is excellent, but it is recommended that patients are treated with the lowest effective dose to control symptoms.

B. Surgical Measures

1. Laparoscopic fundoplication—The goal of surgical therapy is to restore the competence of the LES. A laparoscopic



▲ **Figure 36–8.** Laparoscopic Nissen fundoplication. **(A)** Position of the trocars. **(B)** Completed fundoplication.

total fundoplication (360°) is considered the procedure of choice because it increases the resting pressure and length of the LES and decreases the number of transient LES relaxations (Figure 36–8).

2. Indications for surgery—A laparoscopic fundoplication provides the same excellent results of open surgery, with symptom resolution in more than 90% of patients. It now requires a 1- to 2-day hospital stay and results in both minimal postoperative discomfort and a fast return to regular activity.

The ideal patient is one who has a good response to proton pump inhibitors. A patient who is nonresponsive to medical therapy requires a thorough work-up to elucidate the cause of the foregut symptoms, and an alternative diagnosis ranging from irritable bowel syndrome to gallbladder disease is frequently found. Young patients might also choose an operation early in the course of their disease to avoid a life-long commitment to lifestyle changes and medications. Long-term follow-up of patients treated with either fundoplication or proton pump inhibitors demonstrates surgery to be superior to medical management with regards to control of symptoms.

Patients who have regurgitation with respiratory symptoms or hoarseness are also ideal candidates for a fundoplication. Even the complete elimination of gastric acid secretion by proton pump inhibitors frequently fails to control these symptoms, since it only alters the pH of the gastric refluxate but does not prevent the regurgitation and upward extent of the reflux. Analyzing the pH tracing for a correlation between the symptoms and the episodes of reflux helps to predict the surgical outcome (see Figure 36–7).

Many surgeons also consider the presence of Barrett esophagus as an indication for surgical rather than medical treatment, based on the following considerations: (1) Proton pump inhibitors, although effective in controlling the acid component of refluxate, do not eliminate the reflux of bile, which is a major contributor to the pathogenesis of Barrett epithelium. (2) Patients with Barrett esophagus have a lower LES pressure and a defective peristalsis more often than patients without Barrett esophagus. As a consequence, their mucosa is exposed to larger amounts of gastric refluxate. (3) Evidence suggests that an effective antireflux operation can prevent the progression from metaplasia to dysplasia. The definite answer, however, awaits the results of further randomized control studies; therefore, endoscopic surveillance after laparoscopic fundoplication is recommended.

Prognosis

After a fundoplication, the control of typical symptoms is obtained in about 90% of patients. The success rate is in the range of 70–90% for patients with atypical symptoms, since it is often more difficult to establish, preoperatively, a strong correlation between gastroesophageal reflux and symptoms.

Cote GA, Howden CW. Potential adverse effects of proton pump inhibitors. *Curr Gastroenterol Rep*. 2008;10:208–214. [PMID:18625128] (Review of emerging data on adverse effects of proton pump inhibitor therapy.)

Campos GM, Peters JH, DeMeester TR et al. Multivariate analysis of factors predicting outcome after laparoscopic Nissen fundoplication. *J Gastrointest Surg*. 1999;3:292. [PMID: 10481122] (Preoperative factors that predict a good outcome after laparoscopic fundoplication.)

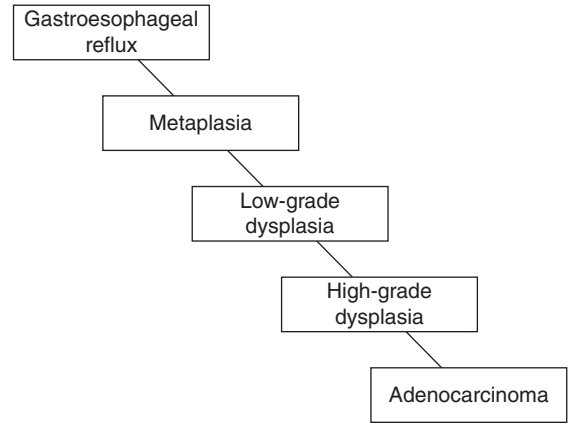
Diener U, Patti MG, Molena D, et al. Esophageal dysmotility and gastroesophageal reflux disease. *J Gastrointest Surg*. 2001;5:260. [PMID: 11360049] (Patients with abnormal esophageal peristalsis have more acid reflux, slower clearance, and worse mucosal injury.)

Garrett CG, Cohen SM. Otolaryngological perspective on patients with throat symptoms and laryngeal irritation. *Curr Gastroenterol Rep*. 2008;10:195–199. [PMID:18625126] (Ear, nose, and throat manefestations of GERD/LPR.)

Jailwala JA, Shaker R. Oral and pharyngeal complications of gastroesophageal reflux disease: globus, dental erosions, chronic sinusitis. *J Clin Gastroenterol*. 2000;30:35. [PMID: 10777170] (Ear, nose, and throat manifestations of gastroesophageal reflux disease.)

Kahrilas PJ. Clinica practice: gastroesophageal reflux disease. *NEJM*. 2008;359:1700–1707. [PMID:18923172] (Review of current diagnosis and treatment strategies for GERD.)
Lundell L, Miettinen P, Myrvold HE et al. Comparison of outcomes twelve years after antireflux surgery or omeprazole maintenance therapy for reflux esophagitis. *Clin Gastroenterol Hepatol*. 2009;7:1264–1265. [PMID:19490952] (Surgery is superior to omeprazole for control of reflux symptoms.)
Patti MG, Arecerito M, Tamburini A et al. Effect of laparoscopic fundoplication on gastroesophageal reflux disease-induced respiratory symptoms. *J Gastrointest Surg*. 2000;4:143. [PMID: 10675237] (Laparoscopic fundoplication is an effective treatment for GERD-induced respiratory symptoms.)
Patti MG, Diener U, Tamburini Aet al. Role of esophageal function tests in the diagnosis of gastroesophageal reflux disease. *Dig Dis Sci*. 2001;46:597. [PMID: 11318538] (Esophageal manometry and pH monitoring are necessary to establish the diagnosis of gastroesophageal reflux disease.)
Patti MG, Robinson T, Galvani C et al. Total fundoplication is superior to partial fundoplication even when esophageal peristalsis is weak. *J Am Coll Surg*. 2004;198:863. [PMID: 15194064] (Study comparing total and partial fundoplication for gastroesophageal reflux disease.)
Patti MG, Tedesco P, Golden J et al. Idiopathic pulmonary fibrosis. How often is it really idiopathic? *J Gastrointest Surg*. 2005;9:1053. [PMID: 16269375] (Gastroesophageal reflux disease has probably a cause-and-effect relationship with idiopathic pulmonary fibrosis.)
Richter JE. Extraesophageal presentations of gastroesophageal reflux disease: an overview. *Am J Gastroenterol*. 2000;95:1. [PMID: 10950098] (Atypical symptoms of gastroesophageal reflux disease.)

GER - Barrett's esophagus - Adenocarcinoma sequence.



▲ **Figure 36–9.** Gastroesophageal reflux disease, Barrett esophagus, and adenocarcinoma sequence.

MALIGNANT DISORDERS OF THE ESOPHAGUS

BARRETT ESOPHAGUS

ESSENTIALS OF DIAGNOSIS

- GERD symptoms (typical and atypical)
- Endoscopic evidence of "salmon pink" epithelium above gastroesophageal junction
- Specialized columnar epithelium on esophageal biopsy

General Considerations

Barrett esophagus is a metaplasia of the esophageal mucosa caused by the replacement of the squamous epithelium with columnar epithelium. About 10–12% of patients who undergo endoscopy for symptoms of GERD are found to have Barrett esophagus. It occurs more frequently in white men older than 50 years of age. This metaplasia may progress to high-grade dysplasia and eventually to adenocarcinoma. Thus, adenocarcinoma represents the final step of a sequence of events in which a benign disease (GERD) evolves into a preneoplastic disease and eventually into cancer (Figure 36–9).

Pathogenesis

Barrett esophagus is due to reflux of gastric acid and duodenal juice into the esophagus. Barrett metaplasia is considered an advanced stage of GERD characterized by a panesophageal motor disorder. When compared with patients with GERD with no mucosal injury or less severe esophagitis, patients with Barrett esophagus have a shorter and weaker LES and decreased amplitude of esophageal peristalsis. As a consequence, the amount of reflux is greater and esophageal clearance is slower. In addition, hiatal hernia is more common in patients with Barrett metaplasia.

Clinical Findings

A. Symptoms and Signs

Patients with Barrett esophagus typically have a long history of GERD. Although most patients experience both typical and atypical symptoms of GERD, other patients may become asymptomatic over time because of the decreased sensitivity of the metaplastic epithelium.

B. Imaging Studies

Barium swallow may show ulcerations, a hiatal hernia, or a stricture. Endoscopy shows a "salmon pink" epithelium above the gastroesophageal junction, which replaces the whitish squamous epithelium. The diagnosis is confirmed

by pathologic examination of the esophageal mucosa and requires the identification of intestinal type epithelium, characterized by the presence of goblet cells.

C. Special Tests

Esophageal manometry often shows a short and hypotensive LES and abnormal esophageal peristalsis. Ambulatory pH monitoring usually shows a severe amount of acid reflux. Esophageal exposure to duodenal juice can be quantified by a fiberoptic probe that measures intraluminal bilirubin (as a marker for duodenal juice). In patients with GERD, the prevalence of esophageal bilirubin exposure parallels the degree of mucosal injury; the bilirubin exposure is higher in patients with Barrett esophagus.

Treatment

A. Barrett Esophagus: Metaplasia

The treatment options for patients with Barrett esophagus are similar to those of patients with GERD without metaplasia; they consist of either proton pump inhibitors or a fundoplication. Other chemopreventive agents are being investigated but are still experimental. A surgical approach might offer an advantage over medical therapy for the following reasons: (1) The successful elimination of reflux symptoms with proton pump inhibitors does not guarantee the control of acid reflux. When pH monitoring is performed in patients with asymptomatic Barrett esophagus who are treated with these medications, up to 80% of them still experience abnormal reflux. (2) Proton pump inhibitors do not eliminate the reflux of bile, a major contributor to the pathogenesis of Barrett epithelium. An antireflux operation prevents both acid and bile refluxate by restoring the competence of the gastroesophageal junction. (3) Recent studies have shown regression of short-segment Barrett's epithelium (<3 cm) in 15–50% of patients. However, because there is no definitive evidence that treatment (medical or surgical) prevents disease progression to cancer, regular follow-up should be performed with endoscopic examination and biopsy.

Endoscopic surveillance with four-quadrant biopsy has been demonstrated to result in earlier detection of high-grade dysplasia and esophageal cancer as well improved survival in patients with Barrett esophagus. Newer modalities of screening using narrow-band imaging and targeted, rather than random, biopsies has demonstrated similar detection rates with fewer biopsies per session.

B. Barrett Esophagus: High-Grade Dysplasia

When high-grade dysplasia is found (and confirmed by two experienced pathologists), two treatment options are available, close surveillance or surgery. Patients unfit for or wishing to delay surgery can enroll in a program of strict endoscopic surveillance, with endoscopy performed every 3 months and four quadrant biopsies obtained for every centimeter of Barrett esophagus. The goal is to detect cancer before it becomes invasive and spreads to lymph nodes. This is best suited to patients who have flat lesions, short segment disease, and/or unifocal disease and are willing to commit to strict follow-up.

For young and medically fit patients, an esophagectomy has traditionally been recommended and still may be appropriate for many patients. The cardinal goal of surgical therapy is to remove the cancer prior to nodal spread, which has a grave effect on prognosis. Early studies of esophagectomy for Barrett esophagus demonstrated invasive cancer in 30% or more of patients thought to have high-grade dysplasia at the time of the operation, prompting strong recommendations for early surgical therapy. However, this number may be much lower according to more recent reviews, lending support for less invasive means of treatment.

Endoscopic mucosal resection (EMR) and radiofrequency ablation (RFA) have been used as less-invasive methods to eradicate dysplastic epithelium and prevent progression to cancer. These techniques may also be used to treat adenocarcinoma limited to the mucosa without submucosal invasion (T1a, N0, M0). However, the long-term outcome of this treatment is still under investigation. The rationale for this treatment modality is to ablate the columnar epithelium, allowing regeneration of the squamous mucosa. Photodynamic therapy has also been used, but due to associations with difficult-to-treat esophageal strictures and buried islands Barrett epithelium under the regenerated squamous epithelium, RFA is now preferred over this modality. Endoscopic surveillance is recommended for patients treated with EMR or RFA.

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Chennat J, Konda VJ, Ross AS et al. Complete Barrett's eradication endoscopic mucosal resection: an effective treatment modality for high-grade dysplasia and intramucosal carcinoma—an American single-center experience. *Am J Gastroenterol.* 2009;104:2684–2692. [PMID: 19690526] (EMR with close endoscopic surveillance is an effective treatment modality for Barrett esophagus with high-grade dysplasia and intramucosal carcinoma.)

Ganz RA, Overholt BF, Sharma VK et al. Circumferential ablation of Barrett's esophagus that contains high-grade dysplasia: A U.S. multicenter registry. *Gastrointest Endosc*. 2008;68:35–40. [PMID: 18355819] (Multicenter trial of EMR for Barrett esophagus with high-grade dysplasia demonstrating a 90% histologic complete response of high-grade dysplasia at 1 year of follow-up.)

Gerson LB, Shetler K, Triadafilopoulos G. Prevalence of Barrett esophagus in asymptomatic individuals. *Gastroenterology*. 2002;123:461. [PMID: 12145799] (Barrett esophagus can be found in patients without symptoms of gastroesophageal reflux disease.)

Gilbert S, Jobe BA. Surgical therapy for Barrett esophagus with high-grade dysplasia and early esophageal carcinoma. *Surg Clin NA*. 2009;18:523–531. [PMID:19500741] (Review of surgical therapy for Barrett esophagus.)

Konda VJ, Ross AS, Ferguson MK et al. Is the risk of concomitant invasive esophageal cancer in high-grade dysplasia in Barrett's esophagus overestimated? *Clin Gastroenterol Hepatol*. 2008;6:159–164. [PMID:18096439] (The prevalence of invasive esophageal carcinoma in patients with Barrett esophagus is lower than previously estimated and intramucosal carcinoma is more common than invasive carcinoma.)

Oelschlager BK, Barreca M, Chang L et al. Clinical and pathologic response of Barrett's esophagus to laparoscopic antireflux surgery. *Ann Surg*. 2003;238:458. [PMID: 14530718] (Antireflux surgery determines regression of short segment columnar epithelium in up to 56% of patients.)

Pouw RE, Gondrie JJ, Sondermeijer CM et al. Eradication of Barrett esophagus with early neoplasia by radiofrequency ablation, with or without endoscopic resection. *J Gastrointest Surg*. 2008;12:1627–1636. [PMID:18704598] (RFA is effective in eradicating Barrett esophagus with early carcinoma.)

Sharma P. Clinical practice: Barrett's esophagus. *NEJM*. 2009;361:2548–2556. [PMID:20032324]. (Review of data on current screening and treatment guidelines for Barrett esophagus.)

ESOPHAGEAL CANCER

ESSENTIALS OF DIAGNOSIS

- Progressive dysphagia, initially for solids and later for liquids
- Progressive weight loss
- Diagnosis confirmed by endoscopy and biopsies

General Considerations

In the United States, esophageal carcinoma accounts for 10,000 to 11,000 deaths per year. The last 30 years have seen a major change in the epidemiology of esophageal cancer in the United States. Until the 1970s, squamous cell carcinoma was the most common type of esophageal cancer, accounting for approximately 90% of the total incidence. It commonly occurred in the thoracic esophagus and mostly affected black men. Over the last three decades, the incidence of adenocarcinoma of the distal esophagus and gastroesophageal junction has progressively increased; currently, it accounts for more than 50% of all new cases of esophageal cancer. Squamous cell cancer is still the most common type worldwide. Esophageal cancer occurs mostly during the sixth and seventh decades of life and is more common in men than in women.

Pathogenesis

The most common contributing factors for squamous cell carcinoma are cigarette smoking and chronic alcohol exposure. Chronic ingestion of hot liquids or foods, poor oral hygiene, and nutritional deficiencies may play a role. Certain medical conditions such as achalasia, caustic injuries of the esophagus, and Plummer–Vinson syndrome are associated with an increased incidence of squamous cell cancer. GERD is the most common predisposing factor for adenocarcinoma of the esophagus. In these cases, adenocarcinoma represents the last event of a sequence that starts with GERD and progresses to metaplasia, high-grade dysplasia, and adenocarcinoma (see Figure 36–9). Obesity has also been identified as an important risk factor.

Esophageal cancer arises in the mucosa and subsequently tends to invade the submucosa and the muscle layers. Eventually, structures located next to the esophagus may be infiltrated (eg, the tracheobronchial tree, the aorta, and the recurrent laryngeal nerve). At the same time, the tumor tends to metastasize to the periesophageal lymph nodes (mediastinal, celiac, and cervical) and eventually to the liver and the lungs.

Clinical Findings

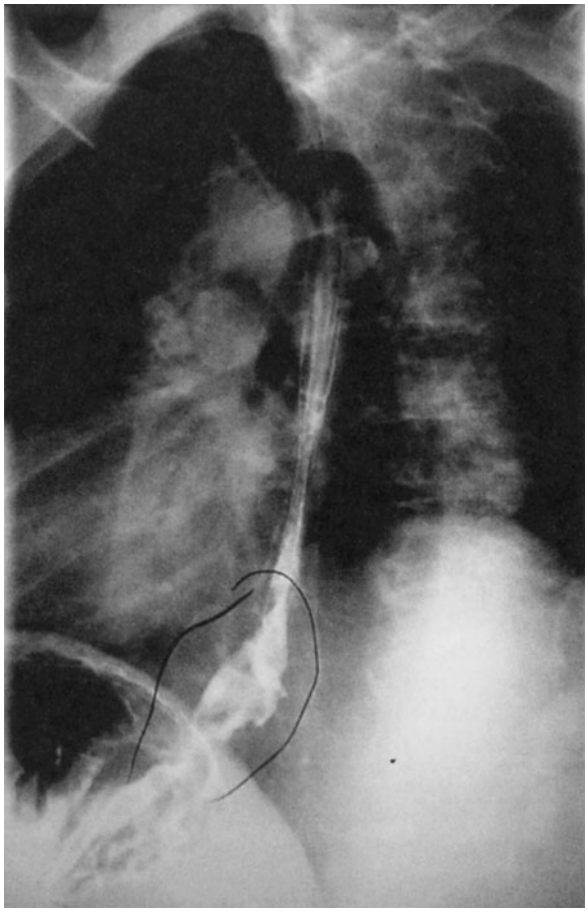
A. Symptoms and Signs

Dysphagia is the most common presenting symptom. Dysphagia initially manifests with the ingestion of solids, but eventually it is experienced with the consumption of liquids. As a result, weight loss occurs in more than 50% of patients. Patients may have pain when swallowing. Pain over bony structures may be due to metastases. Hoarseness is usually due to invasion of the right or left recurrent laryngeal nerve, with paralysis of the ipsilateral vocal cord. Respiratory symptoms may be due to the regurgitation and aspiration of undigested food or to invasion of the tracheobronchial tree, with development of a tracheoesophageal fistula.

B. Imaging Studies

1. Barium swallow—Barium swallow can show both the location and the extent of the tumor. Esophageal cancer usually presents as an irregular intraluminal mass or a stricture (Figure 36–10).

2. Endoscopy—Endoscopy allows for the direct visualization and biopsy of the tumor. For tumors of the upper and midesophagus, bronchoscopy is indicated to rule out invasion of the tracheobronchial tree.



▲ **Figure 36–10.** Adenocarcinoma of the distal esophagus.

C. Special Tests

After the diagnosis is established, it is important to determine the staging of the cancer. In 2010, the AJCC updated the staging system of esophageal cancer to include histologic grade for both adenocarcinoma and squamous cell carcinoma, and location (upper, middle, or lower esophagus) for squamous cell carcinoma (Table 36–2). Abdominal and chest CT scans are used to rule out metastases and the invasion of structures next to the esophagus. Alternately, positron emission tomography scanning can be used. Endoscopic ultrasound is the most sensitive test to determine the penetration of the tumor, the presence of enlarged periesophageal lymph nodes, and the invasion of structures next to the esophagus. A bone scan is indicated in patients who present with a new onset of bone pain.

Differential Diagnosis

Differential diagnoses include peptic strictures due to reflux, achalasia, and benign esophageal tumors.

Table 36–2. TNMG Classification for Esophageal Cancer.

Tumor
Tis—Carcinoma in situ (squamous cell) or high-grade dysplasia (adenocarcinoma)
T1a—Tumor invades lamina propria or muscularis mucosae
T1b—Tumor invades submucosa
T2—Tumor invades muscularis propria
T3—Tumor invades adventitia
T4a—Resectable tumor invading pleura, pericardium, or diaphragm
T4b—Unresectable tumor invading other adjacent structures (aorta, vertebrae, trachea)
Node
N0—No regional node metastases
N1—Metastases in 1–2 regional nodes
N2—Metastases in 3–6 regional nodes
N3—Metastases in seven or more regional nodes
Metastases
M0—No distant metastases
M1—Distant metastases
Grade
G1—Well differentiated
G2—Moderately differentiated
G3—Poorly differentiated

Treatment

A. Surgical Measures

Patients with esophageal cancer are considered candidates for esophageal resection if the following criteria are met: (1) there is no evidence of the spread of the tumor to structures next to the esophagus, such as the tracheobronchial tree, the aorta, or the recurrent laryngeal nerve; (2) there is no evidence of distant metastases; (3) the patient is fit from a cardiac and respiratory point of view.

An esophagectomy can be performed by using (1) an abdominal and a cervical incision with blunt dissection of the thoracic esophagus through the esophageal hiatus (**transhiatal esophagectomy**) or (2) an incision into the abdomen and the right side of the chest (**transthoracic esophagectomy**). After removing the esophagus, continuity of the gastrointestinal tract is re-established by using either the stomach or the colon. Many retrospective and prospective randomized studies have shown no difference in the survival rate between the two operations, suggesting that it is not the *type* of operation that influences survival but the *stage of the disease* at the time the operation is performed. The morbidity rate of the operation is approximately 30% and is mostly due to cardiac complications (eg, arrhythmias), respiratory complications (eg, atelectasis or pleural effusion), and septic complications (eg, anastomotic leak or pneumonia). The mortality rate in specialized centers is less than 5%. As with other complex operations (cardiac surgery, as well as liver and pancreatic resections), a lower mortality rate is obtained in "high-volume centers" because of the presence

of an experienced team composed of surgeons, anesthesiologists, cardiologists, radiologists, and nurses.

B. Nonsurgical Measures

Neoadjuvant therapy based on a combination of radiation therapy and chemotherapy has been attempted to improve both the local control, via radiation therapy, and the distant control of the disease, via chemotherapy. Unfortunately, with the exception of one study, all the randomized trials have failed to show a survival benefit in patients treated by neoadjuvant therapy followed by surgery compared with patients who had surgery alone. Nonoperative therapy is reserved for patients who are not candidates for surgery because of local invasion of the tumor, metastases, or a poor functional status. The goal of therapy in these patients is palliation of the dysphagia, which will allow them to eat. The following treatment modalities are available to achieve this goal: (1) Expandable, coated, metallic stents can be deployed by endoscopy under fluoroscopic guidance to keep the esophageal lumen open. They are particularly useful when a tracheoesophageal fistula is present. (2) Laser therapy (Nd:YAG laser) relieves dysphagia in up to 70% of patients. However, multiple sessions are usually required to keep the esophageal lumen open. (3) Radiation therapy is successful in relieving dysphagia in about 50% of patients.

Prognosis

The stage of the disease is the most important prognostic factor. The overall 5-year survival rate for esophageal cancer remains approximately 25–30%. Patients without lymph node metastases have a significantly better 5-year survival rate than patients with lymph node involvement.

Abrams JA, Buono DL, Strauss J et al. Esophagectomy compared with chemoradiation for early stage esophageal cancer in the elderly. *Cancer*. 2009;115:4924–4933. [PMID: 19637343] (SEER review of patients age 65 or older demonstrating superior results of surgery compared with chemoradiation.)

Burmeister BH, Smithers BM, Gebski V et al. Surgery alone versus chemoradiotherapy followed by surgery for resectable cancer of the oesophagus: a randomised controlled phase III trial. *Lancet Oncol*. 2005;6:659. [PMID: 16129366] (Neoadjuvant therapy does not improve survival.)

Devesa SS, Blot WJ, Fraumeni JF. Changing patterns in incidence of esophageal and gastric carcinoma in the United States. *Cancer*. 1998;83:2049. [PMID: 9827707] (Increased incidence of adenocarcinoma over the last three decades.)

Dimick JB, Wainess RM, Upchurch GR Jr et al. National trends in outcomes for esophageal resection. *Ann Thorac Surg*. 2005;79:212. [PMID: 15620945] (Lower mortality rate for esophageal resection is obtained in high-volume centers.)

Falk GW. Risk factors for esophageal cancer development. *Surg Onc Clin NA*. 2009;18:469–485. [PMID:19500737] (Rates of esophageal adenocarcimoa continue to increase; Barrett esophagus is the most important risk factor for development though obesity is identified as increasingly important as well.)

Ferguson MK, Durkin A. Long-term survival after esophagectomy for Barrett adenocarcinoma in endoscopically surveyed and nonsurveyed patients. *J Gastrointest Surg*. 2002;6:29. [PMID: 11986015] (Surveillance endoscopy allows early diagnosis of cancer in patients with Barrett esophagus.)

Gasper WJ, Glidden DV, Jin C, Way LW, Patti MG. Has recognition of the relationship between mortality rates and hospital volume for major cancer surgery in California made a difference? *Ann Surg*. 2009;250:472–483. [PMID:19730178] (Hospital volume continues to be an important predictor of perioperative mortality for esophagectomy and other major cancer surgeries.)

Law S, Wong J. Current management of esophageal cancer. *J Gastrointest Surg*. 2005;9:291. [PMID: 15694827] (Experience from the University of Hong Kong.)

Visser BC, Venook AP, Patti MG. Adjuvant and neoadjuvant therapy for esophageal cancer: a critical reappraisal. *Surg Oncol*. 2003;12:1. [PMID: 12689665] (Review article on the value of adjuvant and neoadjuvant therapy for esophageal cancer.)

We would like to acknowledge Carlos Galvani, MD, Fernando A. Herbella, MD, and Michael Korn, MD for their contribution to this chapter in the previous editions of CDT.

37

Benign & Malignant Disorders of the Trachea

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Emmanuel P. Prokopakis, MD, PhD & Costas Bizekis, MD

ANATOMY OF THE TRACHEA

ANATOMIC STRUCTURE

The adult trachea measures approximately 12 cm but varies anywhere from 10 to 13 cm depending on height and sex. As there is some variability in the length, the anterior portion of the trachea is not subject to tremendous change, for the most part is composed of cartilage, and is C-shaped. The rings maybe complete or bifid. The posterior part of the trachea is also called the membranous portion and is the part of the airway that moves with breathing (Figure 37–1A).

The diameter of the trachea varies among men and women. For the most part, the adult male tracheal diameter is 1.8–2.3 cm compared to the female airway, which is 1.4–2.0 cm. Each tracheal ring is about 4-mm high and there are approximately two rings per centimeter of trachea.

The cross section of the trachea may vary according to age or may be affected by an underlying disease process. For example, the juvenile trachea is more circular and more triangular in patients with chronic obstructive pulmonary disease.

ANATOMIC RELATIONSHIPS

The trachea is positioned midline in the mediastinum and is surrounded by many vital structures. In the neck, the *esophagus* lies just left of the airway and then at the level of the clavicles is directly posterior and adherent to it down to the level of the carina (Figure 37–1B). This gives us a better understanding of why tracheoesophageal fistulas occur.

Anteriorly and laterally, the *thyroid* is situated in front of the trachea from the cricoid bone to the level of the 2nd to 3rd rings. The isthmus is at the midline and the lobes extend laterally onto the trachea. These two organs have common blood supply from the inferior thyroid artery.

The course of the *recurrent nerves* is very important for the tracheal surgeon. On the right, it comes off the vagus nerve and wraps around the subclavian and traverses superiorly to enter the larynx between the thyroid and cricoid cartilages in order to innervate the intrinsic muscles of the larynx. On the left it comes off the vagus beneath the aortic arch and runs in the tracheoesophageal groove.

In the compact space of the mediastinum, the trachea is also surrounded by the arteries and veins that come off the heart and the aortic arch. The *innominate* or *bracheocephalic artery* comes off the aortic arch and crosses the tracheal midline at and slightly below the level of the sternal notch. This is often the first blood vessel encountered during the pretracheal dissection during mobilization of the airway and also due to its proximity it is very important for the understanding of how certain complications like tracheoinnominate fistula arise. The carotids course the trachea and the thyroid laterally in the neck. The bracheocephalic vein runs in front of the innominate artery and well anterior to the pretracheal plane.

BLOOD SUPPLY

The blood supply of the trachea enters through its lateral pedicles. This is an important point with regard to tracheal resection in that dissection lateral to trachea can only be limited to 1–2 cm in order to prevent devascularization and anastomotic dehiscence (Figure 37–1C).

Upper half receives its blood supply from the inferior thyroid artery, which has three branches (first branch supplies the lower cervical trachea, second branch the middle section, and third branch the upper section).

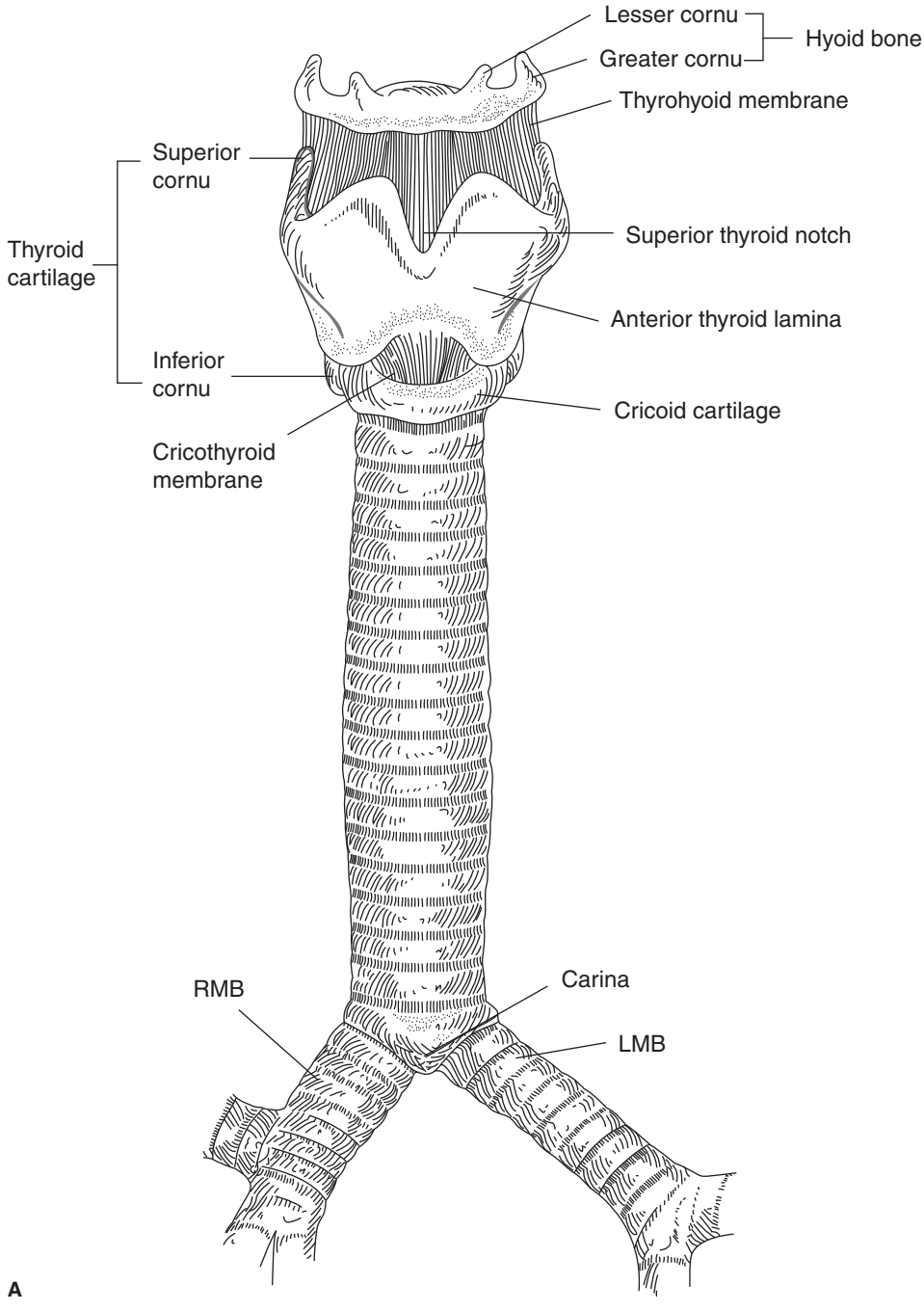
Lower half and carina are supplied by the bronchial arteries (superior, middle, and inferior).

Superior bronchial artery comes off the right side of the aorta.

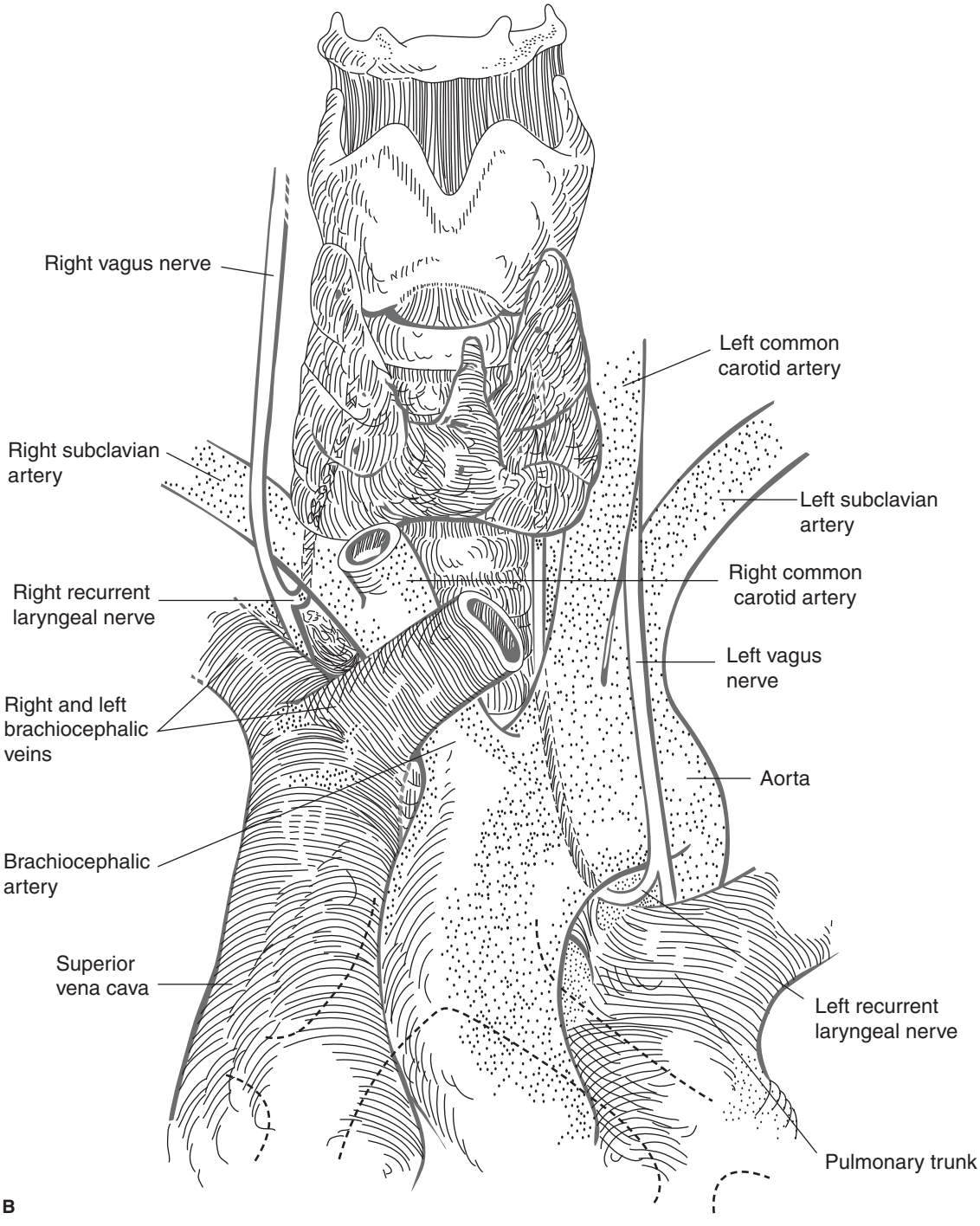
Middle bronchial artery connects with the superior bronchial to supply carina.

Inferior bronchial left bronchial tree.

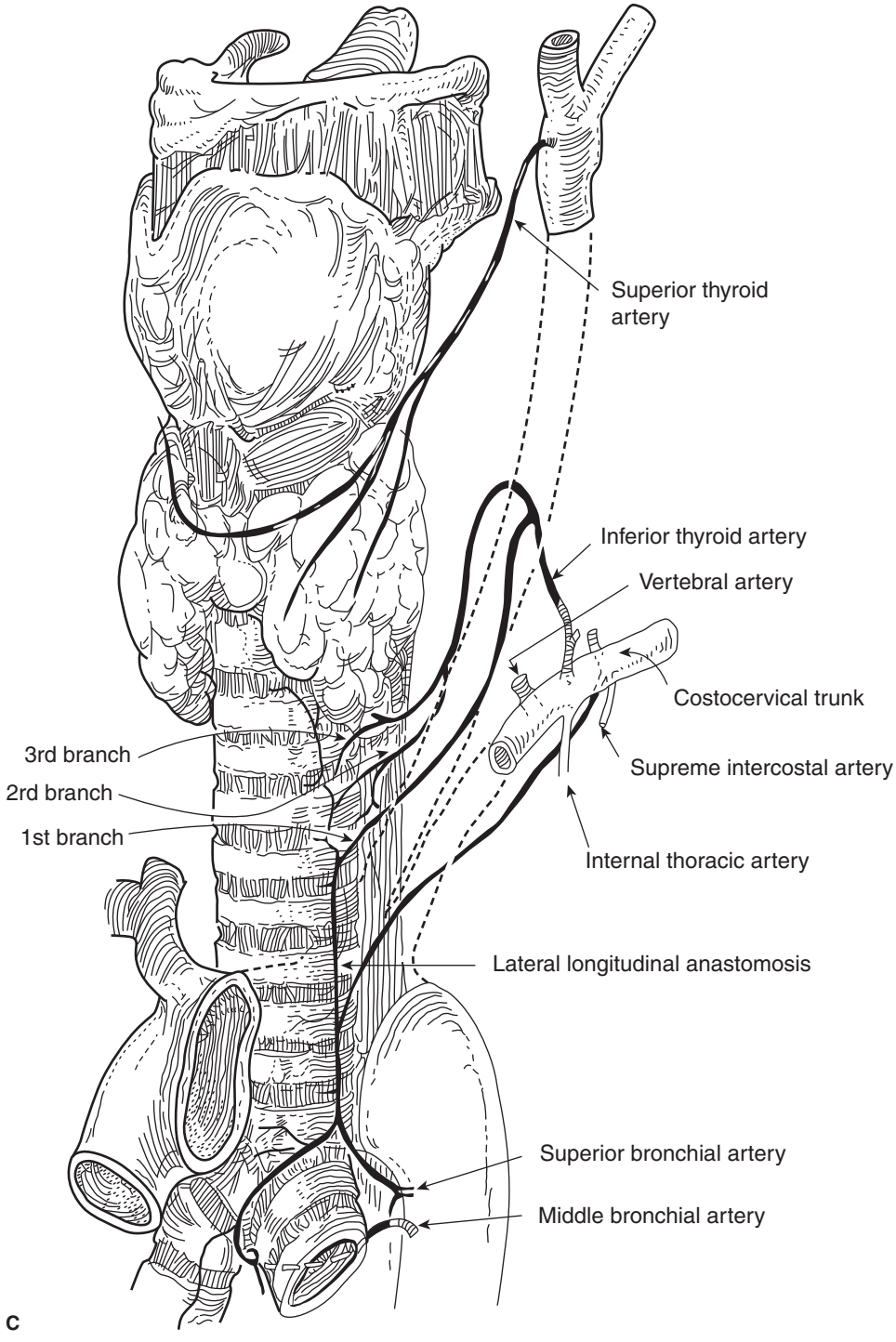
The superior and middle bronchial arteries connect to the inferior thyroid artery through the lateral longitudinal anastomosis.



▲ **Figure 37–1.** Anterior view of the trachea and adjacent structures. **(A)** Anatomical structure of the trachea. *(continued)*



▲ **Figure 37–1.** *(continued)* **(B)** Anatomical relationships.



▲ **Figure 37–1.** *(continued)* **(C)** Blood supply to the trachea, a left anterior view.

Grillo HC. *Surgery of the Trachea and Bronchi*. BC Decker, 2004, pp. 39–49.

TRACHEAL INJURIES

TRAUMA

ESSENTIALS OF DIAGNOSIS

- History of trauma to head, neck, or chest
- Subcutaneous emphysema, pain, dyspnea, hemoptysis, cough, stridor
- Pneumomediastinum, pneumothorax despite chest tube drainage.

General Considerations

Although relatively rare, injuries to the trachea may arise in patients with penetrating or blunt force cervical trauma.

Blunt trauma. This is commonly caused by deceleration injuries at the laryngotracheal junction or at a branch point in the tracheobronchial tree—the two major points of tracheal fixation. Tearing or separation of the trachea can occur. This can also happen as a result of hyperextension of the neck or direct blow, often in the case of automobile accidents. Other than deceleration injuries, the trachea can also experience membranous wall ruptures or tears due to increased intratracheal pressure caused by compression of the chest wall.

Penetrating trauma. The extent of penetrating injuries to the trachea is determined by caliber and size of the weapon or projectile; although case-specific, bullet projectiles tend to result in more injury to adjacent tissues, such as blood vessels and/or the esophagus, as opposed to stab wounds.

Identification & Localization of Injury

First and foremost, establish a stable airway by intubation via fiberoptic bronchoscope. Bronchoscopy is the method of choice for detection and evaluation of any airway trauma. Computed topography (CT) scan can help identify manifestations of tracheal trauma such as pneumomediastinum, pneumothorax, and air within the tissue planes of the neck. Angiography can also be utilized to assess adjacent vasculature in the stable patient. Although varying opinions currently exist regarding intraoperative exploration of tracheal injury, the decision may be made to explore the neck or chest, particularly for inspection of the intrathoracic trachea, esophagus, and related vasculature based on penetration of the platysma for a neck wound and individual findings in the chest (ie, bronchopleural fistula with pneumothorax, hemothorax, or evidence of ongoing bleeding in the chest).

Treatment

A. Nonsurgical Measures

In stable patients with minor injuries, intubation, antibiotic treatment, and close observation may suffice. The endotracheal cuff should be placed below the injury to avoid mediastinal or subcutaneous air.

B. Surgical Repair of Tracheal Damage

This depends on the location and severity of wound and associated injuries; however basic principles of tracheal surgery still apply. A low-collar incision provides almost complete exposure. The best approach to the distal trachea is through a right thoracotomy. This allows access to trachea, carina, right and left main bronchi, and intrathoracic esophagus. Simple lacerations may be repaired via debridement and repair with suture. More complex injuries may require circumferential tracheal resection and or reconstruction as well as end-to-end anastomosis.

Prognosis

Prognosis depends on the overall condition of the patient and other concurrent injuries.

Shrager JB. Tracheal trauma. *Chest Surg Clin North Am.* 2003; 13:291–304.
Bagheri SC, Khan HA, Bell RB. Penetrating neck injuries. *Oral Maxillofac Surg Clin North Am*. 2008;20(3):393–414.
Tisherman SA, Bokhari F, Collier B et al. Clinical practice guideline: Penetrating zone II neck trauma. *J Trauma* 2008;64(5): 1392–1405.

IATROGENIC AND OTHER TRACHEAL INJURIES

Although relatively rare, iatrogenic tracheal injury can occur with prolonged endotracheal intubation. Complications include tracheoinnominate fistula, tracheoesophageal fistula, tracheomalacia, and various lesser injuries that, however infrequent, can be life-threatening and require immediate diagnosis and intervention.

INTUBATION INJURIES

TRACHEOINNOMINATE FISTULA

ESSENTIALS OF DIAGNOSIS

- Prolonged intubation with cuff erosion into innominate artery
- Massive hemorrhage or hemoptysis
- Premonitory or "herald bleed."

General Considerations

Tracheoinnominate fistula is a rare but often fatal complication of tracheal intubation. This is often the result of cuff over inflation or from a poorly positioned tracheostomy tube.

Identification & Diagnosis

Direct bronchoscopy is the most effective diagnostic tool available, although the excessive bleeding is indicative of a likely arterial injury.

Treatment

A. Prevention

Proper technique in performing tracheostomies, as well as limited intubation time (>2 weeks), should be followed to avoid TIF injury. Placement of the tracheostomy between the second and third tracheal rings will dramatically reduce the likelihood of TIF injury. Avoidance of sharply angled, rigid tracheostomy tubes and appropriate alignment of the tube is critical as well.

B. Surgical Intervention

The initial maneuver in managing this potentially fatal complication is to overinflate the tracheostomy cuff. In the majority of cases, this will control the bleeding and the patient can be moved to the operating room. In the event that cuff over inflation fails, manual compression of the artery against the sternum can also control bleeding after the trach is removed and the patient is intubated from above. In the operating room, flexible and rigid bronchoscopy, as well as a sternal saw, should be readily available. The authors recommend sternotomy for exposure with ligation of the artery above and below the fistula. The segment of damaged trachea is excised along with the damaged vessel and reconstructed with primary end to end anastomosis. Strap muscle should then be interposed between the airway and the artery (Figure 37–2).

Prognosis & Follow-up

The low occurrence of TIF is unfortunately accompanied by a high mortality rate (25–50% survival) (Allan and Wright 2003). Immediate recognition and intervention is critical for success in surgical intervention of patients presenting with TIF.

Allan JS, Wright CD. Tracheoinnominate fistula: Diagnosis and management. *Chest Surg Clin North Am.* 2003;13:331–341.
Ailawadi G. Technique for managing tracheo-innominate artery fistula. *Op Tech Thorac Cardiovasc Surg.* 2009;14(1):66–72.
Grillo HC Surgery of the Trachea and Bronchi. BC Decker, 2004, pp 585.

TRACHEOESOPHAGEAL FISTULA

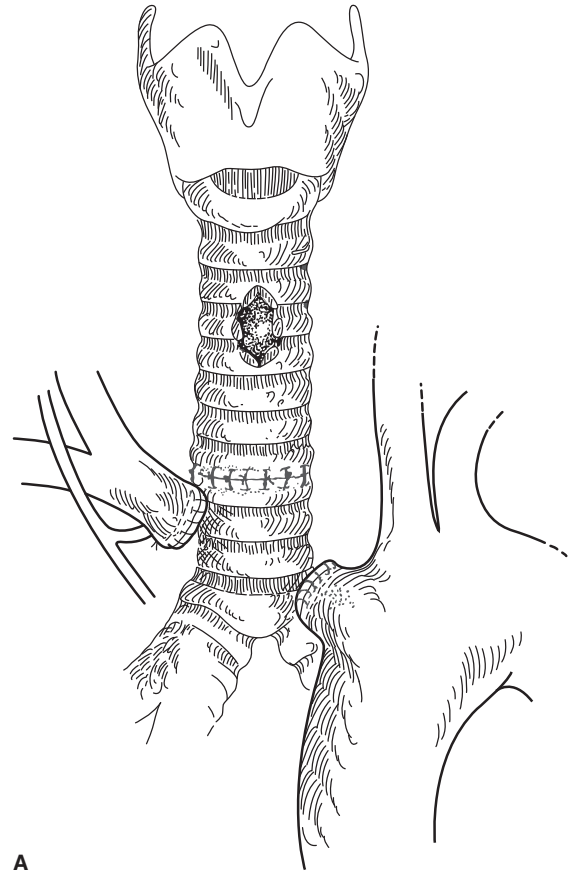
ESSENTIALS OF DIAGNOSIS

- Prolonged endotracheal intubation
- Increased tracheal secretions, gastric contents in the airway, gastric distention
- Recurrent pneumonia, discrepancy between inhaled and exhaled tidal volumes.

General Considerations & Pathogenesis

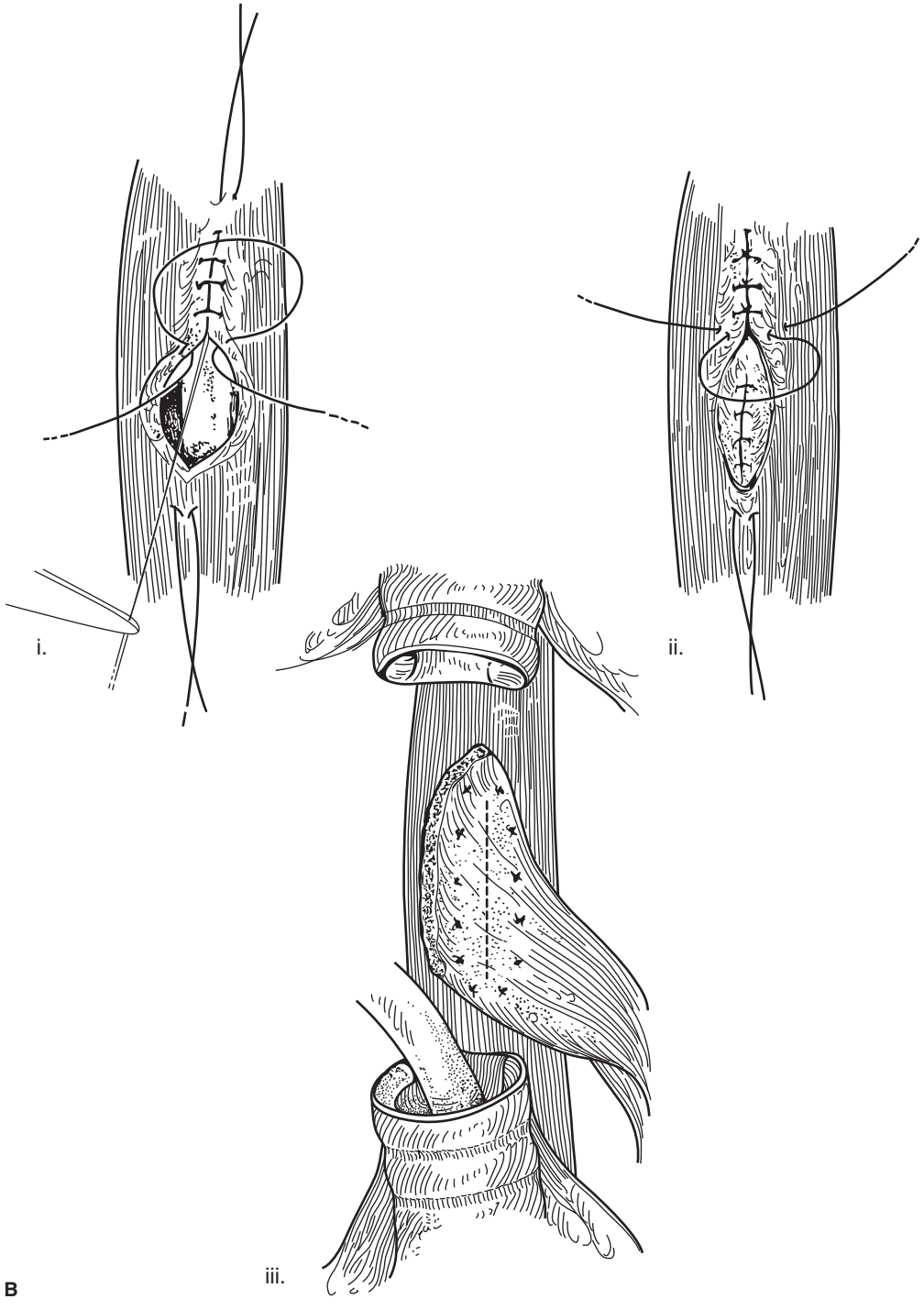
A. Acquired Nonmalignant TE Fistula

Nonmalignant TEF is most commonly caused by cuff over inflation, which places undue pressure on the tissues



A

▲ **Figure 37–2.** Surgical repair of tracheoinnominate fistula. **(A)** Resection of involved trachea and artery. *(continued)*



▲ **Figure 37–2.** *(continued)* (**B**) Tracheo-esophageal fistula repair with **(i, ii)** double-layered closure of the esophagus and **(iii)** interposed strap muscle with primary repair of the trachea.

between the esophagus and airway. This usually occurs from having an endotracheal or tracheostomy tube and a nasogastric tube in for a prolonged time period. Other etiologies of this type are blunt or penetrating trauma, granulomatous mediastinal processes, prior tracheal or esophageal surgery, iatrogenic injuries, stents, and AIDS.

B. Acquired Malignant TE Fistula

This accounts for the majority of acquired TE fistulas and they usually originate from esophageal cancer but can also come from cancer of the lung, trachea, larynx, thyroid, or lymph nodes. This type of fistula carries a very poor prognosis and because of this all attempts at correction should be palliative.

Clinical Findings

Often the first sign is increased tracheal secretions in a patient who is ventilated or has a tracheostomy in place. Also it may be noted that gastric secretions are being suctioned from the airway. Massive dilation of the stomach from air insufflation and recurrent pneumonias are common findings for both types, although in the malignant type this will be in the setting of cancer or prior surgery for esophageal or lung cancer.

Treatment

A. Nonmalignant TE Fistula

The treatment for this is different than the malignant type. This is a benign process and all attempts should be made to correct this surgically. In general, the surgery that is necessary for this requires debridement and two-layered closure of the esophagus followed by resection of the diseased segment trachea and placement of a strap muscle between the esophagus and trachea. This is performed through a collar incision.

B. Malignant Fistula

This should be treated in the least invasive way possible. In general, the authors believe that this type of fistula should be treated with esophageal stenting. This usually can be done with minimal morbidity to the patients and is well tolerated. Other less-invasive options include esophageal exclusion, esophageal bypass, fistula resection and repair, chemotherapy, and radiation therapy. Survival is about a year and rarely beyond that.

Reed MF, Mathisen DJ. Tracheoesophageal fistula. *Chest Surg Clin NA* 2003;13(2):271.

Sharma P, Kozarek R. Role of esophageal stents in benign and malignant diseases. *Am J Gastroenterol.* 2010 Feb;105(2):258–273; quiz 274. Epub 2009 Dec 22.

POSTINTUBATION TRACHEAL STENOSIS

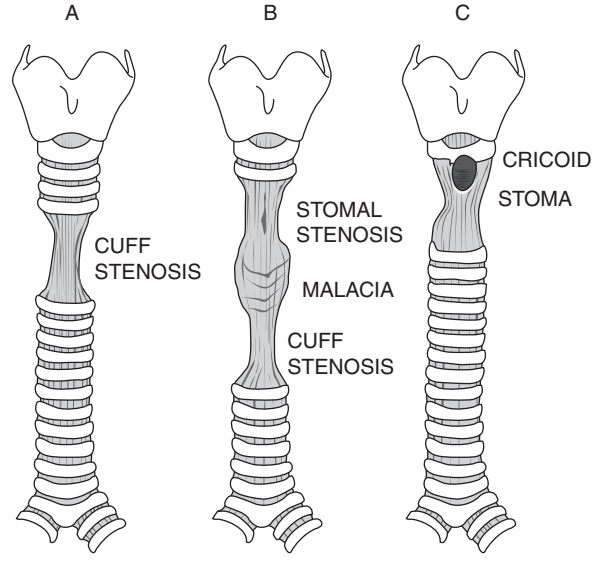
ESSENTIALS OF DIAGNOSIS

- History of prolonged intubation, tracheal injury, tracheostomy
- Progressive shortness of breath
- Wheezing and stridor
- Retention of secretions
- One sided or bilateral pneumonia.

Classification (Stomal Stenosis, Cuff Stenosis, & Subglottic Stenosis) (Figure 37–3)

A. Stomal Stenosis

This results from a prior tracheostomy and is the most common cause of benign tracheal stenosis. Once the trach is removed, granulation tissue forms at the level of the opening in the trachea and scarring of the airway, creating an A-shaped lumen (retraction with anterior narrowing). Significant decrease in luminal diameter (70–75%) needs to occur for patients to become symptomatic although they may remain asymptomatic at rest. Attempts at dilation may transiently work but generally this process will require surgery.



▲ **Figure 37–3.** Classic presentation of postintubation tracheal stenosis types. **(A)** Cuff stenosis. **(B)** Stomal stenosis. **(C)** Cricoid stenosis.

B. Cuff Stenosis

This results from transmural ischemia with resultant scarring located about 3–4 cm below the cricoid. This lesion may transiently respond to dilation but will also require surgery.

C. Subglottic Stenosis

This is caused by trauma to the endolaryngeal structures distal to the vocal cords usually from improperly placed cricothyroidostomy tube or an oversized endotracheal tube.

Management

A. Conservative Measures

Initially the patient with stenosis should be treated in a monitored setting preferably in a intensive care unit with humidified air, heliox (mixture of helium and oxygen), and bronchodilators. Steroids should be tapered and stopped if possible.

B. Surgical Management

Bronchoscopy should be done in the operating room with flexible and rigid bronchoscopes available. The surgeon should have a full size range of rigid scopes from pediatric to larger diameters. The patient should be anesthetized without paralysis or muscle relaxants deepened to an appropriate level and then direct laryngoscopy should be performed followed by insertion of a small rigid bronchoscope. The size of the scope to be used can be chosen based on preoperative CT scan. A tight stenosis should be dilated and followed by placement of an appropriately sized endotracheal tube. The authors use a flexible scope through the rigid in order to assess the degree and length of the stenosis. The flexible scope can also be used intraoperatively to transilluminate light through the trachea to mark the proximal and distal extent of the narrowing.

Most postintubation stenosis cases can be performed through a collar incision and rarely require a partial upper sternotomy. Complete resection of the involved segment is performed with primary end-to-end anastomosis utilizing 3-0 or 4-0 vicryl. Pretracheal mobilization and avoiding injury to the recurrent laryngeal nerves should be kept in mind at all times.

Alternative treatment includes tracheostomy which, if done, should be done through the stenotic segment and T tube placement. Endoluminal treatments, that is, laser, are temporary and metal stents should not be used for benign lesions.

Prognosis

As long as principles of tracheal surgery are maintained, prognosis is very good and the surgery is successful with acceptable mortality in 2–4% range.

Dooms C, De Keukeleire T, Janssens Aet al. Performance of fully covered self-expanding metallic stents in benign airway strictures. *Respiration* 2009;77(4):420–426.
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TRACHEOMALACIA

ESSENTIALS OF DIAGNOSIS

- Dyspnea, cough, sputum production, hemoptysis, expiratory stridor
- History of prolonged intubation
- Recurrent pulmonary infections
- Diminished expiratory flow.

General Considerations

Tracheomalacia refers to a weakness of the trachea that can lead to tracheal collapse most commonly acquired via tracheostomy or endotracheal intubation. Other causes include chronic external compression, emphysema or chronic obstructive pulmonary disease, and relapsing polychondritis.

Diagnosis

Endoscopic visualization via rigid or flexible bronchoscopy is recommended to visualize the location and extent of collapse of the malacic segments. Using local or topical anesthetic without muscle relaxant is recommended as the patient can maintain spontaneous breaths and the actual collapse of the airway during expiration can be visualized. Confirmation of this diagnosis can be made with dynamic computed tomography (CT) scan of the airway as images are taken during the breathing cycle. CT demonstrates a 44% decrease in the cross-sectional area of the airway as opposed to the normal 14%.

Treatment

Initial indications are to control bronchospasms as to reduce pressure swings in the thorax and minimize degree of collapse of the malacic tracheal segments. Depending on extent of malacia, noninvasive positive-pressure ventilation may be effective, also called bi-pap or cpap.

Surgery for tracheomalacia has been modified over the years with the use of muscle, splints, and polytetrafluoroethylene (PTFE). More recently, mesh tracheoplasty appears to be the operation of choice after careful selection of the patients and brief period of tracheal stenting with a Y stent made of silicone. This is performed through a right thoracotomy in

the 4th interspace. The results of this surgery appear to be good in centers where there is a larger volume, more experience, and a multidisciplinary approach to these patients.

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TRACHEAL NEOPLASMS

PRIMARY TRACHEAL NEOPLASMS

ESSENTIALS OF DIAGNOSIS

- Male-to-female ratio of 7:1
- No known risk factors
- Adult onset asthma
- Dyspnea, hemoptysis, cough, wheezing, dysphagia, hoarseness, stridor
- Obstructive pneumonitis.

General Considerations

Primary tracheal tumors are very rare and account for less than 0.2% of all respiratory malignancies. These are more common in men with a ratio of 7:3. Adenoid cystic carcinoma and squamous cell carcinoma are the most common primary malignant tumors. Average age of presentation is 60 years for squamous cell carcinoma and 50 years for adenoid cystic carcinomas. Tracheal tumors can be primary or secondary. Primary tracheal tumors can be benign or malignant, but the secondary ones are either metastatic or a result of direct invasion (Table 37–1).

Clinical Findings

Patients with tracheal tumors may not present with discrete symptoms upfront and the onset of the disease may be insidious. Any patient that presents with adult onset asthma should be investigated for this. Hemoptysis from a bleeding tumor, dysphagia from compression of the esophagus, and hoarseness from recurrent nerve involvement are definite signs of locally invasive disease.

Table 37–1. Tracheal Neoplasms: Histologies of Primary Tracheal Tumors.

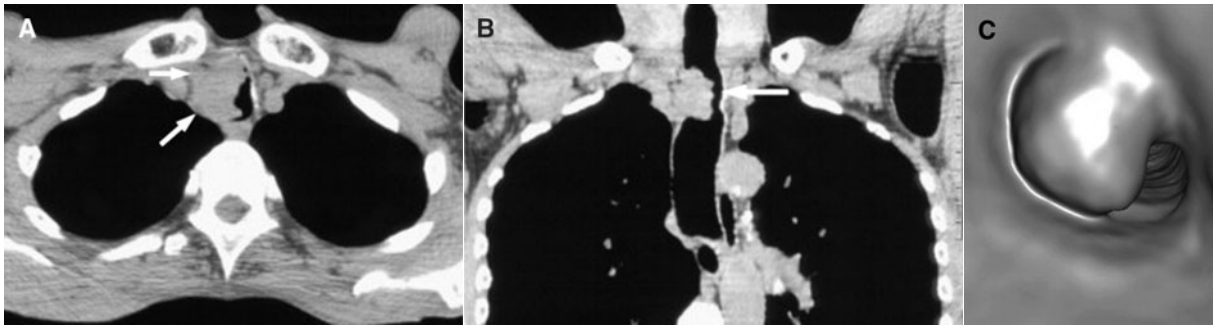
Benign Neoplasms	Malignant Neoplasms
Inflammatory pseudotumor	Squamous cell carcinoma
Hamartoma	Adenoid cystic carcinoma
Squamous cell papilloma	Mucoepidermoid carcinoma
Papillomatosis	Small cell carcinoma
Chondroma	Chondrosarcoma
Chondroblastoma	Spindle cell sarcoma
Hemangioma	Adenocarcinoma
Hemangioendothelioma	Adenosquamous carcinoma
Carcinoid	Carcinoid
Leiomyoma	Leiomyosarcoma
Granular cell	Rhabdomyosarcoma
Fibrous histiocytoma	Malignant histiocytoma
Glomus	Melanoma
Fibroma	Lymphoma
Neurofibroma	*Secondary tracheal neoplasms*
Schwannoma	Direct invasion
Lipoma	Metastatic involvement
Pleomorphic adenoma	
Pseudosarcoma	

Diagnosis

Flexible or rigid bronchoscopy is the most definitive way to obtain a tissue diagnosis. Also it can be used to assess the location of the tumor and the extent of airway involvement. Rigid bronchoscopy can also be helpful in debulking the tumor and draining a postobstructive pneumonia. Treating the infection before helps decrease inflammation in the airway and increases the chances of a well-healed anastomosis after surgery. CT scan can also provide anatomic information and also assess areas of invasion. Benign tumors tend to have smooth borders and may contain fat such as a hamartoma. Carcinoids are smooth-bordered and light up intensely with contrast because they are vascular tumors. Malignant tumors in general will be more invasive to surrounding tissue. High-quality three-dimensional reconstruction can provide a virtual bronchoscopy with images that enhance the detection of localized or diffuse diseases (Figure 37–4). Endobronchial ultrasound can provide information about tracheal wall thickness and extent of extrinsic tumor.

Histology

The two most common histologies for the malignant variant are adenoid cystic and primary nonbronchogenic squamous cell carcinoma. Others include adenocarcinoma large cell, neuroendocrine, small cell, atypical carcinoid, melanoma malignant fibrous histiocytoma, and others listed in Table 37–1.



▲ **Figure 37–4. Tracheal neoplasms. (A, B)** Computed tomography (CT) images of tracheal carcinoma. **(C)** Virtual bronchoscopy reconstruction of the tumor. (Modified and reprinted, with permission, from Ferretti GR, Bithigoffer C, RighiniCA, Arbib F, Lantuejoul S, Jankowski A. Imaging of tumors of the trachea and central bronchi. Radiologic Clinics of North America. 2009 March;47(2):227–241. [Review].)

Malignant Tumors

A. Squamous Cell Carcinoma

It is the most common primary tracheal tumor but less common than its laryngeal and bronchial counterparts. It is more common in men who are smokers with a peak incidence in the 6th and 7th decades of lives. The lower incidence of this as opposed to bronchial squamous cell is thought to be related to higher laminar flow with better mucociliary clearance in the trachea as opposed to the bronchus. Most cases of squamous cell carcinoma are solitary, but synchronous and metachronous lesions with bronchogenic, laryngeal, and esophageal have been reported.

B. Adenoid Cystic Carcinoma

It is also called cylindroma and along with squamous cell carcinoma it accounts for two-third of all tracheal tumors. Its peak incidence is in the 5th decade of life and is equally distributed among men and women. This tumor is not associated with smoking and is slow growing and produces symptoms late. Surgical resection of this tumor is accepted with positive margins because local control with radiation is excellent.

Tumors of Intermediate Malignancy (complete list Table 37–1)

A. Carcinoid Tumor

These are separated into typical and atypical types. The typical carcinoids have a less aggressive nature and when resected with negative margins have a very good prognosis. The atypical variant tends to be much aggressive and highly malignant. The behavior of this tumor as a primary tracheal tumor appears to be similar to that of its bronchial counterpart. This tumor generally does not respond well to radiation, but at least for the atypical variant may have some response to chemotherapy similar to that for neuroendocrine lung cancer. Because of poor response to other treatments, generally they should be resected if possible.

B. Mucoepidermoid Tumor

It is a rare tumor from the minor salivary glands of the airway and usually appears in young people less than 40 years of age. They can present in the trachea and bronchi and have a low- and high-grade variant. The high-grade variant, if left untreated, has a poor prognosis, while the low-grade lesions carry a good prognosis with surgery. Surgery should be performed if possible given poor response to chemotherapy. Unresectable disease can be treated with radiation up to 60 Gy in good performance status patients. Alternatively, palliative techniques utilizing bronchscopic coring out of the tumor, laser cryosurgery brachytherapy, photodynamic therapy, or argon beam coagulation can be used. The prognosis appears to be better with younger children with complete resection and negative margins.

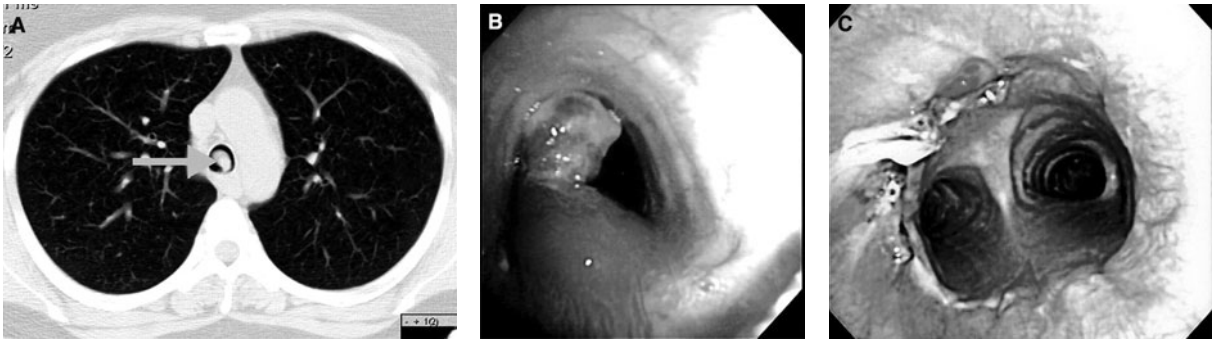
Benign Tumors (complete list Table 37–1)

A. Pleomorphic Adenoma

This is a mixed salivary gland tumor and usually arises from the parotid or submandibular gland, and is rare in the airway. Surgery is the treatment of choice and prognosis is good. Although listed under benign tumors, which is generally the case, there are reports of malignant variants which presented 11 years after resection with metastasis.

B. Squamous Papilloma

These are solitary moderate sized tumors of the trachea, which can cause obstructive symptoms. Treatment is surgical with tracheal resection.



▲ **Figure 37–5.** Diagnosis and surgical treatment of glomus tumor. **(A)** CT scan of glomus tumor. **(B)** Bronchoscopy of glomus tumor. **(C)** Post-resection bronchoscopy.

C. Multiple Papillomatosis

Multiple papillomatosis occurs in adolescence and is associated with human papilloma virus (HPV) infection. Treatment is nonsurgical in this entity and laser ablation appears to be the modality of choice. This may require repeat sessions.

D. Glomus Tumor

It is a benign neoplasm that is rarely found in the trachea. Average age is 43 years (range 10–73 years), with male predominance of 2:1. They are generally asymptomatic but can produce chest pain. They are mostly found in the distal trachea, and tracheal resection is the treatment of choice (before and after image) Figure 37–5.

Treatment

Just as with any tumor, determination of whether it is benign or malignant should be performed with bronchoscopy as the initial step followed by evaluation of the extent of disease. Limited disease confined to the airway versus metastatic disease can be assessed with PET/CT and brain MRI similar to what is performed for evaluation of a lung cancer.

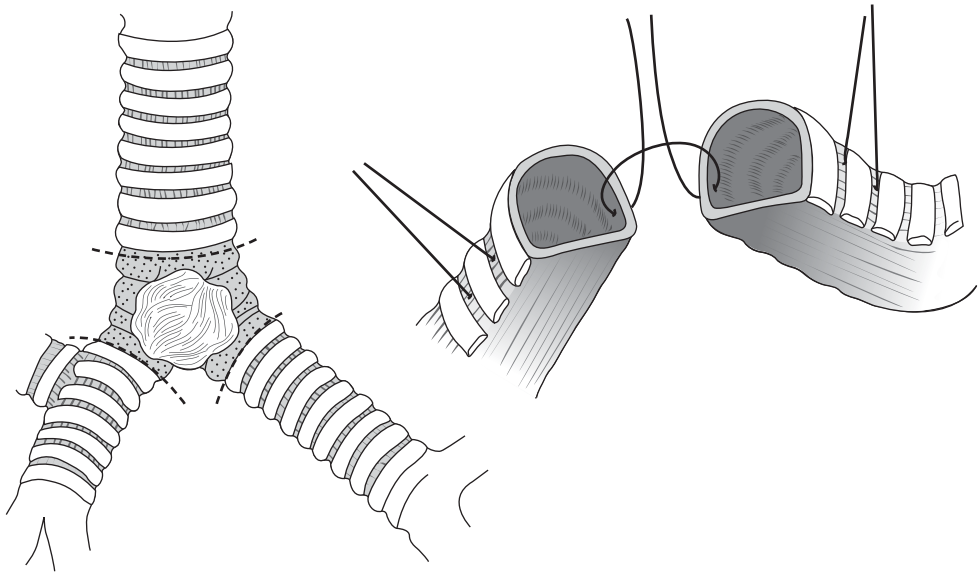
There are three basic options with regard to treatment: tracheal resection, endoscopic resection, and radiotherapy. It has become very clear that resection, when possible, provides the best long-term outcome and prognosis. There is really no role for neoadjuvant therapy (radiation or chemotherapy) prior to surgery as this can only create potential healing problems with the tracheal anastomosis. Tracheal stents should not be used if a patient is deemed resectable because of the additional damage they produce to the airway making resection length longer. If not resectable, metal stents can be placed with flexible bronchoscopy. If a stent is needed prior to surgery, a silicone stent or T-tube is preferred. Patients are considered unresectable if they have metastatic disease or if the tumor is growing into an unresectable structure other than the esophagus. These patients can be treated with endobronchial treatments such as stents but also with radiation or chemotherapy for palliative purposes.

Postoperative radiation may be necessary for positive margins, and at some institutions it is routinely used even with negative margins. There are no real data to support postoperative radiation with complete resection.

Surgery for tracheal tumors depends on the location of the tumor but may include collar incision with or without upper sternotomy for cervical tumors, collar incision with sternotomy for a midtracheal tumor, right thoracotomy for distal tracheal tumors and right thoracotomy or sternotomy for carinal resection, and right or left thoracotomy carinal pneumonectomy (Figure 37–6).

SECONDARY TRACHEAL NEOPLASMS

This refers to invasion of the trachea by any malignancy that is close to the airway. The most common examples of these types of tumors include esophageal cancer, thyroid, and lung cancer. Laryngeal cancer can do this as well either from direct spread or as a result of recurrent disease after laryngectomy. Hematogenous spread from other organs can occur as well. Metastatic breast, melanoma, renal cell, ovarian, sarcoma, and lymphoma can involve the airway in the trachea but more commonly at the bronchial level. Treatment for these patients unless there is an isolated metastasis to the airway with no other disease is strictly palliative. A combination of endobronchial techniques including flexible and rigid bronchoscopy with removal of the tumor, stent placement, laser, brachytherapy, photodynamic therapy, as well as cryotherapy can all be used effectively in combination with chemotherapy and radiation to treat these patients. Prognosis in these patients is very poor with limited survival, and because of this the treatment is aimed at palliation and is not by any means curative.



▲ **Figure 37–6.** Resection of carinal neoplasm with reconstruction of the airway.

Ferretti GR, Bithigoffer C, RighiniCA, Arbib F, Lantuejoul S, Jankowski A. Imaging of tumors of the trachea and central bronchi. *Radiol Clin North Am.* 2009;47(2):227–241. [Review].
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We would like to acknowledge Andrew J. Schreffler, MD, and David M. Jablons, MD, for their contribution to this chapter in the previous editions of CDT.

38 Airway Management & Tracheotomy

Kenneth C. Y. Yu, MD

With airway obstruction, trauma, or elective surgery, control of the airway is the first priority that must be accomplished before any other intervention can proceed. In cases of a rapidly decompensating airway, particularly in pediatric patients or patients with airways that are difficult to manage, the otolaryngologist is frequently consulted to assist in patient airway management.

Patient Evaluation

Successful airway management must begin with a careful, thorough, and rapid evaluation of the airway. Healthy patients presenting with normal head and neck anatomy who undergo elective surgery represent relatively straightforward cases in which standard endotracheal intubation can provide an easy and secure airway. Patients presenting with upper airway obstruction must be evaluated quickly, efficiently, and accurately.

Physical examination is a key element in diagnosing upper airway obstruction. Stridor, or noisy respiration, is a hallmark symptom of upper airway obstruction. The timing of the stridor with respiration can frequently indicate where the obstruction lies. **Inspiratory stridor** normally results when the obstruction is at the larynx or above. **Expiratory stridor** usually indicates a more distal obstruction (eg, a tracheal obstruction). **Biphasic stridor** (ie, noise on both inspiration and expiration) may indicate a subglottic obstruction. The quality of the voice is also important. A muffled voice may reflect supraglottic obstruction, such as from the epiglottitis. A hoarse voice may indicate laryngeal involvement (eg, papillomas or tumors). A breathy or weak voice or cry may suggest vocal cord paralysis. Other signs of upper airway obstruction include suprasternal or substernal retractions, tachypnea, and cyanosis.

An accurate history is also critical in evaluating the airway and formulating the best plan to manage it. The physician should determine whether the obstruction occurred acutely or chronically. The age of the patient also helps in distinguishing the cause of the obstruction. Congenital airway anomalies (eg, laryngomalacia, choanal atresia, hemangioma, and tracheomalacia) and acute inflammatory causes (eg, croup and epiglottitis) are more common in children. In adults, tumors are a more common cause of obstruction. Trauma can cause airway obstruction, and this circumstance is usually easy to diagnose. However, it is important to carefully ascertain the mechanism and type of injury. Suspicion of laryngeal trauma may make conventional endotracheal intubation perilous because it can potentially result in a more compromised airway due to laryngotracheal separation. In these circumstances, the physician should consider performing a tracheotomy while the patient is awake. Similarly, massive maxillofacial trauma may preclude normal translaryngeal intubation; a flexible fiberoptic intubation or a tracheotomy while the patient is awake should be considered in these situations.

Treatment

A. Nonsurgical Measures

Patients with difficult airways should be identified before the induction of anesthesia and intubation so that proper planning and communication between the anesthesiologist and the surgeon can be coordinated. A difficult airway is defined as a situation in which a conventionally trained anesthesiologist experiences difficulty with mask ventilation, endotracheal intubation, or both. In addition, the physician should be prepared for a potentially difficult airway or possible airway loss if both anesthesia induction and intubation are difficult. Both of these situations can be managed with a number of nonsurgical airway management techniques.

1. Oxygen administration—The first and most important task in nonsurgical airway management is to administer oxygen to relieve hypoxia. As the airway obstruction worsens, the physician may have to mask, ventilate, and provide a chin lift and jaw thrust to maintain a patent airway until a more definitive airway can be established. A helium–oxygen mixture of 80% helium to 20% oxygen can be used in some cases to improve ventilation temporarily until definitive control of the airway can be achieved. This mixture, known as

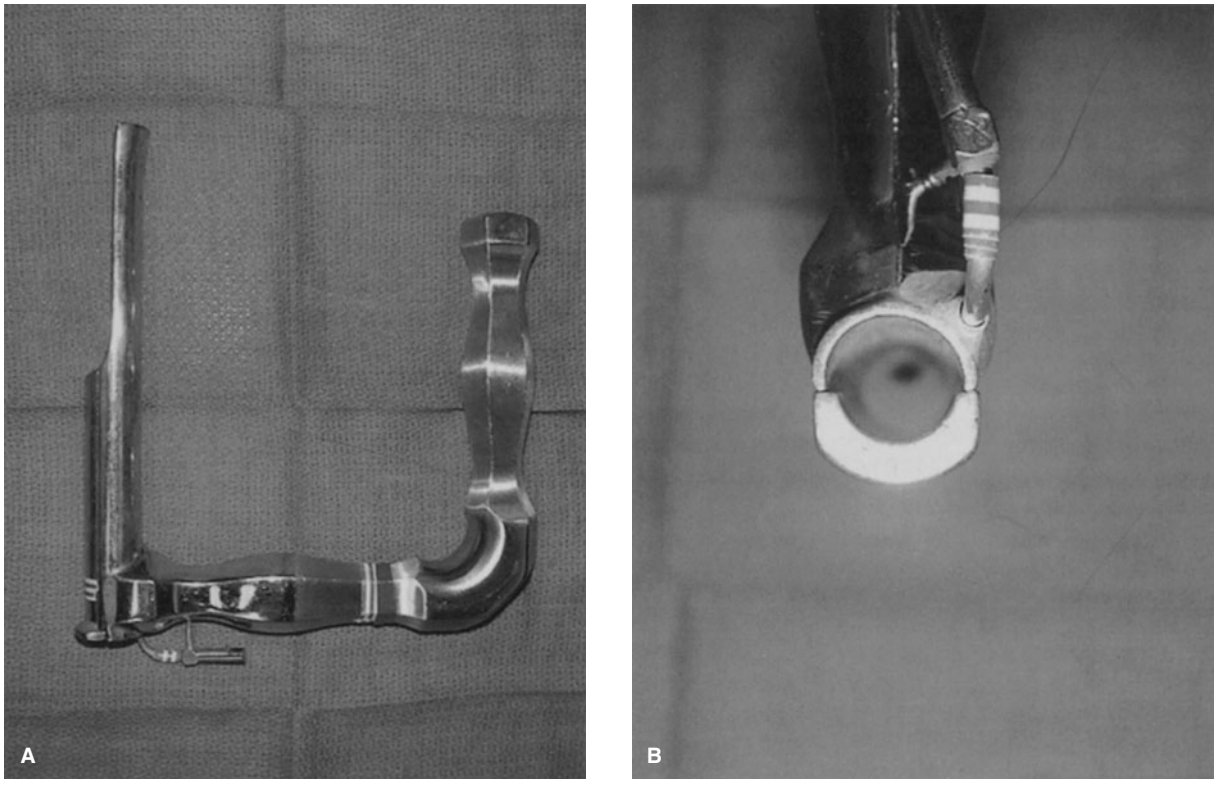
heliox, depends on the decreased density of helium to deliver oxygen past the obstructing airway lesions.

2. Topical decongestants and steroids—Adjunctive medical therapy can be used to decrease upper airway obstruction if there is a component of soft tissue edema. Racemic epinephrine and epinephrine aerosols act as topical decongestants and can be given to try to decrease the edema. However, the effect is short in duration, and they may cause a rebound effect if used repeatedly. Consequently, their use is limited to the inpatient setting. The use of steroids in relieving upper airway obstruction can also be helpful, especially in cases in which edema or inflammation is present (eg, angioedema, croup, and adult supraglottitis). A suggested treatment is to administer methylprednisolone sodium succinate (125 mg IV) as a first dose and then continue with dexamethasone (8 mg IV every 8 hours) for several doses; methylprednisolone succinate has a more rapid onset of action than dexamethasone.

3. Oropharyngeal and nasopharyngeal airways—Oropharyngeal and nasopharyngeal airways are adjuncts to airway support that can be helpful in certain cases. For example, patients emerging from anesthesia or suffering from an altered mental state can have their airways supported with these devices until their mental status improves. Oropharyngeal airways prevent obstruction caused by a relaxed and prolapsed tongue. However, an incorrectly placed oropharyngeal airway can itself cause airway obstruction by pushing the tongue posteriorly into the hypopharynx. If placed in a patient who is still under light anesthesia, coughing and laryngospasm can occur. The traumatic insertion of nasal or nasopharyngeal airways can cause bleeding.

4. Translaryngeal intubation—The definitive nonsurgical control of the airway is via translaryngeal intubation. This procedure should be considered the preferred method of establishing control of the airway in most cases, provided the patient's condition is not so dire that an immediate airway is required, or in situations in which intubation is contraindicated (eg, laryngeal trauma or an obstructing tumor that makes intubation difficult). It is extremely important that a good airway history be obtained and a thorough examination be performed whenever possible before inducing anesthesia and performing an intubation.

5. Jackson sliding laryngoscope—A unique instrument familiar to otolaryngology surgeons is the Jackson sliding laryngoscope (Figure 38–1). This laryngoscope has better



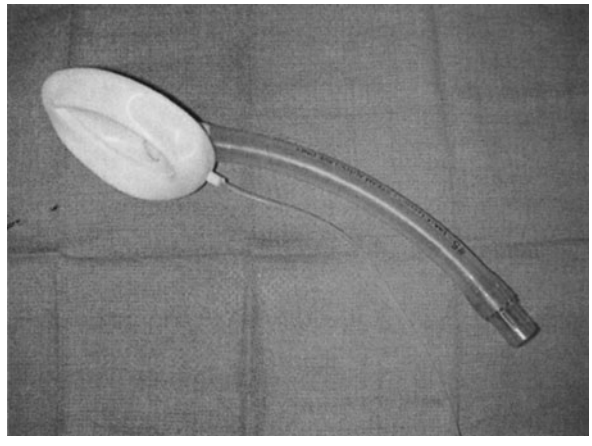
▲ **Figure 38–1. (A)** Side view of a sliding Jackson laryngoscope. **(B)** View along the aperture. The floor can be slid out after insertion of an endotracheal tube.

leverage and lighting compared with the anesthesiologist's blades; the design of the laryngoscope makes it easier to manipulate past obstructing lesions or edematous soft tissue and suction can be used concurrently. Once the glottis is identified, an endotracheal tube is passed into the trachea and the laryngoscope's floor can be slid out to facilitate removal of the laryngoscope. Frequently, the difficult airway can be managed with this technique.

6. Guided endotracheal intubation—Guided endotracheal intubation using a flexible fiberscope is an excellent technique for both routine and difficult airways. Placing an endotracheal tube with a fiberscope tube is particularly useful for an intubation in an awake, spontaneously breathing patient with a known or suspected difficult airway. Fiberoptic endotracheal intubations can be performed either via a nasal or an oral route. Once the route is chosen and anesthesia is achieved (topical or general), the endoscope is passed through the endotracheal tube, through the mouth or nose, and through the larynx into the trachea. The endotracheal tube is then advanced over the endoscope and into the trachea, using the endoscope as a "guidewire." The endoscope is withdrawn after confirming the correct positioning of the endotracheal tube. Flexible fiberoptic intubation has limitations as well. Minimal trauma to these endoscopes may damage the delicate optics and distort the visual field. Bleeding and secretions can obscure the view and make visualization of the glottis extremely difficult. This technique may also be difficult in the uncooperative patient or in patients with inadequate topical anesthesia. Finally, introduction of the endoscope may actually cause complete airway obstruction in patients with severe intrinsic or extrinsic compression of the laryngeal or tracheal airways.

7. Laryngeal mask airway—The laryngeal mask airway (LMA) is useful for establishing the airway in both routine elective cases and many emergency situations involving difficult airways. The LMA can be considered a hybrid between an endotracheal tube and a face mask (Figure 38–2). It can easily be inserted blindly into the hypopharynx; insertion is complete when resistance is felt. No neck movement or laryngoscopy is required. Once the mask is inflated, it fills the hypopharynx and covers the laryngeal inlet. Due to the LMA's size and shape, it is not possible to pass it into the esophagus.

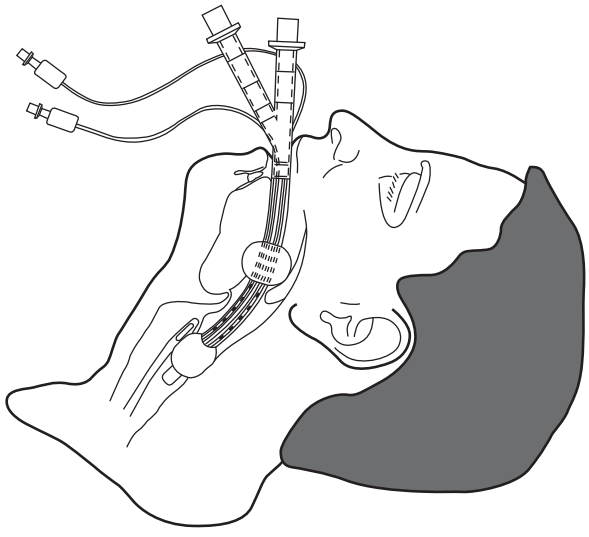
Several series report excellent success rates of 95–99%. Other advantages of the LMA include its simplicity in learning and use, fewer postoperative sore throats and coughing, and less potential for laryngeal injuries. These features also make the LMA an excellent instrument to use in many emergency situations involving the airway. Because this device can be inserted quickly and blindly, it has the potential to provide lifesaving ventilation while a more definitive airway is established. A flexible fiberoptic endoscope can also be passed through the mask's open slit into the trachea, and an endotracheal tube can be passed over the endoscope.



▲ **Figure 38–2.** Laryngeal mask airway.

Since the LMA does not completely separate the airway from the esophagus, the greatest risk in using this device is pulmonary aspiration of regurgitated stomach contents. Contraindications to using this airway include patients with full stomachs or hiatal hernias, obesity, and emergency and abdominal surgeries. The need for controlled ventilation and prone or lateral positions are strong relative contraindications for elective use of this device. Understandably, if the mouth cannot be opened, the LMA is not useful.

8. Other nonsurgical measures—Less common instruments and techniques used in difficult airway situations include the esophageal Combitube, light wand, and the Bullard laryngoscope. The esophagotracheal Combitube is an emergency airway management device for patients requiring rapid airway control. In many cases, this device can provide lifesaving emergency ventilation and oxygenation until a surgical airway can be established. The esophagotracheal Combitube is a double-lumen tube with an open "tracheal" cannula and a blocked distal "esophageal" end, which has ventilating side holes located proximally (Figure 38–3). This device is also blindly inserted, and the upper and lower balloons inflated. Because of its design, the esophagotracheal Combitube can effectively ventilate the upper airway regardless of whether it is placed into the trachea or into the esophagus. If the Combitube tip is in the esophagus, ventilation is achieved through the proximal side ventilation holes of the esophageal port. If this device is inserted into the trachea during the blind intubation, ventilation is accomplished conventionally through the tracheal port. Because of its relatively large size, this Combitube is contraindicated in pediatric and very small adult patients. It should be used with caution in patients with upper esophageal pathology, upper airway tumors, or other compressive lesions of the hypopharynx, larynx, or trachea. Finally, laryngospasm and laryngotracheal foreign bodies can impair ventilation if this device is inserted into the esophagus.



▲ **Figure 38–3.** Esophagotracheal Combitube. The diagram depicts the esophagotracheal Combitube in the esophagus. Ventilation is accomplished via the proximal side ports. (Image used with permission from Nellcor Puritan Bennett LLC, Boulder CO.)

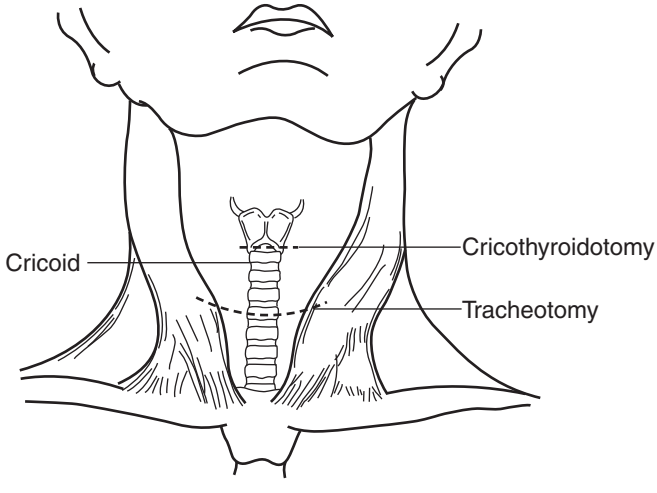
B. Surgical Measures

When endotracheal intubation is not feasible, a surgical airway must be obtained. The two basic surgical techniques to obtain an airway are cricothyroidotomy and tracheotomy. The terms *tracheotomy* and *tracheostomy* are often used interchangeably in error. A **tracheotomy** is generally described as a procedure that involves opening the trachea. A **tracheostomy** is a procedure that exteriorizes the trachea to the cervical skin, resulting in a more permanent tracheal cutaneous fistula; therefore, the term tracheostomy should be reserved for these particular procedures.

The indications for establishing an urgent surgical airway include the following: (1) severe maxillofacial trauma in which injuries make the airway inaccessible for translaryngeal intubation, (2) significant laryngeal trauma in which intubation may potentially cause more damage, (3) excessive hemorrhage or emesis obscuring landmarks required for successful intubation, (4) cervical spine injury with vocal cords that are difficult to visualize, and (5) failed translaryngeal intubation. In emergency situations, cricothyroidotomy is generally considered the procedure of choice because it is fast and simple to perform and it requires very few instruments. However, a tracheotomy can also be performed urgently. It is technically more difficult, bloody, and dangerous compared with elective tracheotomy or cricothyroidotomy. There are rare circumstances in which an emergent tracheotomy is preferred over a cricothyroidotomy, such as true subglottic obstruction (eg, subglottic carcinoma, or large thyroid tumors). Cricothyroidotomy should also be avoided in children because the cricoid cartilage is the narrowest portion of their airway.

1. Tracheotomy—The primary objective of a tracheotomy is to provide a secure airway. The indications for performing a tracheotomy include: (1) bypassing an upper airway obstruction, (2) providing a means for assisting mechanical ventilation (ie, chronic ventilator dependence), (3) enabling more efficient pulmonary hygiene, (4) temporarily securing an airway in patients undergoing major head and neck surgery, (5) relieving obstructive sleep apnea, and (6) eliminating pulmonary "dead space." Ideally, tracheotomies should be performed in a controlled setting—preferably in the operating room—where adequate lighting, instruments, specialized intubation equipment, and assistance are available.

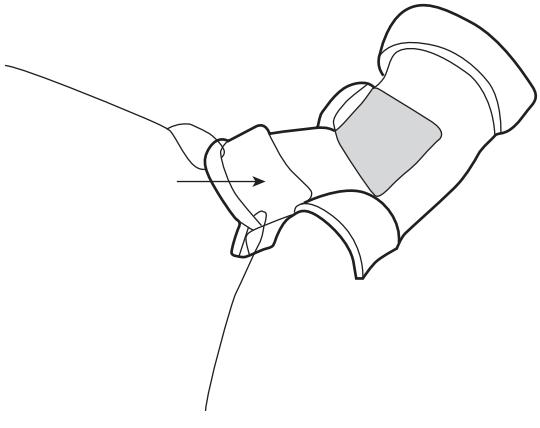
Figure 38–4 depicts the surface anatomy of the neck and the location of the incision for the tracheotomy. The cricothyroid



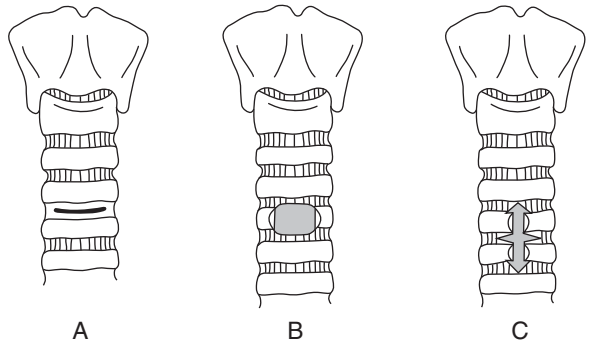
▲ **Figure 38–4.** Diagram of the neck, indicating locations of cricothyroidotomy, and tracheotomy incisions.

membrane has a relatively superficial location and is therefore fairly easy to access in an emergency situation. A tracheotomy is most easily performed if the patient is already intubated and general anesthesia has been administered. However, if the patient has a tenuous airway with impaired ventilatory status, the tracheotomy should be performed with local anesthesia and sedation to avoid paralysis. If the patient is anesthetized, he or she is placed in the supine position with a shoulder roll to extend the neck. The patient with a tenuous airway who undergoes a tracheotomy while awake should be placed in a semi-upright position. Landmarks such as the thyroid notch, the cricoid, the sternal notch, and planned incisions are marked. A transverse incision is marked approximately two fingerbreadths above the sternal notch. Alternately, a vertical incision can be used. The incision is then infiltrated with a local anesthetic containing epinephrine to help decrease bleeding. The neck and upper chest are then prepped and draped in a standard sterile fashion.

The skin incision is made with a 15 blade and the platysma is divided. The strap muscles are then separated in the midline at the median raphe. The strap muscles can then be retracted laterally with appropriate retractors. The anterior jugular veins can also be retracted laterally or ligated and divided as needed. Once the strap muscles are retracted laterally, the thyroid isthmus should be visible in the center of the field. The surgeon can then retract the isthmus superiorly or inferiorly as needed to obtain exposure to the planned tracheotomy. Frequently, in order to facilitate exposure, the clinician can divide and ligate the isthmus. A cricoid hood is used to retract the cricoid superiorly and pull the trachea forward. A Kittner sponge dissector is then used to push the fine fascia away from the anterior wall of the trachea and clearly identify the individual rings. An incision is made between the second and third tracheal rings. A **Björk flap** can be made by creating an inferiorly based tracheal ring flap and suturing this flap to the inferior skin margin (Figure 38–5).



▲ **Figure 38–5.** Björk flap. The incised tracheal ring (see arrow) is then sutured to the inferior neck skin.



▲ **Figure 38–6.** Various incisions used in entering the trachea. **(A)** Simple horizontal intercartilaginous incision; **(B)** resection of a cartilage ring creating an anterior tracheal window; **(C)** cruciate incision.

This technique greatly reduces the incidence of accidental decannulation and makes reinsertion of the tracheotomy tube easier if inadvertent decannulation occurs. Alternately, the surgeon can also resect a single tracheal ring or make a cruciate incision (Figure 38–6). The Björk flap is contraindicated in children because it carries a high risk of tracheal stenosis and persistent tracheocutaneous fistula. It may also be less desirable in patients requiring tracheotomy for only a few days (eg, after maxillofacial trauma or extensive surgery of the oral cavity). Before making the intended tracheotomy incision, the physician should palpate the wound inferiorly to ensure that a high-riding innominate artery is not present; a higher tracheotomy incision may need to be made. After the trachea is entered, the endotracheal tube is withdrawn just proximal to the tracheotomy. A previously tested and appropriately sized cuffed tracheotomy tube is then inserted into the tracheotomy. The ventilator circuit is then switched to the tracheotomy tube, and satisfactory ventilation and oxygenation are confirmed by the anesthesiologist before the tracheal hook and retractors are removed. The tracheotomy plate is then secured to the neck with tracheotomy ties, sutures to the skin, or both. The endotracheal tube can then be removed.

2. Emergent tracheotomy—The emergent tracheotomy is best performed through a vertical incision, beginning at the level of the cricoid cartilage and extending approximately 1.0–1.5 in. If the surgeon is right-handed, the left hand stabilizes the larynx and the right hand holds the scalpel. The incision is made through skin, platysma, and subcutaneous tissues in one swift motion. Strap muscles and the thyroid isthmus are rarely identified during the maneuver. The left index finger is used to palpate the trachea. The blade is then used to incise the trachea where the second or third tracheal ring is estimated to be. Once the airway is entered, the endotracheal tube is inserted into the trachea. A tracheal dilator is useful, but not necessary. A tracheal hook is often helpful

to pull the trachea forward and stabilize it while the endotracheal tube is passed. This technique is particularly helpful in the patient with an obese neck. During the procedure, significant bleeding is ignored until the airway is established; once it is, bleeding in the wound is controlled. If the situation allows, the tracheotomy should be carefully assessed and appropriate revisions made. The vertical skin incision is crucial to the speed of this procedure and can prevent damage to adjacent neck structures.

3. Pediatric tracheotomy—Tracheotomy in the child is carried out in a fashion similar to that of the adult tracheotomy; however, a simple vertical incision in the trachea is used. A Björk flap or the excision of tracheal rings should be avoided in the pediatric patient. Furthermore, tracheotomy in children should be performed with a bronchoscope or endotracheal tube in place to secure the airway. Emergent tracheotomy should be avoided, if possible. At the time of tracheotomy, it is wise to place 4.0 or 5.0 nonabsorbable monofilament guide sutures (one on either side of the vertical tracheal incision) to serve as guides should the tracheotomy tube accidentally come out. By gently pulling the sutures, the trachea can be elevated into the wound and the tracheal incision opened slightly to assist in tube reinsertion.

4. Percutaneous tracheotomy—Since the release of commercially available kits in 1985, the popularity of percutaneous tracheotomy has increased, particularly in the critically ill patient population. While there are several different kits and techniques, the common characteristics include transcutaneous entry with a needle into the trachea, guide wire passage into the lumen, and serial dilation. A tracheotomy tube is then passed into the lumen. After more than two decades, debate continues regarding its safety and efficacy and whether it should represent the standard of care. Proponents argue that percutaneous tracheotomy is easy to perform, has a shorter operative time, ability to perform at bedside, lower expense, lack of need to transport the patient to the operating room with the inherent dangers associated with the transport (ie, unstable patient, line dislodgement), and may even have lower risks of complications. Opponents against percutaneous tracheotomy argue that potential greater complications associated with blind entry into the trachea. The time honored basic principle of exposure is sacrificed in this technique. Patients with obese necks also pose difficult candidates. The risk of blind entry and subsequent catastrophic results has been significantly decreased if one supplants the procedure with flexible bronchoscopic guidance to confirm entry into the trachea. The individual surgeon must weigh the costs and benefits of either procedure and make his or her own decision. Proper patient selection and endoscopic guidance should make the percutaneous technique as safe as open tracheotomies in experienced hands. With today's trend toward less invasive procedures as well as cost control pressures, the ability to offer this service can only enhance a surgeon's productivity. Regardless of which procedure is used, the physician must be skilled in open tracheotomies so that a percutaneous tracheotomy can be converted into an open procedure if the need arise.

C. Postoperative Care

Careful postoperative care is important to the success of tracheotomies. Humidifying inspired air is necessary to prevent crusting and tracheitis. Suctioning the tube and trachea on a frequent basis immediately postoperatively is necessary to clear secretions and prevent plugging. The frequency of suctioning can be decreased as the postoperative time increases and the patient recovers. Stay sutures and Björk flap sutures can be removed in approximately 3–5 days. Also, changing the tracheotomy tube can usually be performed at this time, after an adequate tract has formed.

D. Decannulation

Before decannulation can occur, the disease process that resulted in the need for a tracheotomy must be resolved. Good airway patency allows for successful decannulation. Patency can be evaluated either with a mirror exam of the larynx or by direct fiberoptic endoscopy. Another practical approach is to change the tube to a smaller uncuffed tube. This tube can then be occluded and the patient's respiration observed. The patient with an adequate airway after tube occlusion should tolerate decannulation; tube removal is usually performed after 24 hours of tube occlusion.

Complications

The complications of tracheotomy are listed in Table 38–1. Meticulous hemostasis should be achieved before leaving the operating room. Occasionally, **subcutaneous emphysema** results when air is trapped in the subcutaneous tissues from suturing the surgical incision. The treatment involves removing the skin sutures and inflating the cuff. The physician

Table 38–1. Complications of Tracheotomies.

Early
Infection
Hemorrhage
Subcutaneous emphysema
Pneumomediastinum
Pneumothorax
Tracheoesophageal fistula
Recurrent laryngeal nerve injury
Tube displacement
Delayed
Tracheal-innominate artery fistula
Tracheal stenosis
Delayed tracheoesophageal fistula
Tracheocutaneous fistula

must monitor for the potential development of either pneumomediastinum or pneumothorax if the condition progresses. **Pneumomediastinum** results when air is sucked through the wound or from coughing that forces air into the deep tissue planes of the neck and into the mediastinum. **Pneumothorax** may result from progressive pneumomediastinum or from direct injury to the pleura during tracheotomy. A **tracheoesophageal fistula** can occur if the tracheal incision is made too deep, causing inadvertent injury to the underlying esophagus. **Recurrent laryngeal nerve damage** is possible if dissection occurs lateral to the trachea. **Tube displacement** is a risk of surgery and can be minimized by the use of stay sutures or the Björk flap.

One of the most dire complications of tracheotomy is a **tracheal-innominate artery fistula**, which occurs when the major vessel is eroded by pressure necrosis from the tracheotomy cuff or directly from the tip of the tube itself. It usually presents within 2 weeks of the tracheotomy and carries a 73% mortality rate. It may be indicated by minor sentinel bleeding. The treatment consists of controlling the hemorrhage by overinflating the tracheotomy tube cuff or inserting an endotracheal tube below the level of bleeding while compressing the innominate artery anteriorly against the sternum, with the index finger inserted through the tracheotomy wound. The patient should then be rushed to the operating room for definitive repair.

Tracheal stenosis is another delayed complication and can occur at the level of the stoma, the tracheotomy tube cuff, or the tube tip. A **tracheoesophageal fistula** can also occur in the delayed setting and is considered to be secondary to pressure necrosis from the tracheotomy tube cuff or the tip of a malpositioned tube. An indwelling nasogastric tube may predispose the patient to postoperative complications. A persistent **tracheocutaneous fistula** can sometimes occur after decannulation of a long-standing tracheotomy. Surgical closure is indicated if the stoma remains patent longer than 2 months. Closure involves excising the fistula tract and closing, in layers, the trachea, strap muscles, platysma, and skin.

Altman KW, Waltonen JD, Kern RC. Urgent surgical airway intervention: A 3-year county hospital experience. *Laryngoscope* 2005;115:2101 [PMID: 16369150]. (Discusses how to manage an urgent surgical airway situation in a controlled manner and provides some excellent pearls for one of the most stressful situations that otolaryngologists can encounter.)

Delaney A, Bagshaw SM, Nalos M. Percutaneous dilatational tracheostomy versus surgical tracheostomy in critically ill patients: A systemic review and meta-analysis. *Crit Care* 2006;10(2):R55 [PMID: 16606435]. (A meta-analysis looking at percutaneous tracheotomy vs. open surgical tracheotomy in critically ill patients showing significant reduced infection rate in percutaneous tracheotomy vs. open and equivalent bleeding, major peri-procedural and long term complications in the two groups. Argues percutaneous tracheotomies should be procedure of choice when possible.)

Dupanovic M, Fox H, Kovac A. Management of the airway in multitrauma. *Curr Opin Anaesthesiol.* 2010;23:276 [PMID: 20042974]. (Succinct article highlighting airway management in multitrauma scenario, as well as introductory comments regarding role new video laryngoscopes for intubation.)

Hendersen JJ, Popat MT, Latto IP, Pearce AC. Difficult Airway Society guidelines for management of the unanticipated difficult intubation. *Anaesthesia* 2004;59:675 [PMID: 152000543]. (Thorough discussion of the management of the unexpected difficult airway intubation with an algorithm on managing this situation before a surgical airway must be considered.)

Foreign Bodies

39

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Kevin Burke, MD

ESSENTIALS OF DIAGNOSIS

- SFABL: Patient history
- Witnessed ingestion and history of choking
- High level of clinical suspicion
- Respiratory and swallowing symptoms
- Posteroanterior and lateral neck and chest films are diagnostic

General Considerations

Foreign body ingestion and aspiration are an important cause of morbidity and mortality in the pediatric population. Aerodigestive tract foreign bodies are the cause of approximately 150 pediatric deaths per year in the United States, and choking causes 40% of accidental deaths in children less than 1 y of age. Foreign bodies remain a diagnostic challenge as their presentation can vary from life-threatening airway compromise to subtle respiratory symptoms that are often misdiagnosed. A high level of clinical suspicion can prevent delays in diagnosis and complications related to these delays.

Pathogenesis

Most aerodigestive tract foreign bodies occur in children under the age of 4 y. The high incidence of aerodigestive foreign bodies in children of this age is related to their increased mobility, the introduction of adult food, a high propensity for placing objects in their mouths, incomplete dentition, and immature swallowing coordination. Other populations at risk for esophageal foreign bodies include psychiatric patients, patients with underlying esophageal or neurological disease, and edentulous adults. Coins are the most commonly ingested foreign body, whereas nuts and seeds are the most commonly aspirated foreign body (Figure 39–1). Although fortunately rare, the aspiration of latex balloons is associated with especially high mortality rates. In older children and adults, fish or chicken bones may lodge in the oropharynx.

Damage to the surrounding aerodigestive tract mucosa is related to the type of foreign body and the length of time the foreign body has been present. Granulation tissue formation, erosive lesions, and infections can occur over time and can be minimized with early diagnosis and surgical intervention.

Prevention

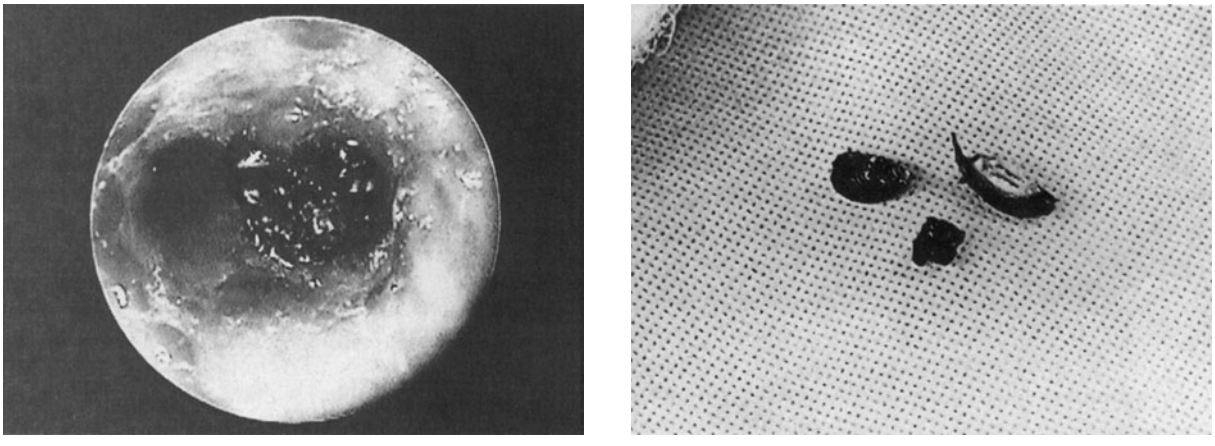
The prevention of ingestion is the most important intervention for potential aerodigestive tract foreign body ingestions. The Consumer Products Safety Act was passed in 1979 and includes criteria for the minimum size of objects >3.17 cm in diameter and >5.71 cm in length) allowable for children to play with, but these regulations are not uniformly enforced. Young children should remain under constant adult supervision and allowed to play only with age-appropriate toys. Small and hazardous objects should be safely stored so as not to be accessible to a newly mobile and curious child. Food should be age appropriate and presented only in an observed setting.

Children with esophageal motility disorders or neurological disorders should be encouraged to chew food slowly and completely to avoid esophageal impactions or aspiration.

Clinical Findings

A. Symptoms and Signs

A witnessed ingestion or aspiration episode should be brought to the attention of a physician. Information that is important to elicit from parents includes the approximate time of ingestion, any history of esophageal dysfunction, and both the severity and the duration of swallowing and respiratory symptoms since the time of ingestion. When an unusual



A B

▲ **Figure 39–1.** **(A)** Clot and surrounding granulation tissue of the right mainstem bronchus; **(B)** Sunflower seed husks pulled from the right mainstem bronchus after the removal of clot.

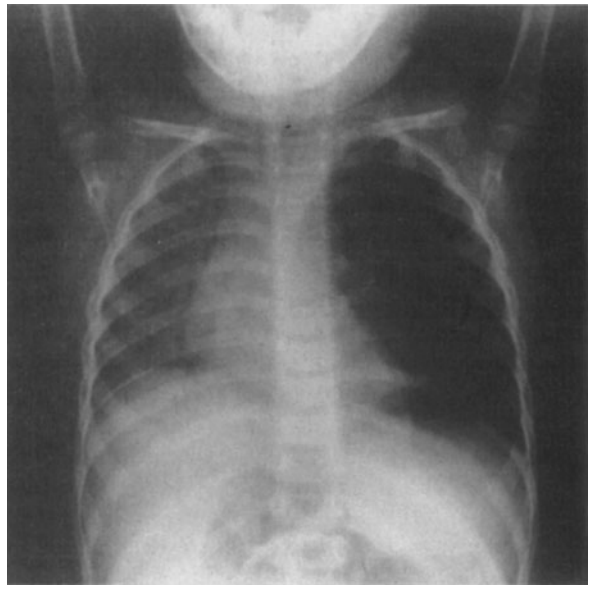
foreign body is aspirated or ingested, it may also be helpful to have the parents bring in a similar object from home.

Typical signs and symptoms of esophageal foreign body ingestion include drooling, dysphagia, emesis, food refusal, and chest pain. Esophageal foreign bodies may also cause respiratory symptoms in a young child. Airway foreign bodies may initially present with an episode of choking, gagging, and cyanosis followed by coughing, wheezing, and/or stridor. Physical examination may reveal asymmetric breath sounds or unilateral wheezing. However, the patient can become asymptomatic when the foreign body lodges more distally in the airway. This can make diagnosis difficult, especially when the initial event is unwitnessed. A high index of suspicion should be maintained when evaluating children presenting with a sudden onset of respiratory symptoms or with recurrent croup, asthma, or pneumonia without the expected response to treatment.

B. Imaging Studies

Posteroanterior and lateral plain films of the neck and chest are the imaging studies of choice. Radiopaque foreign bodies should be straightforward to diagnose, whereas other foreign bodies may be more difficult. Unilateral hyperinflation, localized atelectasis or infiltrates, mediastinal shift, and esophageal air trapping can all be clues to the presence of a foreign body even when no foreign body is visualized. (Figure 39–2). Both posteroanterior and lateral views should be obtained as they can help differentiate between esophageal and tracheal foreign bodies and provide clues as to the type of foreign body. For example, button batteries have a characteristic double contour on lateral view but may be mistaken for coins on posteroanterior views.

Imaging studies should not be used to rule out the presence of a foreign body. High clinical suspicion or historical evidence (ie, witnessed ingestion or aspiration) warrants rigid endoscopy even if imaging studies are normal. If plain films are not diagnostic or the patient cannot cooperate for the imaging exam, airway fluoroscopy is sometimes used.



▲ **Figure 39–2.** Hyperinflated left-lung field secondary to a peanut obstructing the left mainstem bronchus.

This study has the added advantage of demonstrating a dynamic view of the airway; however, it is dependent on the expertise of the radiologist performing the examination. Barium swallow is generally not indicated, and the presence of barium can make esophageal foreign body extraction more difficult.

Differential Diagnosis

The differential diagnosis of aerodigestive tract foreign body is generated in part using presenting symptoms, but it is more dependent on the history obtained from parents or other caregivers. As previously mentioned, children with esophageal foreign bodies may present with airway symptoms or symptoms mimicking nonspecific gastrointestinal illness. These children may be misdiagnosed with pharyngitis or gastroenteritis.

Bronchial foreign bodies may present with chronic cough or wheezing. Common misdiagnoses include asthma, croup, and pneumonia. In children with these diagnoses who continue to seek medical attention and do not appear to respond to appropriate treatments, the presence of an airway foreign body should be considered.

Complications

Complications from aerodigestive tract foreign bodies result from both the type of foreign body and the duration of entrapment. Objects such as button batteries can cause mucosal erosion in as little 6 hours from the time of ingestion. The risk for complications increases with the duration of time the foreign body remains in place. The initial complications from a laryngeal or bronchial foreign body can be severe, including cyanosis, respiratory distress, and even respiratory arrest and death. A ball-valve effect can occur with a partially occluding bronchial foreign body causing hyperexpansion of the affected lung. If complete bronchial occlusion is present, total or partial lung collapse can occur. Late complications of bronchial foreign bodies include granulation tissue formation, pneumonia, empyema, bronchial fistula, and pneumothorax. In the case of esophageal foreign bodies, late complications include granulation tissue formation, mucosal erosions, esophageal perforation, tracheoesophageal fistula, esophageal-aortic fistula, and mediastinitis.

Treatment

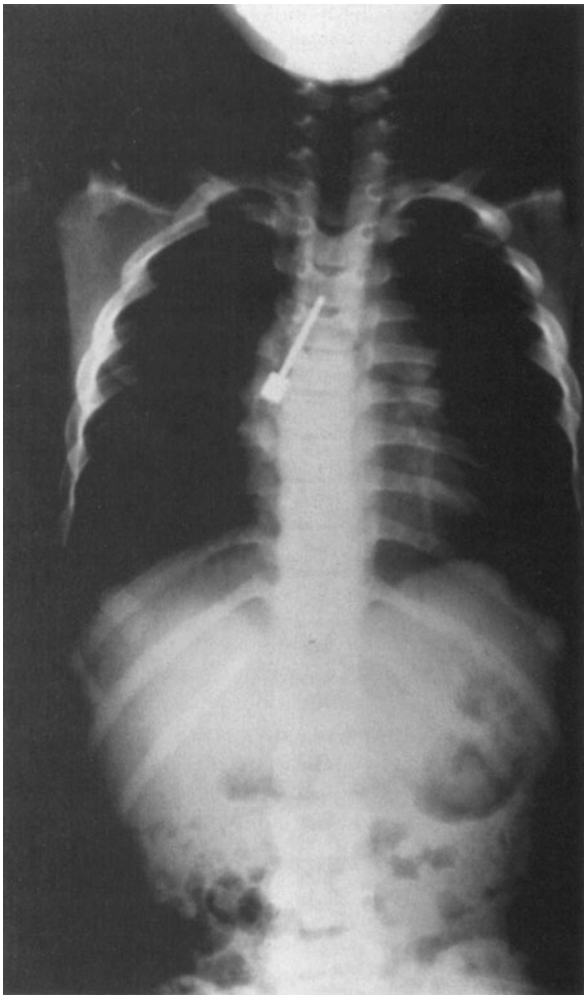
The treatment of choice for aerodigestive tract foreign bodies is rigid endoscopic removal under general anesthesia. This is carried out in the operating room with proper pediatric endoscopic equipment and pediatric anesthesiologists. Rarely, an oropharyngeal foreign body in an older, cooperative child, such as a fishbone impaling the tonsil, may be successfully extracted when the patient is awake.

Alternate methods of removal (eg, Fogarty catheters or flexible endoscopes) have been used in the past, but are generally not recommended because of the difficulty in protecting the airway or adequately controlling the foreign body with these methods. Meat tenderizers, muscle relaxants, and promotility agents have been used in the past for esophageal foreign bodies in adults, but no evidence supports their use in pediatric patients.

Most surgeons agree that an airway foreign body should be addressed at the time of presentation. Rapid sequence techniques may be preferred if aspiration of stomach contents is a concern. The timing of esophageal foreign body removal can be debated based on the type and location of the foreign body, the elapsed time since ingestion, and patient's age. An asymptomatic older child with a distal or midesophageal coin present for less than 24 hours and no history of esophageal disorders may be observed for a period of 8–16 hours to see if the coin will pass. Spontaneous coin passage rates range widely from 9% to 77% in this patient population. In young children, foreign bodies present for longer than 24 hours, sharp metallic or caustic foreign bodies (button batteries), and symptomatic patients (respiratory symptoms, discomfort, pooling, or intolerance of oral secretions) should not be observed for spontaneous passage. A child with a suspected disc battery ingestion requires urgent removal in the operating room to avoid mucosal erosion or perforation.

All equipment should be assembled and connected to appropriate light sources and video equipment before the patient enters the operating suite. The operating surgeon should be gloved and in position before induction, and the plan for induction should have already been discussed between the surgeon and the anesthesiologist. During endoscopic removal in the operating room, communication with the pediatric anesthesiologist is paramount. During manipulation, a stable esophageal foreign body can become an unstable tracheobronchial foreign body, or a partially obstructing bronchial foreign body can become an obstructing laryngeal foreign body. The otolaryngologist and anesthesiologist must be in constant communication to anticipate the patient's developing respiratory status.

Esophageal foreign bodies should be removed via rigid esophagoscopy with the patient intubated for airway protection. The esophagoscope may be introduced with the help of a laryngoscope or under direct vision. The esophagoscope should never be forced, but should be gently advanced, taking care to have the lumen centered in the field of vision. Once the foreign body has been identified, extraction may require removing the entire telescopic forceps and the esophagoscope complex. Care should be taken to avoid accidental extubation by having the anesthesiologist manually secure the endotracheal tube during removal of the esophagoscope. At least one more pass of the esophagoscope should be performed to check for multiple foreign bodies or mucosal damage. A notation of the



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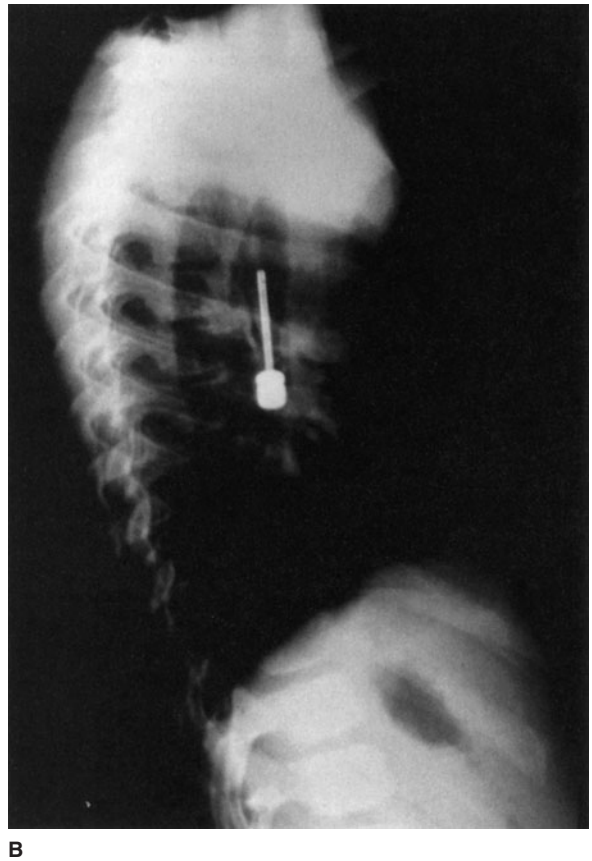

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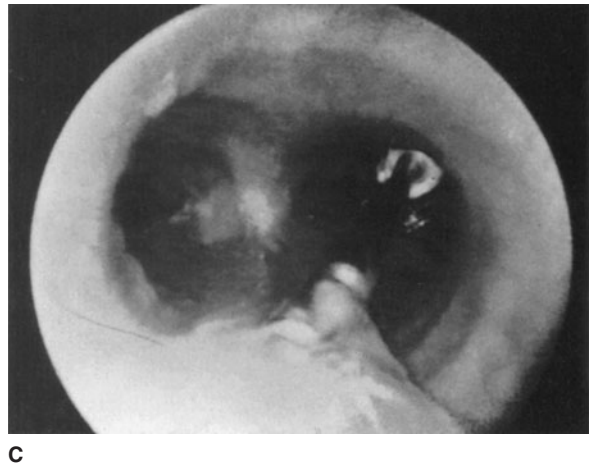

C

▲ **Figure 39–3.** **(A)** Posteroanterior chest x-ray revealing a foreign body in the right mainstem bronchus; **(B)** Lateral x-ray of a foreign body in the right mainstem bronchus; **(C)** Telescopic removal of the foreign body through a rigid bronchoscope.

distance from the esophageal inlet to any signs of mucosal damage should be recorded.

If the foreign body is removed easily without mucosal trauma, the child can be extubated and discharged from the recovery room if he or she is able to take adequate oral intake. If the foreign body has been present for an unknown length of time and there are signs of mucosal damage, the patient may require a longer period of observation postoperatively. Dexamethasone (ie, Decadron) at a dose of 0.5–1.0 mg/kg intravenous may be given if significant

edema is present. A chest x-ray should be performed if there is evidence of a traumatic extraction and any concern of significant mucosal damage to rule out perforation and mediastinal air.

1. Airway—Airway foreign bodies should be retrieved with the patient spontaneously breathing. This facilitates the passage of a bronchoscope, prevents distal migration of the foreign body during positive pressure ventilation, and takes advantage of the natural increase in tracheal and bronchial cross-sectional area during inspiration. Paralytics should be avoided. After mask induction with an inhalational agent, topical lidocaine should be used to anesthetize the vocal folds. Direct laryngoscopy is performed and a rigid bronchoscope is introduced under direct vision. Once the bronchoscope has been introduced, the anesthesiologist may connect to the ventilation port. The foreign body is identified, secured, and removed. Removal may require withdrawing, as a unit, the telescopic forceps and bronchoscope (Figure 39–3). Care should be taken to avoid premature release of the foreign body as this can result in an obstructing laryngotracheal foreign body. The surgeon should also communicate with the anesthesiologist to confirm the depth of anesthesia so as to avoid laryngospasm upon withdrawal of the bronchoscope. Nuts and other foods may require multiple passes. Care should be taken to minimize mucosal trauma. Prior to completion, at least one more pass should be performed to evaluate for multiple foreign bodies and mucosal damage. Depending on the ease of extraction, the child may require a postoperative chest x-ray and close follow-up to rule out the development of pneumonia.

Prognosis

Most children make a full recovery without permanent sequelae from aerodigestive tract foreign body ingestion. Delays in the diagnosis cause the most severe morbidity. Children who have a delayed or technically difficult extraction should be observed postoperatively in an inpatient setting until they no longer require airway support or can tolerate an age-appropriate diet.

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Crysdale WS, Sendi KS, Yoo J. Esophageal foreign bodies in children: 15-year review of 484 cases. *Ann Otol Rhinol Laryngol.* 1991;100:320. [PMID 2018291] (Analysis of esophageal foreign bodies in 426 children revealing that coins are the most commonly ingested foreign body.)

Digoy, GP. Diagnosis and management of upper aerodigestive tract foreign bodies. *Otolaryngol Clin N Am.* 2008;41:485. [PMID 18435994] (A review of the workup and management of patients with suspected foreign bodies.)

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Reilly JS, Walter MD, Beste D et al. Size/shape analysis of aerodigestive foreign bodies in children: A multi-institutional study. *Am J Otolarngol.* 1995;16:190. [PMID 7661316] (A multicenter, retrospective review of the size and shape of foreign bodies requiring surgical removal.)

Waltzman ML, Baskin M, Wypij D, Mooney D, Jones D, Fleisher G. A randomized clinical trial of the management of esophageal coins in children. *Pediatrics.* 2005;116(3):614. [PMID: 16140701] (Randomized, prospective study of 80 children with coin ingestion demonstrating that the spontaneous passage rate is associated with older age, male gender, and coins in the distal third of the esophagus.)

Zaytoun GM, Rouadi PW, Baki DHA. Endoscopic management of foreign bodies in the tracheobronchial tree: Predictive factors for complications. *Otolaryngol Head Neck Surg.* 2000;123:311. [PMID: 10964313] (Review of 504 bronchoscopic procedures for airway foreign bodies revealing type of foreign body, duration of procedure, and history of previous bronchoscopy as most useful predictors of complications.)

40 Airway Reconstruction

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ESSENTIALS OF DIAGNOSIS

- Patient history, including prematurity, history of intubation, feeding history, prior airway surgery, and other medical conditions.
- Physical examination, including weight, stridor, voice quality and cry, craniofacial abnormalities, pulmonary status, and cardiac status.

The following tests are diagnostic:

- Posteroanterior and lateral neck and chest x-rays
- Fluoroscopy
- Computed tomography and magnetic resonance imaging
- Flexible laryngoscopy
- Rigid endoscopy and microlaryngoscopy

General Considerations

Advances in care of premature infants in the last few decades have resulted in increased survival rates and a new population of patients with a history of prolonged intubation. A proportion of these patients develop subglottic stenosis up to 8%, according to some reports. Further advances in endotracheal tube and ventilation management in the last 30 y have decreased the incidence of subglottic stenosis in the neonatal population to <1%. A second population of infants born with congenital subglottic stenosis has remained stable at approximately 5%. These patients provide some of the greatest diagnostic and management challenges for the otolaryngologist.

Other airway abnormalities—both congenital and iatrogenic—including laryngomalacia, vocal fold paralysis, and supraglottic and glottic stenosis, have prompted otolaryngologists to continue to refine surgical airway reconstruction techniques. These techniques are becoming further advanced with the advent of endoscopic minimally invasive surgical procedures including robotic assisted endoscopic airway reconstruction on the horizon.

Cotton RT. The problem of pediatric laryngotracheal stenosis: a clinical and experimental study on the efficacy of autogenous cartilaginous grafts placed between the vertically divided halves of the posterior lamina of the cricoid cartilage. *Laryngoscope.* 1991;101:1. [PMID: 1766310] (Comprehensive review of the history of subglottic stenosis diagnosis and management.)

Faust R, Rahbar R. Robotic surgical technique for pediatric laryngotracheal reconstruction. *Otolaryngol Clin N Am.* 2008;41:1045. (Description of applications of robotic surgery for airway reconstruction.)

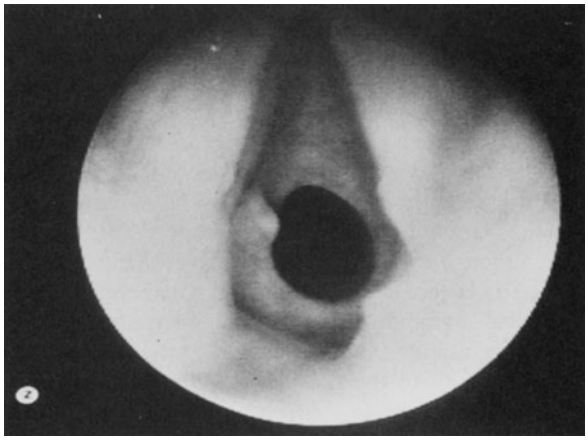
Walner DL, Loewen MS, Kimura RE. Neonatal subglottic stenosis: incidence and trends. *Laryngoscope.* 2001;111:48. [PMID: 11192899] (Review of the incidence trends of neonatal subglottic stenosis revealing improvement over the last three decades.)

Pathogenesis

A. Subglottic Stenosis

The incidence of congenital subglottic stenosis is approximately 5%. The cricoid cartilage develops abnormally and may be elliptical or flattened in shape, causing cartilaginous stenosis. The remainder of subglottic stenosis is considered to be iatrogenic—airway intubation with large tube size relative to airway diameter and duration of intubation both playing roles. Host factors also play a significant role, however, because some children intubated for a very short time develop subglottic stenosis, whereas others with a prolonged intubation history do not.

Acquired subglottic stenosis more often involves soft tissue stenosis in contrast to the congenital form, which results in cartilaginous stenosis. Pressure is considered to play a role, causing initial mucosal edema and inflammation with subsequent ulceration and finally fibrosis (Figure 40–1). Other factors may exacerbate stenosis development such as gastroesophageal reflux disease (GERD) and infection. The



▲ **Figure 40–1.** Circumferential acquired subglottic stenosis.

characterization of stenosis during diagnostic endoscopy, including the location, severity, and length of the stenosis, is extremely important and helps to direct management options and predict outcomes.

B. Laryngomalacia

Laryngomalacia is the most common cause of neonatal stridor (54–75%). The disorder is characterized by reduced laryngeal tone, shortened aryepiglottic folds, and supraglottic collapse causing prolapse of structures into the airway on inspiration. Laryngomalacia is classified into three main types based on the anatomic portion of the supraglottic structures that is prolapsing, although any combination can coexist.

Two main theories of etiology exist. The first proposes that immature cartilage lacks the stiff structure of more mature cartilage. The second theory suggests immature neural innervation, which is a form of hypotonia. Laryngomalacia can be exacerbated by other entities such as GERD, with a coincidence of up to 80%.

C. Vocal Fold Paralysis

Vocal fold paralysis is the second most common cause of stridor in neonates after laryngomalacia, accounting for 10% of congenital lesions of the larynx. This condition may be congenital or secondary to an abnormality along the course of the recurrent laryngeal nerve. Vocal fold paralysis is bilateral in up to 30–62% of cases. The most common etiology is secondary to hydrocephalus from a malformation such as Arnold-Chiari. Protrusion of intracerebral contents through the jugular foramen causes stretching of the vagus nerve. Intubation and birth trauma can lead to compression or stretching of both recurrent laryngeal nerves in the neonate. Iatrogenic causes of vocal fold paralysis include cardiovascular surgery and repair of tracheoesophageal fistulas. Once the primary cause has been addressed, the paralysis should resolve. For idiopathic vocal fold paralysis, surgical intervention may be required.

D. Glottic Stenosis and Supraglottic Stenosis

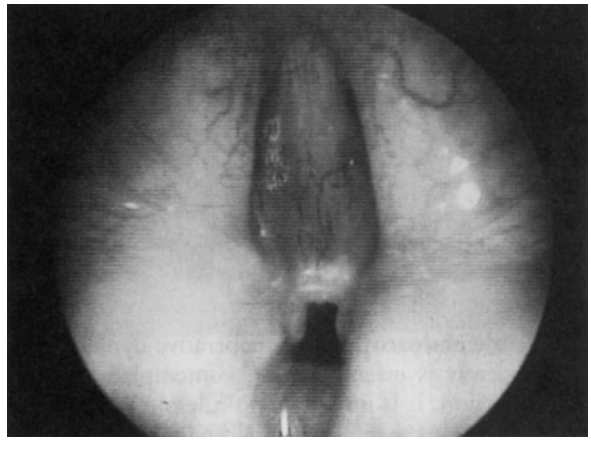
Glottic stenosis is generally iatrogenic, resulting from either traumatic intubation involving a similar pathogenesis as subglottic stenosis or prior laser procedures on the airway such as CO_2 laser excision of a papilloma. The etiology of supraglottic stenosis may also involve prior airway laser surgery or previous open airway procedures involving long-term indwelling stents with subsequent granulation tissue and fibrosis formation. GERD may also play a role in both of these diagnoses.

E. Laryngeal Web

Laryngeal webs can be either congenital or acquired secondary to prior airway procedures, intubation, or infection (Figure 40–2). Congenital laryngeal webs are rare malformations in which abnormal fibrous tissue is formed between two intrinsic structures of the larynx. Congenital webs are considered a form of laryngeal stenosis or atresia and warrant further evaluation for other congenital conditions. The pathogenesis of acquired laryngeal web generally involves development of an inflammatory process in reaction to the initial insult, with subsequent maturation and scar formation.

F. Laryngeal Cleft

Laryngeal clefts are defects in the larynx that arise from the failure of fusion and/or incomplete development of the tracheoesophageal septum. They can be classified based on extent. Type I clefts are defects in the supraglottic interarytenoid region that extends no further than the level of the true vocal folds. Type II clefts extend below the level



▲ **Figure 40–2.** Congenital laryngeal web.

of the true vocal folds. Type III clefts involve a complete defect of the cricoid cartilage, and type IV clefts extend into the posterior wall of the thoracic trachea.

Chen EY, Inglis AF. Bilateral vocal cord paralysis in children. *Otolaryngol Clin N Am*. 2008;41:889. (Review of pediatric vocal cord paralysis—diagnosis and management.)

Holinger LD. Histopathology of congenital subglottic stenosis. *Ann Otol Rhinol Laryngol.* 1999;108:101. [PMID: 10030225] (Summary of classifications of congenital subglottic stenosis found in 29 specimens.)

Matthews BL, Little JP, McGuirt WF et al. Reflux in infants with laryngomalacia: results of 24-h double-probe pH monitoring. *Otolaryngol Head Neck Surg.* 1999;120:860. [PMID: 10352440] (Comparison of proximal and distal probe results in 24 patients presenting with laryngomalacia. Hundred percent demonstrated pharyngeal acid exposure.)

Nicollas R, Triglia JM. The anterior laryngeal webs. *Otolaryngol Clin N Am*. 2008;41:877. (Review of laryngeal web diagnosis and management.)

Perkins JA, Inglis AF, Richardson MA. Iatrogenic airway stenosis with recurrent respiratory papillomatosis. *Arch Otolaryngol Head Neck Surg.* 1998;124:281. [PMID: 9525512] (Seven of 50 patients treated for recurrent respiratory papillomatosis over a 6-y period were found to have iatrogenic airway stenosis.)

Rahbar R, Chen, JL, Rosen RL et al. Endoscopic repair of laryngeal cleft type I and type II: when and why? *Laryngoscope*. 2009;119:1797. (Discussion of management of laryngeal clefts.)

Richter GT, Thompson DM. The surgical management of laryngomalacia. *Otolaryngol Clin N Am.* 2008;41:837. (Excellent review of laryngomalacia diagnosis and management.)

Walner DL, Holinger LD. Supraglottic stenosis in infants and children. *Arch Otolaryngol Head Neck Surg.* 1997;123:337. [PMID: 9076242] (Of 17 patients with supraglottic stenosis, 59% had undergone laryngotracheal reconstruction, and 53% had a history of GERD.)

Walner DL, Stern Y, Gerber ME et al. Gastroesophageal reflux in patients with subglottic stenosis. *Arch Otolaryngol Head Neck Surg.* 1998;124:551. [PMID: 9604982] (A review of esophageal pH probes results in 74 patients with subglottic stenosis, revealing a high incidence of gastroesophageal reflux disease)

Prevention

Advances in airway management of the premature infant over the last 30 y have brought incidence rates of subglottic stenosis from 8% down to <1%. Low-irritant endotracheal tubes, nasal endotracheal intubation, and appropriately sized endotracheal tubes can reduce the risk of developing subsequent airway stenosis. Awareness of the dangers of aggressive laser use in the airway has also contributed to decreased rates of iatrogenic airway lesions such as glottic stenosis and laryngeal web formation.

Clinical Findings

A. Symptoms and Signs

Stridor is one of the foremost features of airway pathology. A more typical presentation of acquired subglottic stenosis, however, may be of a premature infant with a history of intubation that failed on several attempts at extubation in the intensive care unit. For an older child with an initially less-severe airway lesion, voice changes, feeding difficulties, or progressive respiratory symptoms may develop.

B. Imaging Studies

Posteroanterior neck and chest x-rays can be helpful in diagnosing some airway lesions. Airway fluoroscopy may demonstrate coexisting pathology, such as tracheomalacia, but is dependent on the expertise of the radiologist for the diagnosis. Preoperative barium swallow is recommended if a child has a history of feeding difficulties. Computed tomography scanning or magnetic resonance imaging can provide information on both the severity and the length of the stenoses, but should never replace endoscopic evaluation. Imaging studies may also be helpful in diagnosing tracheal compression secondary to a vascular lesion.

C. Special Tests

The association between airway pathology and GERD has been documented. Most airway surgeons currently recommend a preoperative evaluation for GERD for patients undergoing open airway procedures. The study of choice for diagnosis is a **dual-channel pH probe.** This test involves a probe in the pharynx (above the upper esophageal sphincter) and in the esophagus (above the lower esophageal sphincter) for detection of acid over a 24-h period. If GERD is found, medical therapy for 3 mo is recommended before considering airway surgery. If a repeat pH probe is still found to be positive, antireflux surgery is recommended before considering airway surgery.

D. Special Examinations

1. Flexible endoscopic evaluation of swallowing—Flexible endoscopic evaluation of swallowing is recommended for patients undergoing laryngotracheal reconstruction. The test can determine whether there is evidence of laryngeal penetration, premature spillage, aspiration, hypopharyngeal clearance, hypopharyngeal pooling, or laryngeal and hypopharyngeal sensation. In a study of 255 patients undergoing flexible endoscopic evaluation of swallowing, airway reconstruction plans were altered in 15% of patients after identifying poor airway protective mechanisms. This planned alteration resulted in G-tube placement for some patients; for other patients, planned surgical reconstruction was modified with the goal of preventing both compromised postoperative recovery secondary to aspiration and the inability to maintain adequate nutrition.

2. Flexible endoscopy—Preoperative dynamic view of the airway is essential when contemplating airway reconstruction. It is important to rule out possible synchronous lesions such as vocal fold paralysis or laryngomalacia, both of which

are difficult to diagnose when the child is under anesthesia, even if allowed to breathe spontaneously.

3. Rigid bronchoscopy and microlaryngoscopy—Preoperative endoscopy is mandatory to assess the characteristics of a patient's airway pathology. A standard grading scale has been devised based on stenosis of the airway lumen: (1) **Grade I:** <50% stenosis; (2) **Grade II:** 51–70%; (3) **Grade III:** 71–99%; and (4) **Grade IV:** 100%. This scale, although still somewhat subjective, is an attempt to provide an objective parameter of stenosis severity. Other important characteristics to consider in the preoperative endoscopic examination include the length of the stenosis, proximity of extension to the vocal folds, and the exact location of involvement whether anterior, posterior, or circumferential. All these factors are important in planning surgery and predicting outcomes.

4. Pulmonary function tests—A patient's preoperative pulmonary status is an important indicator of the airway reconstruction technique that should be used. Patients with poor pulmonary reserve are not candidates for certain airway reconstruction procedures. Many of these patients are former premature infants and may have an element of chronic lung disease, the severity of which should be identified before proceeding with open airway reconstruction.

5. Voice evaluation—Although most previous studies have evaluated only postoperative voice quality after airway reconstruction surgery, ideally, a preoperative examination would add value for comparison. Initial evaluation would include assessment of the child's overall communicative ability, potential for voicing, and the use of any form of alternative communication. Standardized measures of pediatric vocal parameters including the pediatric voice handicap index may assist in assessment of pre-/postoperative vocal changes.

Halstead LA. Gastroesophageal reflux: a critical factor in pediatric subglottic stenosis. *Otolaryngol Head Neck Surg.* 1999;120:683. [PMID: 10229593] (Of 25 patients presenting with subglottic stenosis empirically treated for GERD, 9 resolved with medical therapy alone, 16 patients underwent endoscopic repair, and only 1 eventually required tracheotomy.)

Myer CM III, O'Connor DM, Cotton RT. Proposed grading system for subglottic stenosis based on endotracheal tube sizes. *Ann Otol Rhinol Laryngol.* 1994;103:319. [PMID: 8154776] (Revised grading system of subglottic stenosis.)

Smith ME, Marsh JH, Cotton RT et al. Voice problems after pediatric laryngotracheal reconstruction: videolaryngostroboscopic, acoustic, and perceptual assessment. *Int J Pediatr Otorhinolaryngol.* 1993;25:173. [PMID: 8436462] (Summary of voice evaluations in eight patients who had undergone laryngotracheal reconstructions revealing patient cooperation as a critical factor both in evaluation quality and in abnormalities in all patients postoperatively.)

Willging JP. Benefit of feeding assessment before pediatric airway reconstruction. *Laryngoscope.* 2000;110:825. [PMID: 10807361] (Results of feeding assessments of 255 patients with structural abnormalities of the aerodigestive tract; 15% had results that altered further management plans.)

Zur KB, Cotton S, Kelchner L et al. Pediatric voice handicap index (pVHI): a new tool for evaluating pediatric dysphonia. *Int J Pediatr Otoryhinolaryngol.* 2007;71:77.

Differential Diagnosis

The differential diagnosis of subglottic stenosis is extensive and reinforces the importance of preoperative endoscopy. It is also important to consider the possibility of synchronous lesions. Diagnoses to consider include laryngomalacia; vocal fold paralysis; laryngeal web, cyst, or cleft; laryngocele; subglottic hemangioma; tracheoesophageal fistula; tracheal stenosis; tracheal compression secondary to a vascular anomaly; and primary tracheomalacia.

Treatment

A. Subglottic Stenosis

Historically, the treatment of symptomatic subglottic stenosis has involved three options: (1) tracheotomy, (2) endoscopic management with laser and dilation for mild to moderate lesions, and (3) airway expansion surgery for severe lesions. Observation with medical therapy is reserved for mild lesions with intermittent, nonprogressive symptoms.

1. Tracheotomy—Tracheotomy continues to be a mainstay of treatment, although most surgeons see this treatment option as temporary, with the eventual goal being decannulation either with or without airway expansion surgery. Tracheotomy is not without complications, however, and requires a significant amount of education about and resources for postoperative care, which can sometimes overwhelm parents. Psychosocial effects on child development also make the tracheotomy a less than ideal permanent treatment.

2. Anterior cricoid split—The anterior cricoid split was developed in an effort to avoid tracheotomy in a specific population of patients: premature infants weighing at least 1500 g without significant confounding cardiac or pulmonary compromise and evidence of anterior subglottic stenosis on bronchoscopy. In this procedure, the anterior cricoid cartilage is divided in the midline, and the incision is extended superiorly through the lower third of the thyroid cartilage and inferiorly through the first and second tracheal rings. The existing endotracheal tube is removed and replaced with a larger diameter tube that is used as a stent for 7–10 days. Steroids are given at 1 mg/kg/d 24 hours before extubation and for 5 days postoperatively. The intended outcome is for a fibrous band to form at the incision site, causing the airway to stay expanded even after stent removal. The success rate of the procedure is reported to be between 70% and 80%. There has been concern that the procedure may disrupt future cartilage growth, but this concern has not been demonstrated thus far.

3. Airway expansion surgery—In older children, the mainstay of airway expansion surgery has been to divide the stenotic area with placement of a cartilaginous graft. Although general principles apply to all laryngotracheal reconstruction procedures, the unique characteristics of each patient's lesion and overall health determine the specific procedure appropriate for that patient.

A. Single-stage surgery—The trend has been toward single-stage reconstruction, meaning that the tracheotomy is removed at the time of expansion surgery with short-term postoperative stenting (7–14 days) with an endotracheal tube. Single-stage reconstruction is not appropriate for all patients, however, especially those with more severe stenoses (Grades III and IV) or with poor pulmonary reserve. Single-stage reconstruction also requires prolonged hospitalization in an intensive care unit and immobilizing the endotracheal tube for the entire postoperative healing period. In the case of younger children, this prolonged immobilization may necessitate heavy sedation or paralysis, which can create complications such as atelectasis or narcotic withdrawal. Endotracheal tube air leak has been used as a prognostic indicator for successful extubation. Leak pressures of <20 cm H_2O are associated with successful extubation.

B. Multistage surgery—Multistage airway expansion procedures are generally reserved for children with more severe lesions or with confounding cardiac, pulmonary, or neurological compromise. These procedures involve cartilaginous grafting and indwelling stents, but the tracheotomy is retained and not removed until after stent removal. Division of the lateral cricoid walls without graft placement may allow for even greater expansion of the subglottic lumen. Sleep studies using a capped tracheotomy may also be helpful in assessing potential decannulation success.

4. Cartilage grafts—The classic cartilage graft used is costal cartilage, but hyoid, thyroid, and auricular cartilage have also been tried. The initial concern about using cartilage grafts was that they may not survive, but histological studies have demonstrated excellent survival and growth over time. Important graft properties are as following: (1) it is of the correct depth so as not to protrude into the airway, (2) the perichondrium is left intact and faces the lumen, and (3) the graft is adequately secured. Traditionally, grafts have been sutured into position, although newer techniques such as fibrin glue and miniplate fixation have also been tried. The classic anterior costal cartilage graft is shaped like a boat with flanges, which, when the graft is inserted into the anterior cricoid incision, are flush with the lateral native cricoid ring. Caution must be taken that the graft does not protrude into the lumen, thereby compromising the lumen diameter. Newer techniques have now been described for endoscopic placement of cartilage grafts to address the posterior component of circumferential subglottic stenosis or as treatment for bilateral vocal fold immobility.

5. Stenting—Patients who undergo posterior cartilage grafting for posterior stenosis generally require a longer period of stenting than patients who undergo anterior grafting alone. Long-term stenting can be associated with significant complications. Many types of stents have been used, leading surgeons to conclude that no one stent necessarily guarantees a complication-free recovery and healing period. The most commonly used stents include rolled silicone sheeting (the "Swiss roll"), polytef tubes (eg, Aboulker or Cotton-Lorenz), and preformed hollow silicone tubes (eg, Montgomery T-tube.)

The optimal stent duration to maximize healing and avoid complications is controversial. For anterior cricoid splits or single-stage laryngotracheal reconstruction with an anterior cartilage graft, a duration of 7–10 days is considered adequate. For posterior cartilage grafts, a stent duration of 2–8 weeks has been recommended. For multistage procedures, stents have been kept in place from several weeks to over a year. Because of the many possible complications of indwelling stents, the most rational approach involves limiting stent duration; ideally, technically adequate expansion surgery should not require long-term stenting. Other medical conditions, such as diabetes and chronic steroid dependence, that may impact healing should also be considered during surgical planning.

6. Decannulation—The decannulation rates of all open airway expansion procedures that include Grades II–IV range from 37% to 100%. Newer techniques are being developed to prevent restenosis, which is the most common reason for decannulation failure. Fibroblast inhibitors including mitomycin-C and 5-fluorouracil (5-FU) have been used with mixed initial results. Other, more extensive procedures designed to remove rather than expand the stenotic segment have also been developed, including cricotracheal resection, slide tracheoplasty, and even tracheal homograft transplantation.

7. Cricotracheal resection—Cricotracheal resection was originally reserved for patients who failed initial laryngotracheal reconstruction with grafting, but it is now being implemented as a first-line treatment for some patients with severe (>70% luminal obstruction) and even moderate stenoses. The procedure involves resection of the entire anterior cricoid arch with preservation of a posterior mucosal flap along the posterior cricoid plate. The normal trachea is then transected and telescoped into the posterior cricoid plate and secured with sutures to the mucosal flap and thyroid cartilage. Involvement of the vocal folds is a contraindication, and generally, a superior margin of 3 mm is recommended for success. Inferior resection margins have extended as low as the second tracheal ring, with the longest reported resection length being 3.0 cm. A tension-free anastomosis is critical for success and a suprahyoid release has been used to achieve this. Care also must be taken to avoid injury to the recurrent laryngeal nerves. A subperichondrial tracheal dissection is recommended to avoid nerve injury. Stenting may involve a single-stage or multistage procedure, with a duration ranging from 1 wk to 3 mo. Decannulation rates of > 90% have been

reported in patients with a history of failed decannulation after prior laryngotracheal reconstruction. Decannulation rates after primary cricotracheal resection in Grades III and IV stenoses have been reported at 95%.

8. Slide tracheoplasty—Slide tracheoplasty has been used for congenital long-segment tracheal stenosis, which is often associated with a pulmonary artery sling. The principles of slide tracheoplasty involve tracheal transection at the midpoint of the stenosis with an anterior midline incision of the distal tracheal segment and a posterior midline incision of the proximal tracheal segment. The segments are then telescoped and sutured, ideally doubling the tracheal circumference and quadrupling the cross section of tracheal lumen.

9. Balloon laryngoplasty—Historically, airway dilation has been performed using rigid bougienage instruments that exert considerable sheering forces across the area of stenosis. These techniques were avoided due to the trauma created by these procedures. More recently, balloon laryngeal dilators have become available that apply controlled radial pressure to the stenotic area. Variable sizes of balloons may be used to match airway size, and pressure can be applied up to 20 atmospheres. Reports, though preliminary, have shown effectiveness of balloon laryngoplasty in both the primary treatment of subglottic stenosis as well as with dilation of restenosis after primary airway reconstruction surgery. Balloon laryngoplasty may serve to stabilize airway stenosis before definitive surgical intervention or even obviate the need for more invasive treatments.

Bent JP, Shah MB, Nord R, Parikh SR. Balloon dilation for recurrent stenosis after pediatric laryngotracheoplasty. *Ann Otol Rhinol Laryngol.* Sep 2010;119(9):619–627. (Report of 10 patients with stenosis treated with balloon dilation after primary laryngotracheoplasty)

Durden F, Sobol SE. Balloon laryngoplasty as a primary treatment for subglottic stenosis. *Arch Otolaryngol Head Neck Surg.* Aug 2007;133(8):772–775. (Series of 10 patients who underwent balloon dilation, 7 of the patients did not require further airway procedures.)

B. Laryngomalacia

The majority of children with laryngomalacia can be managed conservatively. Rarely, a child with significant cardiac or pulmonary compromise or failure to thrive may need surgical treatment. Supraglottoplasty is the primary operation for treating laryngomalacia. Tracheotomy is considered for children who fail supraglottoplasty or infants with multiple medical problems that warrant tracheotomy for reasons in addition to airway compromise. Patients should always be evaluated for GERD before undergoing supraglottoplasty since comorbid rates up to 80% have been demonstrated and GERD compromises postoperative healing.

Supraglottoplasty may be performed with the CO_2 laser, microlaryngeal instruments, or a laryngeal microdebrider. The technique is tailored to the type of laryngomalacia that exists in the particular patient. A wide-mouthed laryngoscope (eg, a Lindholm laryngoscope) may be helpful in providing the best view of the supraglottis. The procedure is usually performed under general anesthesia with spontaneous ventilation. The three most common techniques include (1) trimming the lateral edges of the epiglottis, (2) releasing foreshortened aryepiglottic folds, or (3) excising redundant arytenoid mucosa. Care must be taken to avoid lasing or excising adjacent surfaces to prevent scar formation; overly aggressive surgery can also lead to an increased risk of postoperative aspiration. Most patients can be extubated at the end of the procedure, and often a short course of postoperative steroids is given.

C. Posterior Glottic Stenosis and Vocal Fold Paralysis

Posterior glottic stenosis and bilateral vocal fold paralysis may often be difficult to distinguish and can have similar presenting symptoms. Electromyogram testing can be included as a part of the endoscopic evaluation to confirm vocal fold innervation. Tracheotomy is an option for both diagnoses, but is generally not considered an optimal long-term solution. Endoscopic procedures such as partial or complete arytenoidectomy, cordotomy, and partial cordectomy have been used in small series of pediatric patients with varying success rates. The other functions of the larynx including airway protection may worsen with any of these procedures, thereby increasing the risk of aspiration. Open or endoscopic procedures with posterior cartilage graft placement may also be used.

D. Laryngeal Web

Laryngeal webs can be challenging to address surgically. Symptomatic thin webs can be treated endoscopically with laser excision and application of topical mitomycin-C. Thicker webs generally require laryngofissure with keel placement and a short-term tracheotomy for definitive repair.

Bean JA, Rutter MJ. Pediatric cricotracheal resection: surgical outcomes and risk factor analysis. *Arch Otolaryngol Head Neck Surg.* 2005;131(10):896. [PMID: 16230593] (Review of outcomes of 100 children undergoing cricotracheal resection with a 71% overall decannulation rate and identification of vocal cord paresis as main risk factor for decannulation failure.)

E. Laryngeal Cleft

Type I laryngeal clefts may initially be treated conservatively with thickening of feeds and sometimes a gastrostomy tube placement. Proton pump inhibitors are administered to treat presumed coexisting reflux disease. For patients who fail conservative therapy with worsening aspiration symptoms or respiratory deterioration, some advocate surgical closure of the cleft. Less-invasive endoscopic techniques are currently

favored over open neck approaches. Sutures are placed strategically in order to reapproximate the edges of the mucosal defect and often CO_2 laser is employed to denude the mucosal edges to encourage secondary scarring of the cleft.

Boardman SJ, Albert DM. Single-stage and multistage pediatric laryngotracheal reconstruction. *Otolaryngol Clin N Am.* 2008;41:947. (Review of laryngotracheal reconstruction.)

Carr MM, Poje CP, Kingston L et al. Complications in pediatric tracheotomies. *Laryngoscope.* 2001;111:1925. [PMID: 11801971] (Review of 142 pediatric tracheotomies reveals a 43% incidence of serious complications.)

Cotton RT, Seid AB. Management of the extubation problem in the premature child: anterior cricoid split as an alternative to tracheotomy. *Ann Otol Rhinol Laryngol.* 1980;89:508. [PMID: 7458136] (Introduction of a new technique, the anterior cricoid split, as an alternative to tracheotomy in the management of premature infants who have failed extubation attempts.)

Hartnick CJ, Hartley BEJ, Lacy PD et al. Surgery for pediatric subglottic stenosis: disease-specific outcomes. *Ann Otol Rhinol Laryngol.* 2001;110:1109. [PMID: 11768698] (A valiant attempt to characterize outcomes of airway reconstruction surgery in 199 children with varied lesions and surgical procedures.)

Hartnick CJ, Hartley BEJ, Lacy PD et al. Topical mitomycin application after laryngotracheal reconstruction. *Arch Otolaryngol Head Neck Surg.* 2001;127:1260. [PMID: 11587609] (Randomized, double-blind, placebo-controlled trial of mitomycin application in laryngotracheal reconstruction revealing no difference in restenosis rates.)

Inglis AF, Perkins JA, Manning SC et al. Endoscopic posterior cricoid split and rib grafting in 10 children. *Laryngoscope.* 2003;113(11):2004. [PMID: 14603064] (Review of outcomes of patients undergoing endoscopic management of posterior glottic stenosis.)

Mankarious LA, Goetinck PF. Growth and development of the human cricoid cartilage: an immunohistochemical analysis of the maturation sequence of the chondrocytes and surrounding cartilage matrix. *Otolaryngol Head Neck Surg.* 2000;123:174. [PMID: 10964286] (Immunohistochemical study of cricoid cartilage from various developmental stages revealing a chondrocyte proliferation rate decreasing from ages 1–4.)

Preciado D, Zalzal G. Laryngeal and tracheal stents in children. *Curr Opin Otolaryngol Head Neck Surg.* 2008;16:83. (Review of the use of airway stents.)

Rutter MJ, Hartley BEJ, Cotton RT. Cricotracheal resection in children. *Arch Otolaryngol Head Neck Surg.* 2001;127:289. [PMID: 11255473] (Review of 44 children undergoing cricotracheal resection with a decannulation rate of 86%.)

Sandu K, Monnier P. Cricotracheal resection. *Otolaryngol Clin N Am.* 2008;41:981. (Review of cricotracheal resection including surgical technique.)

Complications

Complications can be grouped into three general categories: intraoperative, early postoperative, and late postoperative. Complications are more likely in patients who have severe initial lesions that require more extensive procedures.

A. Intraoperative Complications

Intraoperative complications can include either pneumothorax (usually secondary to costal cartilage graft harvesting with violation of the pleura) or vocal fold paralysis (usually secondary to dissection around the trachea). Extreme care should be taken when dissecting around the pleura or recurrent laryngeal nerve to avoid injury.

B. Early Postoperative Complications

1. Endotracheal tube and stent displacement—Early postoperative complications can be related to endotracheal tube or stent displacement such as subcutaneous emphysema, pneumothorax, or pneumomediastinum. Care should be taken to secure endotracheal tubes or other stents to avoid these complications. Seroma or wound infection can also occur. Some surgeons recommend empiric or culture-directed antibiotic therapy during the postoperative period.

2. Atelectasis—Atelectasis (with the potential to develop pneumonia) secondary to prolonged intubation, prolonged sedation, and paralysis, as well as narcotic withdrawal, is also a significant postoperative concern. The surgeon and intensive care unit staff must balance the risk of stent dislodgement with the risks of sedation and paralysis. Postoperative care is currently not standardized. After experiences with accidental extubation, some physicians have found alternative airway management methods to avoid reinstrumentation of the airway (eg, the use of bilateral positive airway pressure). Other physicians have recommended an interrupted schedule of paralysis and narcotics or avoidance of all pharmacological restraints in order to avoid side effects. Prolonged nasotracheal intubation can also cause alar necrosis if vigilant daily inspection of the nose and endotracheal tube taping is not performed.

3. Other complications—Patients may also experience dysphagia, aspiration, and even failure to thrive postoperatively secondary to indwelling stents. Adjusting the stent position can sometimes resolve symptoms. Some children may require feeding tube placement until stent removal to allow for adequate nutritional support.

C. Late Postoperative Complications

1. Granulation tissue formation and stenosis—Late complications can include granulation tissue formation at the stent tip and glottic or supraglottic stenosis. Cartilage grafts can also prolapse into the airway, causing restenosis. These complications may be avoided if routine postoperative endoscopy is performed at regular intervals. Some physicians advocate empiric postoperative GERD therapy to eliminate gastroesophageal reflux as a possible cause of either postoperative granulation tissue formation or stenosis. Posterior glottic stenosis may require expansion surgery with a posterior cartilage graft.

2. Problems with voice quality—Voice quality postoperatively may worsen and can be secondary to anterior commissure asymmetry, formation of a glottic web, or vocal fold scarring. Care should be taken intraoperatively to avoid

incision of the anterior commissure. Reconstruction with keel placement can be considered if there is no improvement with conservative measures. Postoperative voice therapy may be indicated since delays in language and communication skills can be a source of significant morbidity for patients and their families.

3. Tracheocutaneous fistula—A persistent tracheocutaneous fistula is another potential complication after a long-standing tracheotomy and may require repair with excision of the epithelial-lined tract.

4. Suprastomal collapse—Suprastomal collapse can occur in patients with long-standing tracheotomies and may require rigid support with cartilage.

5. Arytenoid prolapse and supraglottic collapse—Arytenoid prolapse may occur, most commonly after cricotracheal resection or extensive laryngotracheal expansion procedures. A partial arytenoidectomy may be required, although the potential increased risk of aspiration should also be considered. Postoperative supraglottic collapse can be an extremely challenging problem.

6. Inability to decannulate—An inability to decannulate secondary to restenosis is the most devastating late complication and is more common in Grades III and IV stenoses. Revision airway surgery may increase decannulation rates.

Bauman NM, Oyos TL, Murray DJ et al. Postoperative care following single-stage laryngotracheoplasty. *Ann Otol Rhinol Laryngol.* 1996;105:317. [PMID: 8604897] (Comparison of two protocols for postoperative neuromuscular blockade.)

Cotton RT. Management of subglottic stenosis. *Otolaryngol Clin North Am.* 2000;33(1):111. [PMID: 10637347] (Excellent comprehensive review of diagnosis and management of subglottic stenosis.)

Hertzog JH, Siegel LB, Hauser GJ et al. Noninvasive positive-pressure ventilation facilitates tracheal extubation after laryngotracheal reconstruction in children. *Chest.* 1999;116(1):260. [PMID: 10424540] (Two case reports demonstrating success with bilateral positive airway pressure in maintaining adequate airway parameters as an alternative to reintubation after accidental extubation.)

Ludemann JP, Hughes CA, Noah Z et al. Complications of pediatric laryngotracheal reconstruction: prevention strategies. *Ann Otol Laryngol Rhinol.* 1999;108:1019. [PMID: 10579227] (Review of 82 patients revealing bronchiolitis, wound abscess, ossified cricoid cartilage, Grade IV stenosis, and untreated GERD as indicators of restenosis.)

Prognosis

The success of airway reconstruction techniques is determined by many factors such as the initial severity of the lesion, other patient comorbidities, and the technical expertise and experience of both the surgeon and intensive care unit staff; however, decannulation rates of 80–90% should be obtainable. A team approach is paramount to success. In managing these cases, patients should be counseled not to expect a one-time "fix," but that multiple procedures including interval endoscopy will most likely be required.

41

Sleep Disorders

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SLEEP DISORDERS IN ADULTS

Sleep disorders are prevalent in American society. The National Commission on Sleep Disorders Research estimates that almost 20% of adults suffer from chronic sleep disorders and that an additional 10% suffer from intermittent sleep disorders. Sleep disorders have been linked to over 100,000 automobile accidents yearly with nearly 1500 fatalities and 75,000 injuries annually. They may also be responsible for up to 30% of commercial truck driving accidents. It has been estimated that chronic sleep deprivation costs $15 billion annually in direct medical expenses and an estimated $70 billion in lost productivity.

Although there are many disorders of sleep, this chapter deals specifically with sleep-disordered breathing because it is referable to the otolaryngologist.

CLASSIFICATION OF SLEEP & SLEEP DISORDERS

Sleep

Sleep is a reversible physiologic and behavioral state that manifests as decreased awareness and reaction to external stimuli. Normal sleep architecture comprises two distinct phases: **NREM (non-rapid eye movement) sleep** which comprises 75–80% of sleep and occurs in four stages (Stages I–IV), whereas **REM (rapid eye movement) sleep** which comprises 20–25% of sleep and occurs in two stages. In a normal adult, these two phases of sleep occur in semi-regular cycles, which last approximately 90–120 minutes and occur three to four times per night.

A. NREM Sleep

In the normal adult male, **Stage I (N1) sleep**, which is considered the transition to sleep, occupies 2–5% of sleep and is characterized by an increase in theta waves and a decrease in alpha waves on an electroencephalogram (EEG). Stage I sleep is also marked by a decrease in awareness and in muscle tone. **Stage II (N2) sleep** occupies 45–55% of sleep and is characterized by K-complexes and spindles on EEG as well as decreases in muscle tone and awareness. Stage II sleep is considered by most authorities to be the "true" onset of sleep. **Stages III and IV (N3) sleep** comprise deep sleep, and it occurs predominantly in the first third of the night. The hallmark of deep sleep is the abundance of delta waves on EEG. Stage III sleep occupies 3–8% of sleep, and Stage IV sleep occupies 10–15% of sleep. Stages III and IV are widely considered the most restful stages of sleep. With increasing age, deep sleep progressively occupies less and less of total sleep time.

B. REM Sleep

The remaining portion of sleep is composed of REM sleep, which is divided into tonic and phasic stages. During the **tonic stage**, the EEG becomes asynchronous and muscles lose tone. The **phasic stage** of REM sleep is characterized by rapid eye movements as well as erratic cardiac and respiratory patterns.

Sleep Disorders

Derangements in sleep are categorized by the American Sleep Disorders Association in the International Classification of Sleep Disorders (ICSD), which arranged sleep disorders into four categories: dyssomnias, parasomnias, sleep disorders associated with medical-psychiatric disorders, and proposed sleep disorders (Table 41–1).

The term **apnea** refers to a period of at least 10 seconds during which air flow is absent by nose or mouth. Apnea may be obstructive or central in origin. A **hypopnea** is a decrease in airflow to 10–70% of baseline for more than 10 seconds, associated with arousals or desaturation by at least 3%. The apnea hypopnea index (AHI) is the number of apneas and hypopneas per hour of sleep time and is based on a minimum of 2 hours of sleep. Many have debated the significance of this index because it does not reflect the absolute number of apneas and/or hypopneas, the duration of such events, or the

Table 41–1. Classification of Sleep Disorders.

Category	Subtype	Examples
Dyssomnia	Intrinsic Extrinsic Circadian rhythm disorder	Insomnia, narcolepsy, OSA Poor sleep hygiene Advanced or delayed sleep phase disorder
Parasomnia	Disorder of arousal Sleep-wake transition disorder REM-associated Other	Sleep walking, sleep terrors Sleep talking, nocturnal leg cramps Nightmares Bruxism, infant sleep apnea
Medical-psychiatric disorders	Mental disorders Neurologic disorders Other	Psychosis, anxiety disorders Dementia, fatal familial insomnia COPD, sleep-related GERD
Proposed		Sleep hyperhidrosis, sleep-related laryngospasm

COPD, chronic obstructive pulmonary disease; GERD, gastroesophageal reflux disease; REM, rapid eye movement.

distribution of such events during sleep. Some authors use the respiratory disturbance index (RDI), which is the AHI + arousal index, to help correlate with patient symptomatology.

Obstructive sleep apnea (OSA) is present when the AHI is ≥5 events/h. It is further classified as mild (5–15 events/h), moderate (15–30 events/h), and severe (>30 events/h). The **obstructive sleep apnea syndrome** (OSAS) is diagnosed when the AHI is >15 *and* the patient has nighttime and daytime symptoms.

The **obesity hypoventilation syndrome** is the most clinically severe form of sleep-disordered breathing and is characterized by chronic alveolar hypoventilation, obesity, daytime hypercapnia ($PaCO_2$ > 45 mm Hg). It frequently becomes manifest with pulmonary hypertension and right heart failure.

American Sleep Disorders Association. *The International Classification of Sleep Disorders Diagnosis & Coding Manual.* American Academy of Sleep Medicine, 2001. (Lists and explains the various sleep disorders.)

National Commission on Sleep Disorders Research. *Wake up America: A National Sleep Alert.* Government Printing Office, 1993. (Offers facts and findings regarding sleep deprivation and its effects on citizens.)

SLEEP APNEA

ESSENTIALS OF DIAGNOSIS

- History of habitual snoring, excessive daytime sleepiness, or witnessed apneas.
- Neck size > 17 inches in males or > 15 inches in females and/or body mass index (BMI) > 27 kg/m^2.
- Definitive evidence of OSA by polysomnography.

General Considerations

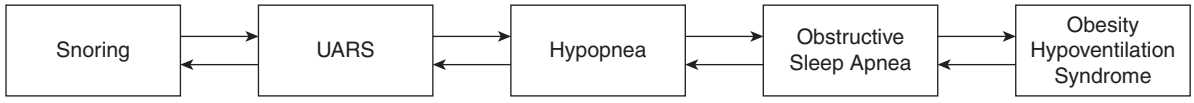
OSA is a disorder characterized by loud, habitual snoring and the repetitive obstruction of the upper airway during sleep, resulting in prolonged intervals of hypoxia and fragmented sleep. As a result, patients with OSA suffer from excessive daytime sleepiness, enuresis, poor work performance, and erectile dysfunction. The long-term sequelae are severe and can include accidents, hypertension, ischemic heart disease, cardiac arrhythmias, and stroke.

Large cohort studies have demonstrated that OSA is common: almost 25% of adult men 20–60 years old and 9% of adult women 20–60 years have an AHI > 5 events/h. It was further found that 4% of adult men and 2% of adult women had OSA syndrome with an AHI > 15 and both daytime and nighttime symptoms. Despite its prevalence, it is estimated that almost 85% of people with OSA remain undiagnosed.

Pathogenesis

The pathogenesis of OSA is multifactorial, and it is widely accepted that OSA lies somewhere on a continuum of sleep-disordered breathing (Figure 41–1) that begins with snoring and ends with obesity hypoventilation syndrome. Determining what causes a person to be susceptible to the conditions on the continuum is one of the goals of treatment.

Air moving through the upper airway encounters resistance in transit to the lungs, and in the apneic person, this resistance is increased. This new resistance increases the load on the respiratory musculature, which is required to overcome upper airway resistance with higher negative inspiratory pressures. The negative inspiratory pressure narrows the upper airway in an incremental fashion until, theoretically, the airway collapses. Soft tissue compliance, redundant upper air way mucosa, and pharyngeal dilator muscle tone are all presumed to play an important role. Clinically, this



▲ **Figure 41–1.** The continuum of sleep-disordered breathing. The concept of sleep-disordered breathing is that increasing upper airway resistance (UARS) can cause progressively worsening disease that can manifest with similar as well as new signs and symptoms.

translates to progressive vibration and collapse of the upper aerodigestive soft tissue structures, causing snoring and obstruction of air flow.

The nose and nasal cavity appear to play less crucial roles in the pathogenesis of OSA. Over half of the normal resistance in the upper airway is generated at the internal nasal valve, and obstruction at this point narrows this inlet and increases upper airway resistance. Septal deviation and other causes of nasal obstruction may play a role in the pathogenesis of sleep-disordered breathing, and patients with allergic rhinitis have an increased risk for developing sleep-disordered breathing because of significant turbinate or mucosal swelling. However, these features are not believed to play significant roles in the average patient with OSA.

Prevention

A number of risk factors for OSA have been identified. Obesity is one of them. A threefold increase in the prevalence of OSA occurs with 1 standard deviation increase in BMI above normal. Results from one study demonstrate a positive correlation between AHI severity and both the BMI and the circumference of a patient's neck. Although men represented 47.2% of the study cohort, 71% of the participants with an AHI > 30 were men, indicating that men disproportionately represent those with OSA.

Although whites and blacks appear to be evenly represented as AHI severity increases, Native Americans appear to be disproportionately represented in groups with higher AHI. In addition to weight, neck circumference, sex, and race, other factors such as genetic syndromes (discussed later) and endocrine factors have also been implicated OSA. Patients with growth hormone abnormalities, specifically acromegaly, may develop OSA as a consequence of changes in craniofacial structure and upper airway collapsibility.

Clinical Findings

A. Signs and Symptoms

The most common nighttime symptoms of OSA include loud, habitual snoring, apneas, choking or gasping sounds, and nocturia or enuresis. Vibrations in upper airway soft tissues produce the loud, crescendo snoring and signify increased upper airway resistance. Apneas, which frequently terminate abruptly with gasping noises, represent complete upper airway obstruction. The negative inspiratory pressure generated during apneic events is transmurally delivered to the contracting heart and stretches the right atrium. As a consequence, atrial natriuretic peptide is released, leading to nocturia and enuresis in some patients. The repetitive arousals and frequent awakenings to micturate lead to sleep fragmentation, which may lead to daytime symptoms.

Nearly 30% of adult men and 40% of adult women with an AHI > 5 events/h report not feeling refreshed in the morning when arising. In addition, 25% of adult men and 35% of women with an AHI > 5 events/h complain of excessive daytime sleepiness, which can cause frequent napping or dozing, poor work performance, and automobile accidents.

B. Physical Exam

1. Systemic evaluation—All patients should be evaluated for hypertension since it is correlated with OSA severity. Because studies have shown a positive correlation between OSA and BMI > 27.8 kg/m^2 in men and BMI > 27.3 kg/m^2 in women as well as neck circumference—measured at the level of the cricothyroid membrane—>17 inches in men and >15 inches in women, weight and neck circumference should be recorded.

The outward appearance of thyromegaly or signs of dry skin, coarse hair, or myxedema may lead to a diagnosis of hypothyroidism, and an inattentive or unkempt patient who seems disengaged or speaks with a sad or flat affect may have undiagnosed depression. Both these conditions can cause excessive sleepiness or fatigue and should be considered before diagnosing OSA.

2. Head and neck—The patient is always examined in the Frankfurt plane—a line bisecting the inferior orbital rim and the superior rim of the external auditory meatus that is always parallel with the floor. To assess the patient for maxillary retrusion, a line dropped from the nasion to the subnasale should be perpendicular to the Frankfurt plane. To assess the patient for retrognathia, a line bisecting the vermillion border of the lower lip with the pogonion should be perpendicular to the Frankfurt plane as well. If the pogonion is retroposed more than 2 mm, retrognathia is suspected. A lateral cephalometric x-ray helps evaluate this area with precision.

3. Nose—The nose should be examined for signs of gross deformity, tipptosis, asymmetry of the nostrils, and internal valve obstruction. The examiner can perform the modified Cottle maneuver to dilate the nasal valve and assess for

improvement in breathing. The nasal cavity should be thoroughly examined for turbinate size, signs of polyps, masses, rhinitis, and purulent discharge. The septum should be examined for signs of defects or deviation. Nasopharyngoscopy permits evaluation of the posterior choanae (to discover the rare case of stenosis or atresia), the eustachian tube orifices, the velopharyngeal valve, and the adenoids, and it can provide direct observation of the velopharynx during the Müller maneuver, which some believe to be helpful in identifying the site of obstruction in OSA.

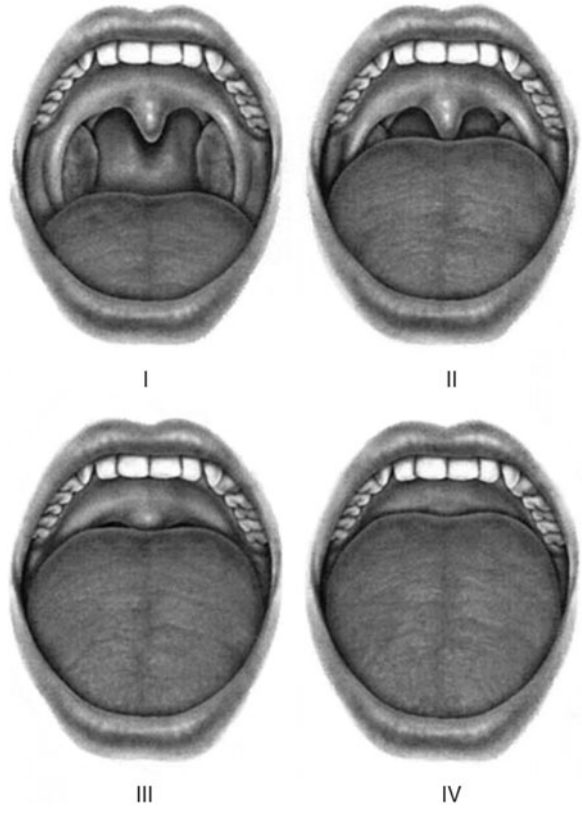
4. Oral cavity—The tongue should be examined for size and for stigmata of OSA. A normal-sized tongue rests below the occlusal plane, and a tongue that extends above this plane is graded as mildly, moderately, or severely enlarged. Tongue crenations, or ridging, if found, may indicate macroglossia. The relationship between the tongue and the soft palate should also be observed, specifically to determine whether an enlarged tongue obscures vision of the palate, whether the palate itself is low-lying or deviated, or whether the posterior pharyngeal wall is obscured by both. The morphology of the soft palate (ie, thick, webbed, posteriorly located, low, and so on) should also be noted. The uvula is also described as normal, long (>1 cm), thick (>1 cm), or embedded in the soft palate. The tonsils should be described as being surgically absent (0) or by their size (1, 2, 3, or 4+, respectively, indicating a 0–25%, 25–50%, 50–75%, or > 75% lateral narrowing of the oropharynx). The tonsils should also be examined for any asymmetry or any other pathology. A narrow oropharynx, independent of tonsil size, should also be noted. A system of examination and staging of the oral cavity examination has been described termed the Obstructive Sleep Apnea/Hypopnea Syndrome Score (OSAHS Score), which is described below.

5. Hypopharynx—The hypopharynx can be evaluated by means of flexible nasopharyngoscopy to assess the base of tongue and the lingual tonsils and to look for masses obstructing the supraglottic, glottic, or subglottic larynx. Obliteration of the vallecula, retrodisplacement of the epiglottis obscuring the larynx, lateral pharyngeal narrowing, and general obstruction by the tongue base may indicate hypopharyngeal collapse during sleep. Any abnormalities in appearance, symmetry, and movement of the vocal cords should be noted. Many perform the Müller maneuver to assess collapse of the retropalatal and retroglossal areas during inspiration against a closed nose and mouth scored as a percentage of closure during the maneuver. Opinions on the clinical usefulness of this maneuver are mixed.

6. Obstructive Sleep Apnea/Hypopnea Syndrome Score (OSAHS Score)—Although description of the structures as noted above appears useful in determining the site of obstruction in OSA, a more formalized staging system has been created (Table 41–2). This system includes three sections including (a) the standard description of tonsils from 0-4, (b) the oral cavity/tongue (Figure 41–2), and (c) BMI. It

Table 41–2. The Friedman Staging System.

Stage	Friedman Palate Position	Tonsil Size	Body Mass Index
I	1 2	3, 4 3, 4	<40 <40
II	1, 2 3, 4	1, 2 3, 4	<40 <40
III	3 4	0, 1, 2 0, 1, 2	<40 <40
IV	1, 2, 3, 4	0, 1, 2, 3, 4	>40



▲ **Figure 41–2.** Friedman palate position. The Friedman palate position is based on visualization of structures in the mouth with the mouth open widely without protrusion of the tongue. Grade I allows the observer to visualize the entire uvula and tonsils. Grade II allows visualization of the uvula but not the tonsils. Grade III allows visualization of the soft palate but not the uvula. Grade IV allows visualization of the hard palate only.

has been shown to be useful to predict the probability of success in uvulopalatopharyngoplasty for sleep apnea and can serve as a single score to describe patients with OSA.

C. Imaging Studies

A host of imaging modalities can play a role in identifying the patient with OSA; however, most of them have limited clinical application, and some remain investigational.

1. Cephalometry and X-rays—Lateral cephalometric studies and plain film x-rays are useful in evaluating the patient with observable craniofacial abnormalities such as midface hypoplasia or mandibular retrusion. These studies are required for precise evaluation of maxillary retrusion, retrognathia, and micrognathia, and they help in planning Phase I and Phase II surgical procedures (discussed later in this chapter). The studies are inexpensive to perform, and the equipment is widely available. However, as a diagnostic tool for OSA in general, they suffer from several limitations including exposure to radiation, absence of supine imaging, and lack of soft tissue resolution.

2. Computed tomography (CT) scanning and magnetic resonance imaging (MRI)—CT scanning and MRI are also commonly available and have facilitated an increased understanding in the differences between the normal and apneic airways (Figure 41–3). Images obtained with both modalities can be used to recreate three-dimensional models of the upper airway and have been used to evaluate apneic airway dynamics during respiration. Both modalities, however, are significantly more expensive than the previously mentioned modalities and have a number of contraindications. Furthermore, CT and MRI have yet to be proved effective in identifying patients with OSA or reliably characterizing OSA severity.

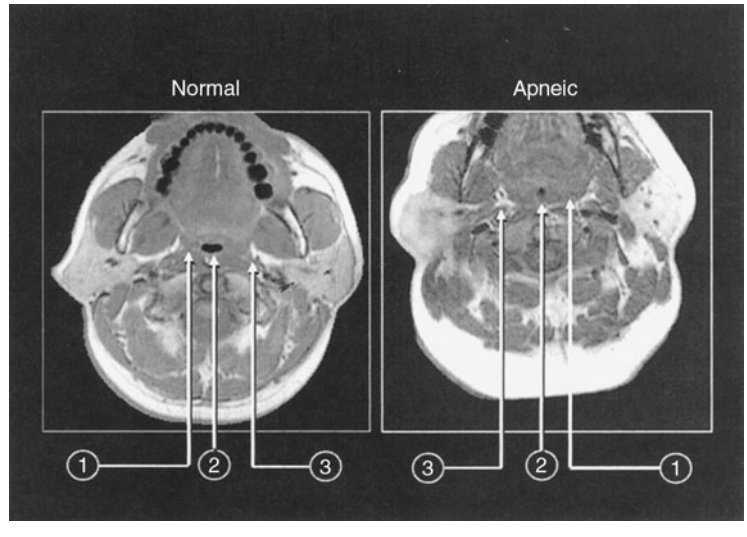
D. Special Tests

1. Subjective tests—Subjective tests permit the patient to evaluate his or her drive to sleep. These include the **Epworth Sleepiness Scale (ESS)**, the **Functional Outcomes of Sleep Questionnaire (FOSQ),** and the **Stanford Sleepiness Scale (SSS).** For the ESS, the examinee is asked to rate the likelihood of falling asleep during particular events; in the FOSQ, the examinee is asked to assess the impact of sleepiness on the ability to conduct daily activities; and in the SSS, the examinee is asked to rate how sleepy he or she is at the current moment. The ESS offers the advantage of having correlated with multiple sleep latency testing and with AHI.

2. Multiple sleep latency testing—The multiple sleep latency test is an objective test that evaluates sleep drive and consists of a series of naps occurring at 2-hour intervals repeated every 2 hours. Patients are encouraged to sleep while their physiologic parameters are monitored. Normal sleep latency is 10–20 minutes; however, patients with excessive daytime sleepiness often have sleep latencies of 5 minutes or less.

3. Polysomnography—The definitive study to evaluate OSA is overnight polysomnography (PSG) because it permits direct monitoring of the patient's brain activity, respiratory patterns, and muscle activity during sleep. The PSG records the duration of sleep and events (snoring, hypopneas, apneas, thoracoabdominal excursion, limb movement, and so on) occurring during sleep. Its clinical utility lies in its ability to diagnose and characterize the severity of OSA. In addition, PSG can differentiate among OSA, central sleep apnea, and some other causes of excessive sleepiness.

4. Drug-induced sleep endoscopy—This examination consists of examination of the patient during drug-induced sleep in a well-controlled setting, typically with propofol



▲ **Figure 41–3.** Comparative axial anatomy. Axial magnetic resonance images acquired at the retropalatal levels in a normal patient (left) and an apneic patient (right) demonstrating (1) increased lateral pharyngeal wall dimensions, (2) decreased retropalatal airway area, and (3) increased lateral pharyngeal fat pads in a representative apneic patient. (Image contributed by Richard J. Schwab, MD, University of Pennsylvania Health System, Philadelphia, PA.)

administered as the sedating agent. This examination provides the closest representation yet of dynamic obstruction of a patient during sleep. It has proven itself to be a safe, feasible, and valid assessment of the upper airway, though correlation with specific surgical interventions on identified sites has not been made.

Complications

Nearly 20% of all drivers report falling asleep behind the wheel at least once in their lives, and patients with OSA have an increased risk. Patients with an AHI > 40 events/h are more than three times more likely to crash an automobile than are controls, and patients with excessive daytime sleepiness can be as incapacitated as intoxicated (blood alcohol level > 0.1%) volunteers on reaction-timed sequences. Predicting who has an increased risk, however, is difficult. Legal standards and obligations of the physician vary from state to state with regard to the issue of reporting patients at risk or with a history of sleep-related accidents.

Establishing a relationship between OSA and hypertension has been confounded by multiple clinical variables; however, one study has demonstrated that men and women with an AHI > 30 events/h have a 1.5 relative risk and a 1.17 relative risk, respectively, for developing hypertension. When studies control for hypertension, patients with OSA have an increased risk of cardiovascular mortality secondary to myocardial ischemia: patients studied overnight with Holter monitors demonstrate myocardial ischemia that is decreased with continuous positive airway pressure (CPAP) therapy. There is strong evidence for the increased incidence of fatal and nonfatal cardiovascular outcomes in patients with severe OSA who have not been treated when compared with normal volunteers in recent studies. An increased prevalence of sleep-disordered breathing has been found in patients with first-time stroke as early as AHI > 5 events/h, and patients with AHI > 11 events/h have 1.5 times the odds-adjusted risk for stroke.

Treatment

A. Nonsurgical Measures

1. CPAP therapy—The most widely deployed treatment for OSA is CPAP, which is the first recommended therapy for patients with OSA. CPAP decreases snoring and apneas and improves symptoms of excessive daytime sleepiness. Moreover, a 3-year study demonstrated that patients with excessive daytime sleepiness who were treated with CPAP significantly decreased their accident rates to levels comparable to normal controls. The American College of Chest Physicians recommends initiating CPAP therapy for all patients with an AHI > 30 events/h and for all patients with an AHI of 5–30 events/h who are symptomatic. Although CPAP is 90–95% effective in eliminating OSA, its continued efficacy relies on patient compliance, with average usage being 4–5 hours/night and 85% compliance at 6 months under the absolute best of circumstances. Despite immediate objective and subjective improvements, no definitive studies establish the duration of regular use necessary to reduce or eliminate long-term sequelae. Patients often complain of claustrophobia, headache, rhinitis, facial or nasal irritation, aerophagia, and inconvenience or social embarrassment while using CPAP, all of which limit its use.

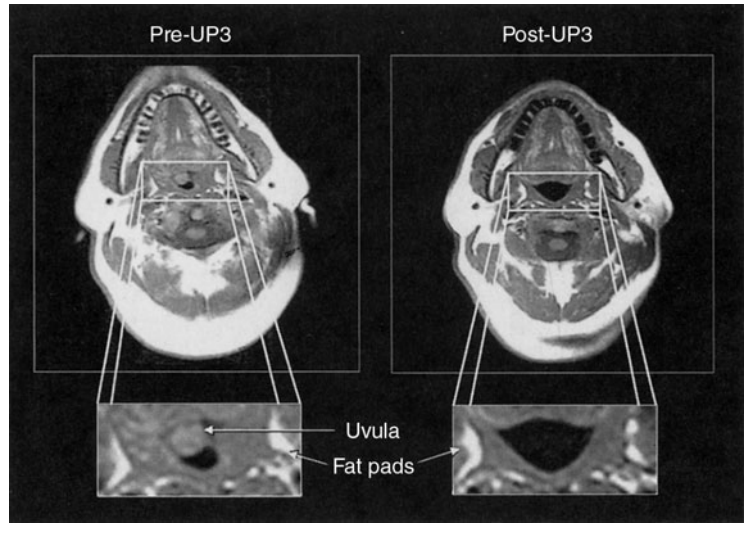
2. Oral appliances—Oral appliances can be used in patients with primary snoring, those with mild-to-moderate OSA, and those refusing CPAP. The more thoroughly tested of the oral appliances are the **titratable mandibular repositioning devices**. In mild-to-moderate OSA, these devices have been shown to decrease AHI to levels comparable to CPAP therapy, to improve symptoms of excessive daytime sleepiness, and to decrease AHI in some patients unsuccessfully treated with uvulopalatopharyngoplasty. Nightly use of oral appliances is typically tolerated better than CPAP. Patients wearing oral appliances may complain of jaw or temporomandibular joint pain (both of which seem to be lessened by the titratable oral appliances), head aches, and excessive salivation. The long-term effects and outcomes of patients with OSA who use oral appliances are incompletely studied.

3. Weight loss—Overweight patients should be encouraged to lose weight because moderate reductions in weight have been demonstrated to increase upper airway size and improve upper airway function. Coordination of weight loss with a dietitian may improve outcome and in many cases is necessary (eg, in diabetics and the morbidly obese). Since many patients with OSA are morbidly obese, bariatric surgery has been evaluated as a treatment for weight loss in this population, but it is not recommended for routine weight loss in patients with OSA.

4. Lifestyle modifications—Patients should also be informed to avoid sedatives, alcohol, nicotine, and caffeine in the evening because these substances can influence upper airway muscle tone and central mechanisms.

5. Positional therapy—Positional therapy has been suggested as an adjunctive therapy for patients who have primarily supine-dependent obstructive events, which are easily identified on PSG. Patients are instructed to sleep in the lateral decubitus position rather than the supine position, and a host of techniques have been used to prevent reversion to the supine, such as sewing tennis balls to the backs of shirts and rearranging pillows.

6. Other treatment—External nasal dilators and ephedra- or ephedrine-based products are also popular treatments for snoring and OSA. Although some have been demonstrated to reduce snoring in patients with chronic rhinitis or nasal obstruction, most of these products have failed to show any consistent benefit in the treatment of primary snoring or OSA. Ephedra-based products are not evaluated by the FDA and are therefore discouraged as treatment.



▲ **Figure 41–4.** Pre- and post-UPPP axial anatomy. Axial magnetic resonance images acquired at the same retropalatal level in a patient before and after UPPP. UPPP, uvulopalatopharyngoplasty. (Image contributed by Schwab RJ et al. University of Pennsylvania Health System, Philadelphia, PA.)

B. Surgical Measures

1. Preoperative considerations—Surgical treatment of patients with OSA is complex and must be individualized. Surgical treatment is targeted as sites identified in physical examination and the other described examinations to maximize effectiveness and minimize surgical morbidity. A staged approach is typically used that targets the likeliest sites of obstruction with planned retesting and reexamination of patients 4–6 months after surgery to determine the effect of surgical treatment on the OSA patients.

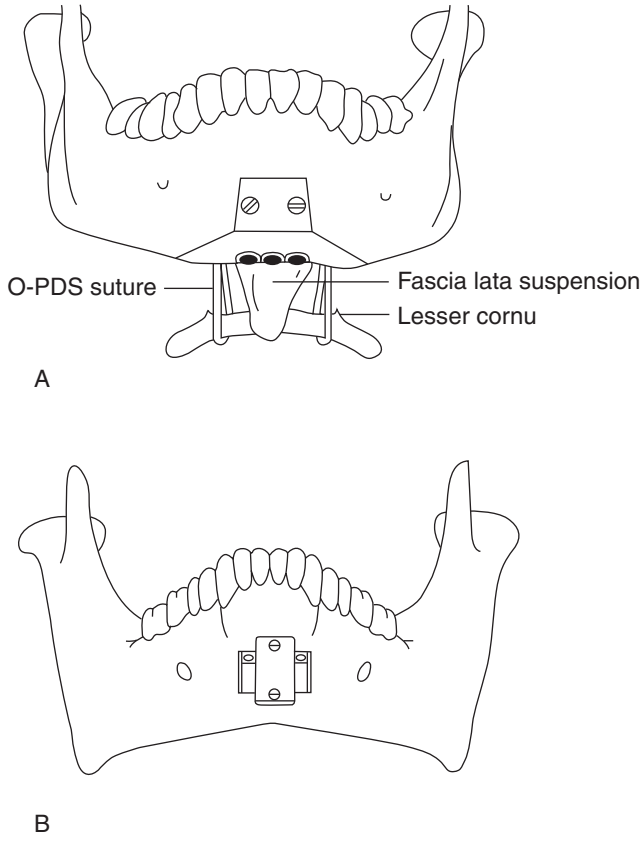
One of the most widely accepted protocols for approaching sleep apnea surgery is based on a series of 306 consecutive surgically treated patients with OSA, by Nelson Powell and Robert Riley. In the Powell–Riley protocol, selecting patients for surgery begins with a thorough physical examination, upper airway endoscopy with the Müller maneuver, cephalometric studies, and overnight PSG. This will be described below as Phase I and Phase II surgery.

2. Phase I surgery—Patient treatment is initiated with Phase I surgery: (1) patients with **Type I** upper airway anatomy (ie, oropharyngeal obstruction) undergo uvulopalatopharyngoplasty (UPPP); (2) patients with **Type II** upper airway anatomy (ie, oropharyngeal and hypopharyngeal obstruction) undergo UPPP and genioglossus advancement with or without hyoid myotomy; and (3) patients with **Type III** upper airway anatomy (hypopharyngeal obstruction) undergo genioglossus advancement without palatal surgery. Of note, patients with an AHI > 30 events/h have an increased risk for perioperative airway complications and require overnight observation; they also have a decreased threshold for intubation or a temporary tracheotomy.

All patients undergoing Phase I surgery require general anesthesia and must be informed of potential risks related to anesthesia, postoperative pain, infection, bleeding, and short- and long-term velopharyngeal insufficiency in UPPP patients.

A. Uvulopalatopharyngoplasty—The UPPP procedure entails conservative excision of the inferior margin of the soft palate, including the uvula, as well as excision of redundant mucosa with suture fixation of the pharynx and palate. If the tonsils are present, they are excised. Meta-analysis demonstrates that UPPP significantly reduces AHI, apnea indices, and oxygen desaturations as well as increases REM sleep in postoperative patients. UPPP is effective in eliminating snoring in 90% of selected patients. When "success" is defined as a 50% reduction in AHI, UPPP is 53% successful and has been demonstrated to increase upper airway cross-sectional area and airway volume at the retropalatal level (Figure 41–4). When patients have Type II or Type III upper airway anatomy, as age, BMI, and AHI increase, UPPP becomes less effective.

B. Genioglossus advancement—Performing genioglossus advancement attempts to correct the retroglossal obstruction that occurs in patients with Type II and Type III upper airway anatomy by placing the geniohyoid muscle and genioglossus muscle under increased tension via a mandibular osteotomy. Genioglossal advancement can be achieved by performing a limited osteotomy (Figure 41–5A) or by creating a rectangular window and *sliding* the geniohyoid complex anteriorly (Figure 41–5B). The latter procedure may by performed using various sagittal or circular osteotomy devices with custom or prefabricated plating systems. Suspension of the hyoid bone from the mandible has been largely supplanted by approximating the hyoid bone and the thyroid cartilage (Figure 41–6). (Genioglossus advancement, therefore, increases retroglossal airspace by virtue of drawing the genial tubercle and genioglossus complex anteriorly. Typically, patients with an AHI > 30 events/h require



▲ **Figure 41–5.** Genioglossal advancement. **(A)** Mortise genioplasty. **(B)** Block genioplasty.

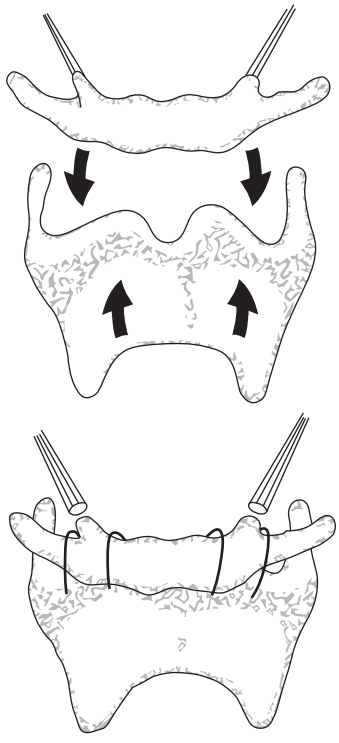
genioglossus advancement for treatment because of base of tongue obstruction. Phase I surgery in patients with Type II upper airway anatomy is approximately 60–65% successful (defined as a 50% reduction in AHI or a postoperative AHI equivalent to preoperative AHI while using CPAP). Phase I surgery in patients with Type III upper airway anatomy who undergo genioglossus advancement alone is 66–85% successful. In these two groups (UPPP with genioglossus advancement and genioglossus advancement alone), the nocturnal oxygen desaturation is significantly improved.

3. Phase II surgery—Patients who do not improve (as evidenced by PSG) by 6 months after Phase I surgery are encouraged to undergo Phase II surgery.

A. Maxillary-mandibular osteotomy—Maxillary-mandibular osteotomy, or advancement of both the maxilla and mandible, is performed in Phase II surgery. Phase II surgery (following Phase I surgery) is 97–100% successful in reducing AHI and in improving blood-oxygen desaturation, as well as increasing Stages III, IV, and REM sleep. For patients adhering to the Phase I and II protocol, the overall success rate is approximately 95% (observed over a 1- to 4-year follow-up period). However, the overall success rate, which includes those dropping out of the protocol, is 77% (observed over an average of 9 months of follow-up).

4. Laser-assisted uvuloplasty (LAUP)—LAUP is similar to UPPP in that the inferior margin of the soft palate and the uvula are excised. However, LAUP differs from UPPP in that it uses a laser (CO_2, argon, KTP) rather than a knife, is performed with topical and local anesthesia, is not designed to address the tonsils or pharyngeal narrowing, and is performed in 1–3 office sessions. If there is evidence of obstructing tonsils or redundant pharyngeal mucosa, LAUP should not be offered. In addition, LAUP is not typically used in patients with an AHI > 30 events/h. Results of LAUP in selected populations are variable, and the procedure is approximately 50% effective for OSA and 80–90% effective for snoring with fewer complications and less morbidity for patients than UPPP. Side effects of LAUP include moderate pain, bleeding, risk of velopharyngeal insufficiency, and infection.

5. Radiofrequency ablation—Radiofrequency ablation of the palate is also a relatively new procedure that can be used to treat patients with primary snoring or an AHI < 15 events/h who have predominantly palatal obstruction. Radiofrequency ablation delivers approximately 500 J to



▲ **Figure 41–6.** Hyoid myotomy. Modified myotomy in which the hyoid bone is advanced anteriorly and inferiorly and approximated to the thyroid cartilage.

target tissues causing coagulative necrosis, scarring, and eventually tissue contraction. Initial reports suggest that radiofrequency ablation is approximately 75% effective in eliminating snoring, and despite improvement in ESS scores, it does not change AHI. Radiofrequency ablation of the tongue and tongue base may also be used. Risks of radiofrequency ablation include pain, bleeding, velopharyngeal insufficiency, palatal fistula, and infection.

6. Tongue base surgery—Treatment of tongue base obstruction is a challenging area of surgery for sleep apnea. Procedures initially used for tongue reduction included use of tracheotomy and demonstrated significant morbidity and pain. Because of this, they never gained widespread acceptance by physicians or patients. More recently, less invasive procedures to treat tongue base obstruction have been developed that have reduced morbidity significantly and have gained some acceptance in the algorithm for treatment.

A. Tongue reduction—Tongue base reduction has been performed utilizing cold ablation therapy, thus reducing tissue necrosis, edema, and pain. Midline laser glossectomy as well as submucosal open glossectomy have also been used with decreased morbidity. Studies evaluating the efficacy of transoral robotic tongue base resection are presently being performed.

B. Suspension procedures—Procedures that suspend the hyoid bone or tongue base though suture stabilization have been used to treat hypopharyngeal obstruction. Advancement and suture fixation of the hyoid bone to the thyroid cartilage appears to open the hypopharyngeal airway, though effectiveness has been difficult to demonstrate in the published literature. Similarly, suture suspension of the tongue base and hyoid bone has been used with some effectiveness, though technical challenges remain to provide a consistent and reliable method that will gain acceptance among practitioners and patients.

7. Tracheostomy—The final and gold standard surgical treatment for OSA is tracheostomy, which bypasses the upper airway obstruction completely. Tracheostomy is indicated in patients with corpulmonale, obesity hypoventilation syndrome, nighttime arrhythmias or disabling excessive daytime sleepiness who refuse CPAP and surgical intervention or in those who have failed previous surgical interventions. Tracheostomy is highly successful in eliminating excessive daytime sleepiness, improving AHI to normal levels, and normalizing sleep architecture. However, it is not 100% effective in eliminating symptoms and sequelae in all patients, and it is associated with complications such as dysphagia, plugging, tracheal stenosis, and granuloma formation. Decannulation and reversal of tracheostomy usually are uncomplicated and result in the return of symptoms.

8. Palatal implants—The placement of soft palate implants has been approved for use in snoring and in mild-to-moderate OSA. When inclusion criteria are met for this procedure, approximately 63.9% of patients experience a reduction in AHI to < 10 events/h, though treatment effect is small. Complications such as implant extrusion and worsening of symptoms have been reported. Practitioners typically utilize this method for simple snoring, where proper patient selection can achieve acceptable results.

9. Postoperative considerations—All patients should be reexamined by repeat PSG 4–6 months after surgery. Continued postoperative follow-up permits the evaluation of subjective and objective improvement as well as the opportunity to address additional sites of obstruction as necessary.

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SLEEP DISORDERS IN CHILDREN

Sleep disorders in children are common, and the prevalence of these disorders varies with the developmental age of the child. Parents of infants and toddlers bring to routine health care visits disturbance of sleep as their most frequent complaint. Thirty to fifty percent of these parents request specialized care to address their child's perceived sleep problems. Sleep disorders also affect adolescents: More than 50–75% of adolescents report that they desire more sleep than they are currently receiving. Although the emergence of the various sleep disorders occurs at different stages of ontogeny, sleep disorders in children are classified with adult sleep disorders according to the American Sleep Disorders Association International Classification of Sleep Disorders.

CLASSIFICATION OF SLEEP & SLEEP DISORDERS

Sleep

In children, recognizable sleep stages do not arise until they are approximately 6 months of age. Before 6 months, PSG can be used reliably to distinguish only NREM sleep from REM sleep. In the neonate, NREM sleep occupies approximately 50% of total sleep time and NREM-REM cycles occur fairly regularly throughout the night—approximately every 50 minutes. Infants generally spend half of their day asleep and frequently sleep uninterrupted for 3–4 hours punctuated by awakenings for feeding; this cycle tends to decrease in frequency as infants progress in age. By the second year of life, children begin to develop separation anxieties that may inhibit sleep initiation.

The development of preschool-aged children often presents a challenge to parents because this age group desires to stay up later than parents allow. Encouraging preschool-aged children to sleep can be difficult and may become manifest with pleas for continued parental attention (eg, rereading a bedtime story). Concrete dreaming is observed in preschool-aged children, and the appearance of dyssomnias (eg, hypersomnolence or OSA) is also frequently observed in this group.

Sleep Disorders

Parasomnias appear largely in school-aged children. The most common parasomnias seem to be nightmares, night terrors, somnambulism, and enuresis, all of which occur during Stage IV sleep. School-aged children may also cling to preschool-aged behaviors or habits that interfere with sleep, such as wanting to stay up late, sleeping with parents, or sleeping with the light on or the door open.

The development of normal adult sleep architecture occurs throughout the adolescent period. Adolescents generally require approximately 9 hours of sleep per night, which is more than the 7–8 hours of sleep required by adults. Sleep deficit in adolescents often becomes manifest with excessive sleepiness and poor school performance that can be confused with other psychiatric, medical, or sleep disorders when it is merely due to insufficient sleep time. Disorders such as narcolepsy and advanced/delayed sleep phase syndromes also begin to appear in this age group.

As in adults, the otolaryngologist deals primarily with the diagnosis and treatment of sleep disorders related to sleep-disordered breathing, mainly OSA. As previously stated this dyssomnia usually emerges in preschool-aged children (but can appear at any age) and is often quite different in children than in their adult counterparts.

SLEEP APNEA

ESSENTIALS OF DIAGNOSIS

- History of snoring, witnessed apneas, restless sleep, or enuresis
- Evidence of obstructive tonsils and/or adenoids on physical exam
- Evidence of OSA from overnight PSG.

General Considerations

A number of epidemiologic studies have determined that OSA in children is common. As in adults, OSA in children is characterized by snoring and transient obstruction of the upper airway during sleep that results in sustained periods of hypoxia and a host of nighttime and daytime symptoms. Nighttime symptoms in children are comparable to those in adults; however, the daytime symptoms and sequelae are often not comparable, with children developing agitation or attention deficits (as opposed to excessive sleepiness) and unique long-term health complications such as failure to thrive and poor growth in addition to the usual cardiopulmonary problems. Studies show a significant percentage of children diagnosed with Attention Deficit Disorder suffer from concomitant OSA. Adenotonsillectomy has been shown to decrease inattention and impulsivity in normal children postoperatively. The relationship between these diseases is a subject of continued study.

Studies have shown that primary snoring, which should be distinguished from OSA, is found in approximately 3–12% of preschool-aged children, and OSA occurs in approximately 2–3% of children aged 6 months to 18 years, with peaks in prevalence in preschool-aged children. In this population of children, a number of risk factors are highly predictive of sleep-disordered breathing.

Pathogenesis

The most common cause of upper airway obstruction in children is adenotonsillar hypertrophy. Specifically, the pathology underlying adenotonsillar hypertrophy and upper airway obstruction is related to the disproportionate growth in adenotonsillar tissue and in the pharynx itself during development. Many, but not all, studies have demonstrated adenotonsillar hypertrophy as the primary etiology in childhood sleep-disordered breathing; others not finding a relationship between adenotonsillar hypertrophy and upper airway obstruction implicate muscle tone, upper airway narrowing, as well as adenotonsillar hypertrophy as the critical factors. Tonsillar hypertrophy has been well described as a cause of upper airway obstruction, and studies have demonstrated that children with OSA are more likely to have 3+ and 4+ tonsils (75% of children with OSA studied) than children without OSA. Nevertheless, studies also demonstrate that adenotonsillectomy does not eliminate OSA in all children.

Other less common causes of OSA in children are attributed to genetic disorders that cause nasopharyngeal or oropharyngeal obstruction early in life, such as Down syndrome, Crouzon syndrome, Apert syndrome, and bilateral choanal stenosis or atresia. Syndromes with micrognathia or retrognathia, such as Pierre Robin sequence, mandibulofacial dystosia, Weaver syndrome, cerebrocostomandibular syndrome, and Treacher-Collins syndrome, present with glossoptosis of the geniohyoid and genioglossus muscles. Glossoptosis results in hypopharyngeal obstruction due to the altered relation ships between the mandible and the hyoid and appears to be worsened by cleft anomalies. Defects such as bifid epiglottis, laryngomalacia, webs and strictures, and cleft larynx also contribute to OSA.

Prevention

As in adults, obesity in children is associated with sleep-disordered breathing. In a study of nearly 400 children ages 2–18, obese children were 4–5 times more likely to have sleep-disordered breathing than nonobese children. Although obesity in children has been strongly associated with sleep-disordered breathing, it is important to remember that not all children with OSA are obese. Also, although blacks represented 27% of those studied, they represented 56% of children with an AHI > 10 events/h, indicating a disproportionate representation of children with sleep-disordered breathing. Black children are 3–4 times more likely to have sleep-disordered breathing than are white children. Factors such as age, gender, and exposure to cigarette smoke were not found to significantly correlate with presence of sleep-disordered breathing.

An increased prevalence of sleep-disordered breathing was also observed in children with chronic cough, occasional wheeze, persistent wheeze, asthma, and sinus-related problems. Chronic cough was the strongest predictor of sleep-disordered breathing (with an odds ratio of 8.83), and although both were significantly correlated with sleep-disordered breathing, *persistent* wheeze was found to be a stronger predictor of sleep-disordered breathing than *occasional* wheeze (odds ratio of 7.45 versus 3.29, respectively). Sinus-related disease was related to sleep-disordered breathing with a 5.10 odds ratio, and asthma was related to sleep-disordered breathing with an odds ratio of 3.83.

Clinical Findings

A. Signs and Symptoms

As in adults, children exhibit the stereotypical nighttime symptoms such as snoring (quiet or loud), choking or gasping, restless sleep, witnessed apneas, and enuresis. It is important to remember that the quality or volume of snoring does not correlate well with the severity of OSA in children. Children exhibit a number of nonspecific daytime symptoms, such as chronic mouth breathing, hyponasality, dysphagia, and halitosis, as well as other symptoms not typically expressed by adults, such as aggression, hyperactivity, and learning disabilities. The physician can obtain subjective information from parents by having them complete the Obstructive Sleep Disorders-6 (OSD-6) survey, which has been validated and addresses the patient's physical suffering, sleep disturbance, speech or swallowing disorder, emotional distress, activity limitation, and the caregiver's concerns. Corroboration with schoolteachers can be helpful in attesting to the level of participation in school, learning progress, and school performance at the level of peers. Daytime sleepiness in children is not a typical manifestation in contrast to the adult population.

B. Physical Exam

All children should be evaluated for appropriate height and weight gain according to the American Association of Pediatricians (AAP) recommendations because children with OSA are four to five times more likely to be over weight than children without OSA. Treatment to control weight may be necessary as part of the overall treatment plan.

A thorough head and neck exam, including cranial nerve examination, begins with identifying stigmata associated with genetic syndromes. Although all portions of the upper airway need to be evaluated, significant attention should be directed to the nasopharynx and the oropharynx. Inspection of the nasal cavity for masses or rhinitis, the posterior nasal cavity for choanal stenosis or atresia, and the nasopharynx for the adenoids with nasopharyngoscopy is performed when possible.

Thorough inspection of the oral cavity for macroglossia and the oropharynx for obstructing tonsils can be performed by direct observation. As in adults, tonsils are described as 1, 2, 3, or 4+ in size, respectively, indicating a 0–25%, 25–50%, 50–75%, or >75% lateral narrowing of the oropharynx. Palpation of the hard and soft palate is essential to diagnose submucous clefts. The hypopharynx and larynx can be inspected with fiberoptic endoscopy and assessed for abnormalities as well.

C. Special Tests

1. Polysomnography—Although overnight PSG has been standardized and is used frequently in diagnosing OSA in adults, it is neither standardized nor practical at this moment for the routine diagnosing all children with OSA. However, the American Thoracic Society (ATS) recommends that PSG be performed in children according to specific criteria, some of which are summarized in Table 41–3. The ATS consensus statement on PSG reporting in children defines an obstructive apnea as the cessation of airflow during thoracoabdominal excursion; however, it does not establish a maximally acceptable time interval as in adults. Some authors have stated that a normal apnea index in children is 0.1 ± 0.5 events/h; thus, it would seem that *any* duration of airflow cessation is abnormal in children. The ATS consensus statement defines hypopnea as a 50% reduction in airflow; however, others have defined hypopneas as 50% reduction in respiratory effort, 50% decreases in airflow with decreases in blood oxygen sat uration, or combinations of the above. Since determining the end points of hypopneas can be difficult, end-tidal CO_2 > 45 mm Hg for more than 60% of sleep time has also been used to score a hypopnea. By strict criteria, children with an AHI > 5 events/h are considered to have OSA, although, as noted above, some believe that any apnea at all is abnormal. Routine use of PSG in the diagnosis of OSA in children is not recommended. Furthermore, children with upper airway resistance and significant sleep fragmentation often have normal sleep study results.

Table 41–3. Sample American Thoracic Society Indications for Performing Polysomnography in Children.

1. Differentiating primary snoring from OSA-related snoring.
2. Evaluate EDS, corpulmonale, failure to thrive, or polycythemia in the snoring child.
3. Uncertainty about whether results of exam are sufficient to warrant surgery.
4. Children with laryngomalacia with worsening symptoms during sleep.
5. Obesity in children associated with unexplained hypercapnia, snoring, or disturbed sleep.
6. Child with sickle cell anemia and symptoms of OSA or sleep-related vasoocclusive crises.
7. If weight loss or CPAP is selected as primary therapy (in order to titrate).

CPAP, continuous positive airway pressure; EDS, excessive daytime sleepiness; OSA, obstructive sleep apnea.

2. Other tests—Other studies such as sleep questionnaires, abbreviated PSG, which has been shown to have a 97% positive predictive value and a 47% negative predictive value, nighttime video and audio recording, and sleep sonography have also been evaluated, but are not typically used for routine diagnosis.

Complications

Children with OSA incur the same health complications as do adults with OSA, and these include a host of cardiopulmonary complications as well as consequences that are

unique to children, such as failure to thrive, poor growth, short stature, learning disabilities, mental retardation, behavioral problems, and attention deficit/hyperactivity disorder. Studies com paring pre- and post-adenotonsillectomy data for height and weight demonstrate significant gains in height and weight following adenotonsillectomy, and performance in school is also demonstrated to increase after adenotonsillectomy.

Treatment

A. Nonsurgical Measures

1. CPAP therapy—Because the cause of OSA is more clearly defined in children and surgical treatment is significantly more successful in children than in adults, CPAP therapy is reserved for patients with specific contraindications to surgery, patients with persistent OSA despite surgical treatment, and patients refusing surgical therapy. CPAP is approximately 85% effective in eliminating OSA in children and improves nadir SaO_2 as well as REM sleep. Children older than 2 years of age are noted to be poorly compliant with CPAP therapy and frequently complain of the same side-effects that adults experience. As with adults, there are no conclusive data that CPAP use in children is beneficial in eliminating the long-term sequelae of OSA.

2. Weight loss—General measures used to treat children with OSA include weight loss and treatment of preexisting medical conditions deemed to influence the development of sleep-disordered breathing. Overweight children should be encouraged to lose weight; however, for patients with Down syndrome or Prader-Willi syndrome, this may not be practical. The ATS recommends that those choosing weight loss as the primary therapy undergo PSG to evaluate the severity of apnea and its progress.

3. Other treatment measures—Respiratory tract maladies such as rhinitis, sinus disease, wheezing, and asthma have also been linked to OSA; attempts to treat these conditions should parallel treatment of OSA. In addition, children with gastroesophageal reflux disease should also be treated with age-appropriate measures in coordination with a gastroenterologist or pulmonologist.

B. Surgical Measures

1. Adenotonsillectomy—Adenotonsillectomy is highly successful in eliminating OSA in children and should be recommended as first-line therapies if the family is amenable and there are no specific contraindications. Adenotonsillectomy is indicated in children with obligate mouth breathing, snoring, and OSA, and care must be taken in patients with secondary palate or submucous clefts, because adenoidectomy may increase the risk of velopharyngeal insufficiency. Additional caution is advisable for surgery in children younger than 3 years of age owing to increased frequency of complications. By objective measures, adenotonsillectomy improves quality of life and is approximately 85–95% effective in *eliminating* OSA in children. A more recent study using the OSD-6 survey to evaluate the quality of life of children pre- and post-adenotonsillectomy demonstrated an 87.7% improvement in short-term quality of life with 74.5% reporting a large improvement in quality of life. Only 5.1% reported a worsening in quality of life.

2. Other surgical measures—Although they are performed less commonly because of the high success rate of adenotonsillectomy, the procedures performed on adults (UPPP, osteotomies and advancements, and tracheostomy) are performed in children as well. Because these procedures are performed less commonly and more frequently in patients with craniofacial disorders, their use and evaluation must be made on an individualized basis.

PROGNOSIS

The prognosis of untreated OSA in children can be severe, with such long-term consequences as hypertension, myocardial ischemia, congestive heart failure, and stroke. Clinicians must also be aware that untreated OSA in children presents additional complications such as failure to thrive, short stature, mental retardation, and learning disabilities. In contrast to management of adult cases, the management of OSA in children is frequently gratifying. For children, studies comparing pre-and post-adenotonsillectomy data for height and weight demonstrate significant gains in height and weight following adenotonsillectomy, and performance in school is also demonstrated to increase after this procedure.

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Disorders of the Thyroid Gland

42

Grace A. Lee, MD & Umesh Masharani, MRCP (UK)

ANATOMY & HISTOLOGY

The normal thyroid gland is located anterior to the trachea and midway between the apex of the thyroid cartilage and the suprasternal notch (Figure 42–1). Important neighboring posterior structures include the four parathyroid glands situated behind the upper and middle thyroid lobes, and the recurrent laryngeal nerves coursing along the trachea. The thyroid consists of two pear-shaped lobes connected by an isthmus. The typical dimensions of the lobes are 2.5–4.0 cm in length, 1.5–2.0 cm in width, and 1.0–1.5 cm in thickness. Also, in about 50% of patients, a small pyramidal lobe is present at the isthmus or adjacent part of the lobes. The functional unit of the thyroid is the follicle consisting of a central collection of colloidal material (thyroglobulin) surrounded by a single layer of polarized epithelial cells.

A normal thyroid gland weighs approximately 10–20 g, depending on dietary iodine intake, age, and weight. The thyroid gland usually grows posteriorly and inferiorly, since it is limited from upward extension by the sternothyroid muscle. In large multinodular goiters, substernal extension is not uncommon.

The thyroid gland has a rich blood supply, derived from the superior, inferior, and the small inferior ima artery (Figure 42–2). Venous flow returns via multiple surface veins draining into the superior, lateral, and inferior thyroid veins.

THYROID HORMONES

THYROID HORMONE SYNTHESIS

The essential steps to thyroid hormone production are as follows (Figure 42–3).

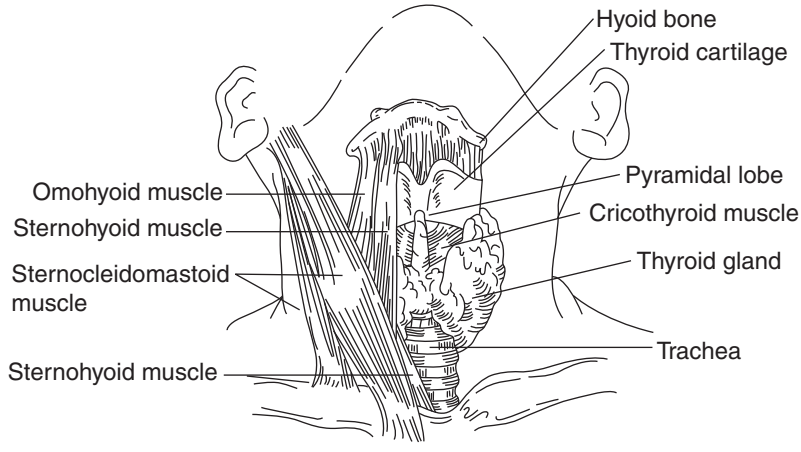
1. Active uptake of iodide (I^-) into the thyroid cell (trapping)—Iodide is actively transported across the basal membrane of the thyroid cell by membrane-bound sodium-iodide symporters (NIS). The iodide concentration inside the cell is about 30 to 40 times greater than in the plasma. NIS action is stimulated by thyroid-stimulating hormone (TSH).

2. Oxidation of iodide and iodination of tyrosyl residues in thyroglobulin (organification)—Iodide entering the thyroid cell is oxidized by locally produced hydrogen peroxide to an active iodide intermediate which then covalently binds to the tyrosyl residues in thyroglobulin at the apical-colloid border. The thyroglobulin molecule is a dimer of two identical chains and about 1/3 of the tyrosyl residues of the molecule undergoes iodination. Thyroid peroxidase (TPO) catalyzes both iodide oxidation and iodination of tyrosyl residues.

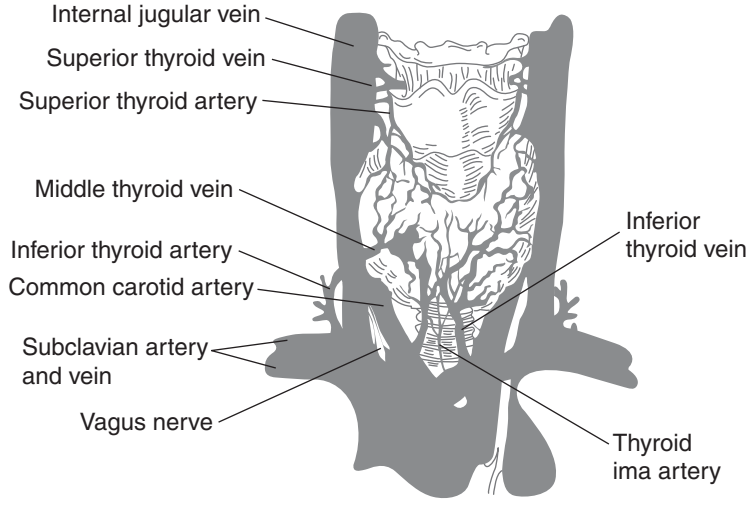
3. Linking pairs of iodotyrosine molecules within thyroglobulin to form thyroxine (T_4). and triiodothyronine (T_3) (coupling)—The coupling of iodotyrosyl residues in thyroglobulin is also catalyzed by TPO. Two molecules of diiodotyrosine (DIT) couple to form T_4; and one molecule of monoiodotyrosine (MIT) and DIT couple to form T_3. In thyroglobulin molecule containing 0.5% iodine by weight, there are approximately three molecules of T_4 and one molecule of T_3.

4. Proteolysis of thyroglobulin and the release of free iodothyronines and iodotyrosines—After a variable period of storage in the thyroid follicles, thyroglobulin is taken up into the thyroid cell by pinocytosis. The colloid vesicles fuse with lysosomes containing proteolytic enzymes releasing T_4, T_3, inactive iodotyrosines, peptides, and amino-acids. The T_4 and T_3 enter the circulation, whereas MIT and DIT are deiodinated and their iodide conserved.

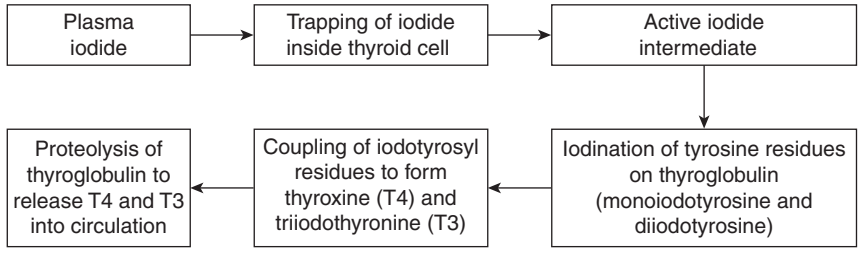
A small amount of intact thyroglobulin is normally released into the circulation. The amount is markedly increased in thyroiditis, nodular goiter, and Graves' disease. It is a very useful tumor marker in patients who have had total thyroidectomy and ablation for differentiated papillary



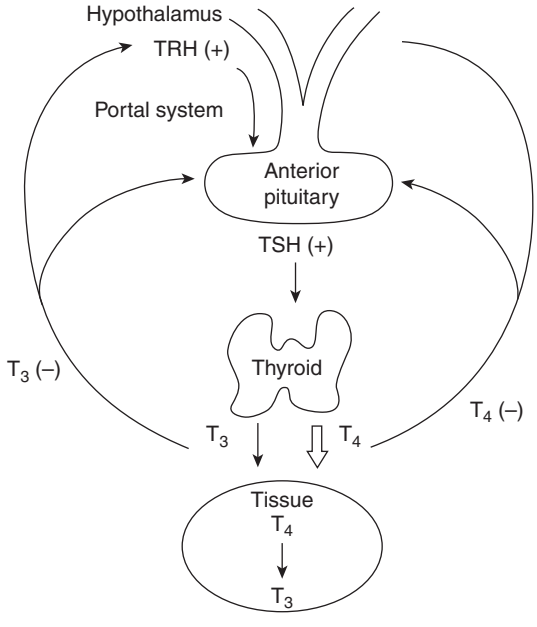
▲ **Figure 42–1.** Gross anatomy of the thyroid gland. (Reproduced, with permission, from Greenspan FS: *Basic and Clinical Endocrinology.* Originally published by Appleton & Lange. New York: The McGraw-Hill Companies, 1983.)



▲ **Figure 42–2.** Arterial and venous blood supply of the thyroid gland. (Reproduced, with permission, from Lindner HH: *Clinical Anatomy.* Originally published by Appleton & Lange. New York: The McGraw-Hill Companies, 1989.)



▲ **Figure 42–3.** Thyroid hormone synthesis.



▲ **Figure 42–4.** The hypothalamic-pituitary thyroid axis. The hypothalamus secretes thyroid-releasing hormone (TRH), which causes the pituitary to release thyroid-stimulating hormone (TSH). In turn, TSH stimulates most of the thyroid hormone formation of T_4 and some of the formation of T_3. T_4 and T_3 negatively feed back on the hypothalamus and pituitary, completing the regulatory cycle.

or follicular thyroid cancer. Detectable thyroglobulin in these circumstances indicates the presence of thyroid cancer cells.

Thyroid hormone synthesis is mostly controlled by the hypothalamic-pituitary-thyroid axis, as illustrated in Figure 42–4.

THYROID HORMONE TRANSPORT

Thyroid hormones are mostly bound to carrier proteins; 99.96% of T_4 and 99.60% of T_3 are bound in the serum (Figure 42–5). The small fraction of unbound T_4 and T_3 hormones are responsible for biologic activity. Thyroid hormones are transported throughout the body bound to three carrier proteins in the serum: (1) thyroxine-binding globulin (TBG) which has a single binding site for T_4 or T_3. In patients who have TBG deficiency, the total T_4 and T_3 levels are low but the free hormone levels are normal and so the patients are clinically euthyroid. TBG levels are increased during pregnancy and with estrogen therapy. (2) Thyroxine-binding prealbumin (TBPA), also known as transthyretin which binds about 10% of circulating T_4; and (3) albumin which binds about 15% of circulating thyroid hormones.

METABOLISM OF THYROID HORMONES

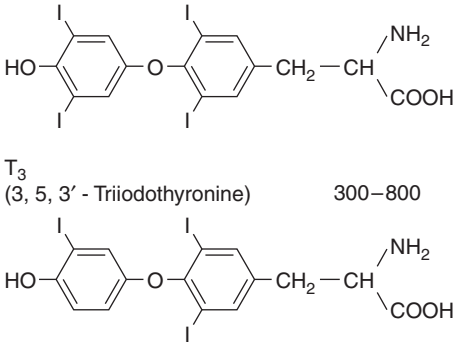
Biologic activity is dependent on the degree and location of iodination (see Figure 42–5). T_3 is three to eight times more potent than T_4. T_4 is the predominant circulating thyroid hormone, whereas T_3 is the main peripherally active hormone. The thyroid normally secretes about 100 nmol of T_4 and 5 nmol of T_3. Most of the peripheral T_3, therefore, is derived from circulating T_4 by the action of peripheral 5′-deiodinases. Certain drugs can inhibit the conversion of T_4 to T_3: propylthiouracil, amiodarone, ipodate, glucocorticoids, and propranolol. T_4 has a half-life of approximately 7 days, whereas T_3 has a half-life of 1 day.

ASSESSMENT OF THYROID FUNCTION

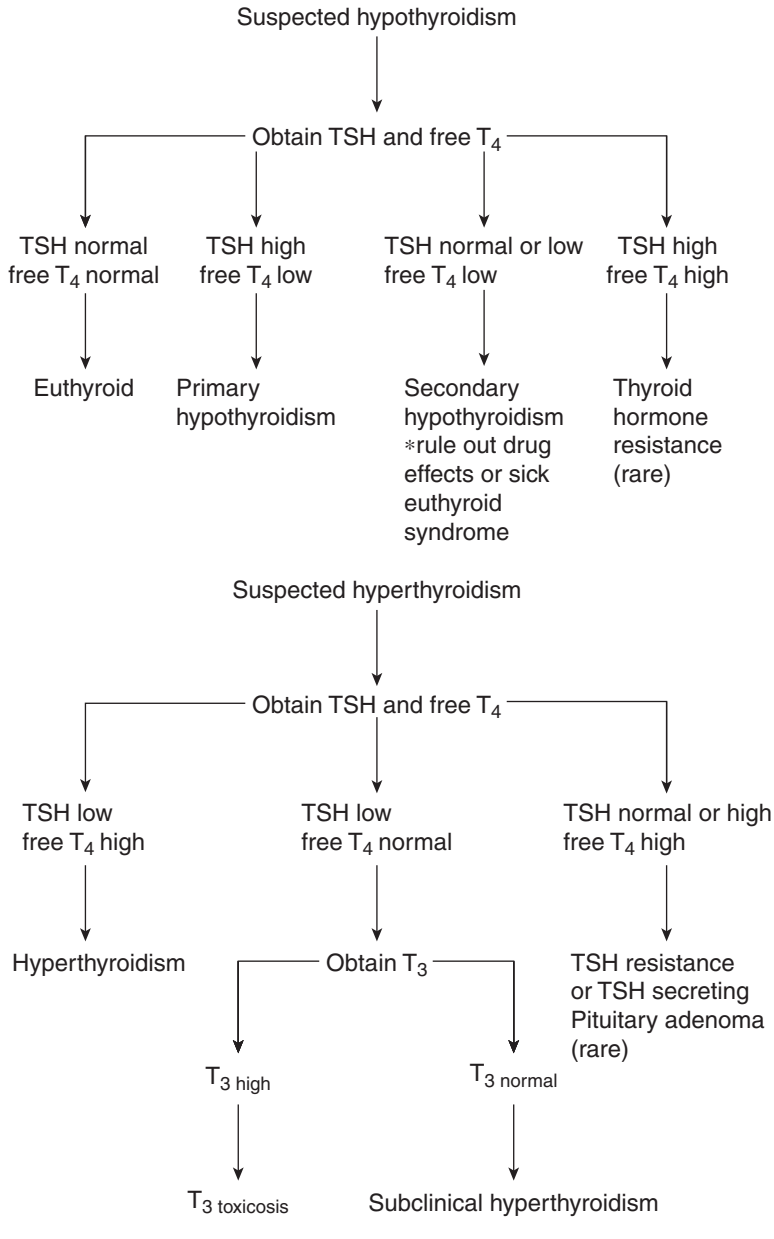
THYROID FUNCTION TESTS

The most commonly used thyroid function tests in clinical practice are serum immunoassays for TSH (or thyrotropin) and free thyroxine (or free T_4, also known as FT_4). TSH can

	Biologic activity	Protein-bound hormone	Free hormone (biologically active)
Thyroxine or T_4 (3, 5, 3′, 5′ - tetra iodothyronine)	100	99.96%	0.04%
T_3 (3, 5, 3′ - Triiodothyronine)	300–800	99.60%	0.40%



▲ **Figure 42–5.** Thyroid hormone structure and biologic activity.



▲ **Figure 42–6.** Diagnostic approach to thyroid function tests. TSH, thyroid-stimulating hormone.

be used alone in screening for overt thyroid disease, but both TSH and FT_4 are needed for the diagnosis, especially if pituitary or hypothalamic disease is suspected. With a normal hypothalamus and pituitary, TSH maintains an inverse relationship with FT_4. Figure 42–6 provides an algorithm for the evaluation of thyroid function tests. The common profiles of thyroid function tests in different disease states are outlined in Table 42–1. TSH is an extremely sensitive pituitary indicator of thyroid disease, but it requires 4–6 weeks to reflect changes in thyroid hormone levels. FT_4 is a less sensitive indicator of thyroid hormone production, but it may be helpful in monitoring more acute changes in thyroid activity. In evaluating hyperthyroidism, it may also be helpful to obtain a total T_3 or FT_3 to rule out T_3 thyrotoxicosis.

Thyroid-Stimulating Hormone Immunoassay

The TSH assays currently used are immunoassays based on two monoclonal antibodies detecting different epitopes of the TSH. Most laboratories use either a second- or third-generation TSH assay, which detects levels as low as

Table 42–1. Patterns of Thyroid Function Tests.

TSH	Free T_4	T_3	Diagnosis
Normal	Normal	Normal	Euthyroid
Normal	Low normal or low	Low or normal	Central hypothyroidism or sick euthyroid or drugs
High	Low	Normal or low	Primary hypothyroidism
High	Normal	Normal	Subclinical hypothyroidism
High	High	High	TSH resistance syndrome[a]
Low	High or normal	High	Hyperthyroidism
Low	Normal	Normal	Subclinical hyperthyroidism or drugs
Low	Normal	High	T_3 toxicosis[a]
Low	Low	Low	Central hypothyroidism or sick euthyroid or drugs

[a]Denotes rare conditions

0.10 and 0.01 mU/L, respectively. TSH is a sensitive measure of the response of the pituitary gland to circulating FT_4 levels.

The reference range for most TSH assays is 0.4 to 4.0 mIU/L. It is likely, however, that some individuals with thyroid dysfunction, especially subclinical hypothyroidism, were included when this reference range was established. The TSH level for truly euthyroid subjects lies in the 1.0 to 1.5 mIU/L with a normal range of 0.4 to 2.5 mIU/L

TSH levels are elevated mostly in primary hypothyroidism and are accompanied by a low level of FT_4. Table 42–2 lists situations in which the TSH is elevated (other than in hypothyroidism), including drugs, recovery from an acutely ill state, acute psychiatric admission, and the very rare TSH-secreting pituitary tumor.

A decreased TSH level should be interpreted in conjunction with the FT_4 level. A decreased TSH level with an elevated FT_4 level suggests primary hyperthyroidism. A low FT_4 level with a normal to decreased TSH level may indicate secondary or central hypothyroidism (<5% of all cases of hypothyroidism), which are due to a pituitary or hypothalamic tumor. A number of situations, including drugs and nonthyroidal illness, can also cause both low TSH and FT_4 levels (see Table 42–1).

Free Thyroxine Immunoassay (FT_4)

Direct FT_4 determination by an immunoassay has largely replaced indirect measurements of FT_4 concentrations, such as the free T_4 index (FT_4I), which is the product of resin T_3 (or T_4) uptake and total T_4. Most laboratories use a chemiluminescent immunoassay to measure FT_4 levels. It is valid in most cases, except in patients with very high or low thyroid-binding proteins or severe illness. Under these circumstances, the measurement of FT_4 levels by equilibrium dialysis is more reliable. FT_4 is elevated in hyperthyroidism and decreased in hypothyroidism. Table 42–2 lists the conditions that affect FT_4 levels. Of note, the antiepileptic drugs phenytoin, carbamazepine, and rifampin can cause a significantly increased hepatic metabolism of T_4. Also, drugs and illness rarely suppress the TSH to undetectable levels. The measurement of FT_4 levels by dialysis is spuriously elevated by heparin, which activates lipoprotein lipase, which in turn generates fatty acids that displace T_4 from TBG.

Total Triiodothyronine (T_3)

Total T_3 measures both the free and bound T_3 in circulation. Total T_3 is helpful in diagnosing hyperthyroidism with

Table 42–2. Drugs and Their Effects on Thyroid Function Tests.

True hyperthyroidism	Iodine and iodine-containing drugs (amiodarone, IV contrast), lithium, interferon alfa, interleukin 2
True hypothyroidism	Iodine and iodine-containing drugs (amiodarone, IV contrast), lithium, interferon alfa, interleukin 2
Suppressed TSH secretion	Glucocorticoids, dopamine, dobutamine, octreotide, amphetamines, opioids, nifedipine, and verapamil, dopamine antagonists, atypical antipsychotics, phenothiazines
Low T_4 by decreased absorption of T_4	Cholestyramine, soy-based foods, colestipol, aluminum hydroxide, calcium carbonate, iron sulfate, sucralfate
Low T_4 by increased T_4 clearance	Phenytoin, carbamazepine, phenobarbital, rifampin
High T_4 by inhibited T_4 to T_3 conversion	Amiodarone, iodine and iodine-containing substances, glucocorticoids, propylthiouracil, propranolol

elevated T_3 levels but normal T_4 levels (ie, T_3 toxicosis). The preferential secretion of T_3 can be seen in early Graves' disease or toxic multinodular goiter.

Free T_3

Free T_3 (FT_3) is a newer test that allows for the direct measurement of FT_3 levels via a chemiluminescent assay or a radioassay.

Antithyroid Peroxidase Antibody

TPO is the key enzyme that catalyzes the iodination of thyroglobulin and the coupling of iodinated tyrosyl residues to form T_3 and T_4. TPO is located on the microvilli at the thyroid--colloid interface. Almost all patients with Hashimoto's thyroiditis have antithyroid peroxidase (anti-TPO) antibodies present—these antibodies are usually measured to diagnose Hashimoto's thyroiditis. A large number of patients with Graves' disease also have anti-TPO antibodies.

The prevalence of TPO antibody positivity in the population is in the range of 5% to 12%. Its prevalence is increased in patients with other autoimmune diseases such as type 1 diabetes and pernicious anemia. A detectable TPO antibody in the absence of an overt thyroid disease is a risk factor for future development of hypothyroidism. TPO antibody positivity is also a risk factor for development of thyroid dysfunction in patients taking amiodarone, interferon-alpha, interleukin-2, and lithium therapies.

Thyroglobulin Antibody

Autoantibodies against thyroglobulin are present in patients with autoimmune thyroid disease. Most of these patients are also positive for TPO antibodies. Thyroglobulin antibody is primarily measured in conjunction with estimation of thyroglobulin level where its presence can lead to spurious results (vide infra).

TSH receptor antibodies (TRab)

Two classes of TSH receptor antibodies are associated with autoimmune diseases of the thyroid: (a) antibodies that activate the TSH receptor (thyroid-stimulating antibodies (TSAb)) resulting in Graves' hyperthyroidism; and (b) antibodies that block binding of TSH to its receptor (thyroid stimulation blocking antibody (TBAb)). Both TSAb and TBAb can be detected alone or in combination with Graves' disease and Hashimoto's thyroiditis. The relative contributions of the two classes of the antibodies may modulate the severity of Graves' hyperthyroidism and may change in response to treatment. TSAb, also referred to as thyroid-stimulating immunoglobulin (TSI), is an indirect test that confirms the diagnosis of Graves' disease. TSI is positive in approximately 90% of patients with Graves' disease, and negative both in normal patients and patients with Hashimoto's thyroiditis. Patient serum is incubated with either human thyroid cell culture or hamster ovary cells that express recombinant human TSH receptor; cyclic adenosine monophosphate (AMP) activity is measured. TSI is also of diagnostic value in patients with normal thyroid function who have exophthalmos. The measurement of TSI is helpful during pregnancy—high titers increase the risk of neonatal thyrotoxicosis.

Serum Thyroglobulin

Serum thyroglobulin is the precursor protein required for the synthesis of T_4 and T_3. The normal measure is <40 ng/mL in individuals with normal thyroid function, and <5 ng/mL in patients after a thyroidectomy. Thyroglobulin is raised when the thyroid is overactive, such as with Graves' disease or multinodular goiter. In very large goiters, the elevated levels of thyroglobulin reflect the gland size. In subacute or chronic thyroiditis, thyroglobulin is released as a consequence of tissue damage.

Thyroglobulin is a very useful marker for thyroid cancer, both to assess treatment efficacy and to monitor for recurrence after total thyroidectomy and radioiodine ^{131}I therapy. Because thyroglobulin is made only by the thyroid gland, its level serves as an indicator of the presence of thyroid tissue, as in well-differentiated thyroid cancer. It is necessary to measure for endogenous thyroglobulin antibodies as part of interpreting the measurement of the thyroglobulin level. These antibodies can interfere with the assay and give spuriously high or low levels, depending on the measurement method used.

Radioactive Iodine Uptake & Scan

Radionuclide imaging of the thyroid with ^{123}I or ^{99m}Tc is useful in evaluating the *functional activity* of the thyroid. The two tests that use radioactivity to assess the thyroid are the radioactive uptake and scan. Radioactive uptake evaluates thyroid function by reporting the percentage uptake of iodine, whereas the scan produces an image of the distribution of iodine in the thyroid. The radioactive scan gives information regarding the size and shape of the thyroid, as well as information about nodules that are either functioning ("hot" nodules) or nonfunctioning ("cold" nodules). ^{123}I can be used to assess both radioactive uptake and scan, but ^{99m}Tc can only be used for scanning. A ^{99m}Tc study gives results within 30 minutes, whereas ^{123}I images are obtained at 4–6 and at 24 hours. ^{123}I delivers less radiation than ^{131}I because of its short half-life of 13 hours and the absence of beta radiation. Its gamma photo energy of 159 keV is ideally suited for thyroid scanning. Both ^{123}I and ^{99m}Tc are contraindicated in pregnancy.

^{123}I allows assessment of the turnover of iodine by the thyroid gland. After 100–200 μCi of ^{123}I, radioactivity over

the thyroid area is measured by scintigraphy at 4 or 6 and at 24 hours. The normal ranges of uptake vary with iodine intake. In areas of low iodine intake and endemic goiter, uptake may be as high as 60–90%. In the United States, with a relatively high intake, the normal uptake is 5–15% at 6 hours, and 8–30% at 24 hours.

Both ^{123}I uptake and scan are useful in delineating the cause of hyperthyroidism. Uptake is elevated in thyrotoxicosis due to Graves' disease and toxic multinodular goiter. Uptake is low in subacute thyroiditis, the active phase of Hashimoto's thyroiditis with the release of preformed hormone, exogenous thyroid hormone ingestion, excess iodine intake (from amiodarone, iodinate contrast dyes, or kelp pills), and hypopituitarism. More rare causes include ectopic thyroid hormone production from HCG (human chorionic gonadotropin), struma ovarii, and metastatic follicular thyroid carcinoma. ^{131}I uptake and scans are very useful in monitoring the recurrence of well-differentiated thyroid cancer. Typically, 2–3 mCi of ^{131}I is given to the patient, and images of the thyroid and the whole body are taken to look for recurrence or metastases. If the patient is treated with high-dose ^{131}I to ablate remnant thyroid cancer, a post-treatment thyroid and whole-body scan is often helpful to look for tumor tissue that weakly uptakes iodine.

Nonthyroidal Illness & Thyroid Function Tests

Severely ill patients exhibit altered thyroid function tests. Most hospitalized patients have lower serum T_3 concentrations due to inhibition of the peripheral conversion of T_4 to T_3 by 5′-deiodinase. Severely ill patients (50% of patients in the ICU and 15–20% of hospitalized patients) can have a low serum T_4 level. This low level is mostly due to very low levels of thyroid-binding proteins, but the exact mechanism remains to be elucidated. The degree of T_4 depression has been directly correlated with the overall patient outcome. Most hospitalized patients also have slightly depressed but detectable levels of TSH. It has been suggested that hospitalized patients may have a subtle form of central hypothyroidism as a protective mechanism against their ill health and an increased catabolism. Studies have shown that administering thyroxine to patients who are ill has no benefit and may, in fact, be harmful. In the recovery phase of nonthyroidal illness, the TSH level tends to transiently rise before it returns to normal levels.

The assessment of thyroid function in the setting of nonthyroidal illness is difficult and should be undertaken only when there is a strong suspicion of thyroid disease. A straightforward approach to thyroid function tests in a patient who is hospitalized is to measure both TSH and FT_4. An elevated TSH, especially >20 μU/mL, is suggestive of primary hypothyroidism. In 75% of cases, patients with an undetectable TSH using a third-generation TSH assay are likely to have primary hyperthyroidism. A depressed but detectable TSH usually accompanied by a low T_4 level could indicate nonthyroidal illness, drug effect, subclinical hyperthyroidism, or central hypothyroidism. In these situations, other aspects of the patient history and examination may be helpful in making the diagnosis. The presence of a goiter, known pituitary disease, and thyroid test results obtained *before the illness* can direct the diagnosis and treatment. If nonthyroidal illness or a drug effect is highly suspected, the intermittent monitoring of thyroid function tests may be warranted.

Dayan CM. Interpretation of thyroid function tests. *Lancet* 2001;357(9256):619 [PMID: 11558500]. (A practical approach to thyroid function tests with a focus on common test pattern interpretation and the avoidance of pitfalls.)

Klee GG, Hay ID. Biochemical testing of thyroid function. *Endocrinol Metab Clin North Am* 1997;26(4):763 [PMID: 9429859]. (A more comprehensive analysis of thyroid function tests.)

PHYSICAL EXAMINATION

There are three basic maneuvers in examining the thyroid. The patient should be seated with only a slightly flexed neck to relax the sternocleidomastoid muscles. The thyroid should first be observed while the patient swallows a sip of water. An enlarged gland or nodules can be observed as the gland moves up and down. The thyroid gland should then be palpated from behind the patient, with the middle three fingers on each lobe of the gland. While the patient swallows, thyroid nodules or an enlargement can be noted as the gland passes beneath the examiner's fingers. A normal thyroid is usually found to be 2 cm in length and 1 cm in width. A generalized enlargement of the thyroid is called a **diffuse goiter** (from *gutta*, Latin for "throat"), whereas an irregular enlargement is termed a **nodular goiter.**

THYROID MASSES

THYROID NODULES

General Considerations

The prevalence of palpable thyroid nodules is approximately 5% in women and 1% in women. High resolution ultrasonography can detect thyroid nodules in 19% to 67 % of randomly selected individuals. The nonpalpable nodules discovered on ultrasound or other imaging studies are referred to as incidentally discovered nodules or "incidentalomas." The clinical importance of having a thyroid nodule rests on the need to exclude thyroid cancer. About 5% to 15% of nodules are malignant depending on age, sex, radiation exposure, and family history.

Table 42–3. Clinical Evaluation of Thyroid Nodules.

	Low Risk	High Risk
History	Family history of goiter	Family history of thyroid cancer or thyroid cancer syndrome such as Cowden's syndrome, familial polyposis, Carney complex, multiple endocrine neoplasia [MEN] 2 syndrome . Incidental nodule discovered during 18FDG–PET scan History of head and neck radiation; total body irradiation for bone marrow transplantation Recent growth of nodule Hoarseness, dysphagia
Epidemiology	Older woman	Young adult, male, or child
Physical exam	Soft nodule Multinodular goiter	Solitary, firm nodule Vocal cord paralysis Firm lymph nodes
Serum factors	High titer of thyroid antibodies, hyper- or hypothyroidism	
^{123}I Thyroid scan	"Hot nodule"	"Cold nodule"
Ultrasound of thyroid	Pure cystic lesion	Solid or semicystic lesion
Thyroxine therapy	Regression	Increase in size of mass

Clinical Findings

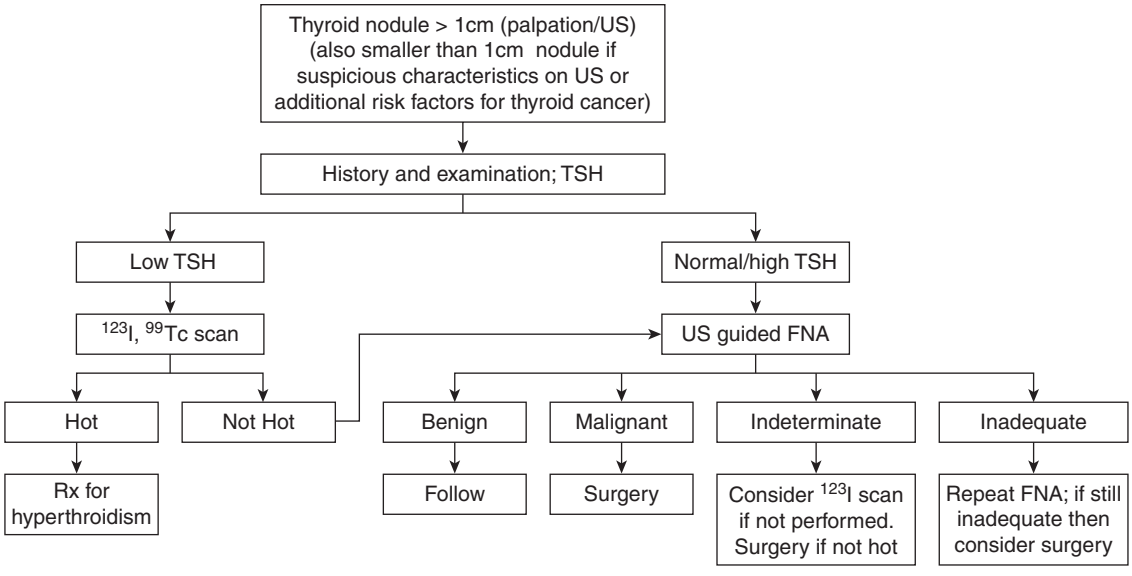
The initial evaluation of a thyroid nodule involves a careful history taking and physical examination (Table 42–3). Generally, incidental nodules over 1 cm in size discovered on imaging studies should undergo further evaluation since they have a greater potential to have clinical significant malignancies. Nonpalpable nodules have the same risk of malignancy as palpable nodules of the same size. Smaller than 1 cm incidental nodules, however, should be evaluated if there are suspicious sonographic findings or have additional risk factors for thyroid cancer. Risk factors include age, with adults younger than 30 or older than 60 years of age carrying a high risk for thyroid cancer; history of childhood head or neck irradiation or total body irradiation for bone marrow transplantation; and family history of thyroid cancer or thyroid cancer syndrome such as Cowden's syndrome, familial polyposis, Carney complex, multiple endocrine neoplasia [MEN] 2 syndrome in a first-degree relative. Recent growth, or evidence of hoarseness, dysphagia, or obstruction, should also raise suspicion. Incidental thyroid nodules are found in approximately 1–2% of people undergoing 2-deoxy-2[18F]fluoro-d-glucose positron emission tomography (18FDG-PET) imaging. The risk of malignancy in these 18FDG-positive nodules is about 33% and the cancers may be more aggressive and therefore undergo prompt evaluation.

An ultrasound study is particularly helpful in distinguishing a cyst from a solid nodule and also in identifying other nonpalpable nodules. Ultrasound can also identify nodules that are more concerning for malignancy, that is, those that have microcalcifications, irregular borders, and increased blood flow.

After primary thyroid disease is ruled out with normal thyroid function tests, the diagnostic procedure of choice is a fine-needle aspiration (FNA) biopsy of the thyroid nodule. Indications for a biopsy include solitary thyroid nodules, multiple nodules, or dominant or growing nodules that exist within a multinodular goiter. Although in the past, multinodular goiters and multiple nodules were thought to have a decreased incidence of thyroid cancer, recent data have suggested that the incidence of thyroid cancer may be higher. When more than two thyroid nodules are >1 cm, those with suspicious sonographic appearance should be biopsied. If none of the nodules have suspicious characteristics then it is reasonable to aspirate the dominant nodule(s).

Patients with subclinical or overt hyperthyroidism (low or suppressed TSH) and thyroid nodules (single or multiple) should undergo a radionuclide scan using either technetium 99mTc pertechnetate or ^{123}I prior to the FNA. If the nodule in question is hyperfunctioning ("hot") then an FNA is not necessary since such nodules are rarely malignant. If, however, the nodule is nonfunctioning ("cold") or isofunctioning ("warm") then an FNA is indicated. A FNA biopsy is performed using a 23- to 25-gauge needle with or without local anesthesia, and usually with ultrasound guidance. Several passes are made into the thyroid nodule, and the aspirated material is used in thin smear slides that are both air dried and alcohol preserved.

Cytopathologic examinations are typically reported as benign, suspicious or indeterminate (eg, follicular neoplasms), malignant, or nondiagnostic. One review of a thyroid biopsy reported that 70% of FNAs were benign, 10% were suspicious or were follicular neoplasms, 5% were malignant, and 15% were nondiagnostic. Cystic lesions yield serous fluid with immediate involution of the nodule.



▲ **Figure 42–7.** Algorithm for the management of thyroid nodules.

Although a malignant growth is less likely to occur in a purely cystic lesion, the fluid should still be sent for cytologic examination. If the cyst has tissue in the wall, then FNA of this region should be performed under ultrasound guidance. FNA is considered nondiagnostic if the specimens show a lack of follicular epithelium or the presence of excessive bloody dilution. A recent review of more than 5000 FNA procedures revealed an accuracy of over 95%, with a false-negative rate of 2.3% and a false-positive rate of 1.1%. Genetic markers (BRAF, RAS, RET/PTC, Pax8-PPARγ) or protein markers (galectin-3 expression) may be helpful in directing the treatment of indeterminate thyroid nodules.

Treatment

An algorithm of thyroid nodule management can be found in Figure 42–7. The management of a malignant growth, as indicated by FNA, requires total thyroidectomy, with careful attention paid to local, palpable lymph nodes that may require neck dissection at the time of surgery. Follicular adenomas are often deemed "indeterminate" because they are difficult to distinguish from follicular carcinomas on FNA. Evidence of vascular or capsular invasion is required for the diagnosis of follicular carcinoma. Roughly 10–20% of all suspicious lesions actually prove to be follicular carcinoma on excision.

Benign thyroid nodules are usually followed up clinically; these growths may enlarge, stay the same size, or involute. Serial ultrasounds are particularly helpful in follow-up measurements. Suppressive therapy of benign thyroid nodules is controversial. Most studies have not shown regression of solitary nodules with exogenous thyroxine, whereas some studies have shown a 20–30% reduction. Currently, most authorities do not recommend L-thyroxine therapy in the treatment of solitary nodules. Nodules that increase in size raise concern for a malignant growth and require reexamination with repeat FNA or surgical removal. Cystic lesions quickly involute on aspiration but are more prone to recur. In addition, FNA of cystic lesions can yield nondiagnostic cytology because of the difficulty of performing a biopsy of the thin cystic wall. Repeat FNAs are often required, and ultimately surgical removal may be needed. One small randomized trial showed that suppressive therapy for cystic nodules was not helpful.

The evaluation of a thyroid nodule discovered in a pregnant woman is the same as for a nonpregnant woman except that radionucleotide scans are contraindicated. For many pregnant patients found to have differentiated thyroid cancer on FNA, surgery can be deferred until after delivery. Retrospective studies indicate that there is no difference in recurrence or survival rates in women undergoing surgery during or after pregnancy. Surgery in the second trimester may be considered if there is ultrasound evidence for growth of the lesion or if the disease is advanced.

MULTINODULAR GOITER

General Considerations

With multinodular goiter, the thyroid gland is usually large, weighing from 60 to 1000 g. On pathologic examination, it contains nodules that vary in size, number, and appearance. Some nodules contain colloid and others are cystic,

containing brown fluid that indicates previous hemorrhage. Some of the nodules have autonomous function. The spectrum of function of these goiters ranges from the euthyroid state, with some degree of autonomous function, to thyrotoxicosis (eg, toxic multinodular goiter).

Clinical Findings

The principal clinical features of a nontoxic goiter are the same as those of a thyroid enlargement. Large goiters can cause dysphagia, a choking sensation, and inspiratory stridor. Hemorrhage into a nodule can present with acute painful enlargement and may induce or enhance obstructive symptoms.

Treatment

Thyroid hormone suppressive therapy may be effective in suppressing the growth of the multinodular goiter and preventing the development of new nodules. Up to 60% of these goiters respond to such treatment. Long-term treatment is required because stopping the suppression results in regrowth of the gland. It is important to start with a low dose of L-thyroxine and carefully monitor the FT_4 and TSH levels, aiming for a level of FT_4 in the normal range and a level of TSH in the low-normal range. Careful follow-up is necessary to monitor both for the development of autonomous function within the gland and for thyrotoxicosis. Radioactive iodine treatment is increasingly used and can result in a reduction of the thyroid volume and is safe in the treatment of a nontoxic multinodular goiter. Hypothyroidism can occur in 22–40% of subjects within 5 years after ^{131}I treatment. Surgery should be considered in patients when either the gland grows on suppressive treatment or there are obstructive symptoms. Surgical complications, such as recurrent laryngeal nerve damage and hypoparathyroidism, can be as high as 7–10%.

For a toxic multinodular goiter, control of the hyperthyroid state with antithyroid drugs followed by ^{131}I treatment is treatment of choice. Subtotal thyroidectomy is an alternate option. Patients who have some degree of autonomous function in their multinodular goiter can develop overt thyrotoxicosis when exposed to an iodine load (eg, amiodarone treatment or IV contrast). This iodide-induced thyrotoxicosis can be treated with methimazole and betaadrenergic blockade. ^{131}I treatment may not be possible because of the large iodine pool. Total thyroidectomy is curative but is feasible only if the patient can withstand the stress of surgery.

Cooper DS et al. American Thyroid Association (ATA) Guidelines Taskforce on Thyroid Nodules and Differentiated Thyroid Cancer. Revised American Thyroid Association management guidelines for patients with thyroid nodules and differentiated thyroid cancer. Thyroid. 2009;19(11):1167–214 [PMID: 19860577]. (Review of currently recommended approach to thyroid nodules.)

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THYROID CANCER

Thyroid cancer represents about 3% of all cancers in women and 1% of cancers in men, with an estimated incidence of 37,000 new cases in 2008. In the past three decades, the incidence of thyroid cancer has increased by almost 50%; however, mortality rates have declined by 20%. This may be due to earlier detection by FNA and subsequent treatment. There are four main pathologies encountered in thyroid cancer: papillary, follicular, medullary, and anaplastic carcinomas (Table 42–4).

PAPILLARY CARCINOMA

General Considerations

Papillary carcinoma is the most common thyroid cancer, representing 75% of all thyroid cancers. It has the best prognosis, with a 5% mortality rate at 20 years for patients with no evidence of local invasion at diagnosis. In addition to a history of childhood exposure to radiation, risk factors for papillary carcinoma include familial papillary carcinoma, Cowden syndrome (eg, multiple hamartomas of the skin and mucous membranes), and familial adenomatous polyposis coli.

Clinical Findings

Microscopically, papillary carcinoma consists of single layers of thyroid cells arranged in avascular projections or papillae, which manifest as large pale nuclei, intranuclear inclusion bodies, and anaplastic features. "Psammoma bodies" are laminated calcified spheres and are usually diagnostic

Table 42–4. Frequency of Thyroid Cancer.

Cancer	Percentage
Papillary carcinoma	75%
Follicular carcinoma	16%
Medullary carcinoma	5%
Undifferentiated	3%
Other	1%
(Lymphoma, fibrosarcoma, squamous cell carcinoma, teratomas, hemangioendothelioma, and metastatic carcinomas)	

of papillary carcinoma. Papillary carcinoma can be either purely papillary or mixed with follicular carcinoma; both are treated with similar therapies. Certain histopathologic variants, such as tall cell, columnar cell, and diffuse sclerosing types, are associated with a higher risk of recurrence.

Papillary carcinoma typically has an indolent natural history. Usually unencapsulated, these lesions grow slowly, with intraglandular metastasis and local lymph node extension. Approximately 25% to 50% of patients have involvement of cervical lymph nodes at presentation. In the late stages, it can spread to the lung. In older patients, chronic low-grade papillary carcinoma may rarely convert to an aggressive anaplastic carcinoma.

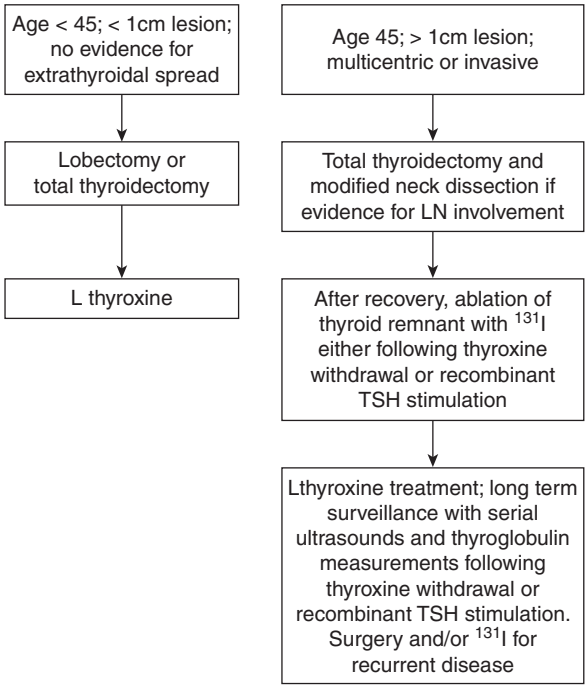
Treatment

Because papillary carcinoma retains the ability to synthesize thyroglobulin and to concentrate iodine in the early stages, radiation therapy is often effective. The initial treatment involves either partial thyroidectomy or total thyroidectomy with possible modified neck dissection (Figure 42–8).

A. Surgical Measures

Preoperative ultrasound can identify lesions in the contralateral lobe and in the cervical lymph nodes assisting in the accurate staging of the disease. Prognosis depends on age, the size of the lesion, and evidence of extrathyroidal spread. Patients younger than 45 years of age who have lesions <1 cm with no evidence of intra- and extrathyroidal involvement are considered to have a low risk for future recurrence. All other patients should be considered at high risk. For both low-risk and high-risk patients, total thyroidectomy is generally recommended although a partial thyroidectomy may be adequate for the former group. If lymph node involvement is present on the initial evaluation, the patient should undergo a modified neck dissection as well; however, neck dissection is not indicated in the absence of lymph node involvement. Completion thyroidectomy is indicated if diagnosis of malignancy is made after lobectomy of an indeterminate lesion.

In the hands of a skilled surgeon, thyroid surgery portends less than a 1% complication rate; the primary complications are hypoparathyroidism and recurrent laryngeal nerve damage. Immediately after surgery, the patient should be placed on suppressive T_4 therapy.



▲ **Figure 42–8.** Algorithm for the management of papillary or follicular cancer. Tg, thyroglobulin; TSH, thyroid-stimulating hormone.

B. Postsurgical Measures

After undergoing a total thyroidectomy, patients should receive radioiodine to ablate the normal thyroid remnant or residual microscopic disease. The radioablation decreases the likelihood of recurrent disease and also allows the physician to subsequently follow thyroglobulin levels as a marker for thyroid cancer activity.

Remnant ablation can be performed either following thyroxine withdrawal or recombinant TSH stimulation. **The thyroxine withdrawal protocol** requires thyroxine therapy to be stopped for 6 weeks and L-triiodothyronine (25 to 50 mcg) to be initiated for 4 weeks. The patient is then taken off all thyroid hormone therapy and goes on a low iodine diet for 2 weeks. This protocol allows for a rise in the patient's TSH level, which stimulates iodide uptake by the residual tumor. At maximal TSH stimulation (usually a TSH of > 50 μU/mL), thyroglobulin is drawn and 1–3 mCi of ^{131}I is administered to the patient. The patient is scanned for residual radioactive iodine uptake 24–72 hours later. A treatment dose of ^{131}I is then given. The previous dose of thyroxine and regular diet can be restarted 2 days after the ^{131}I treatment dose. Patients can also be given 1 week of L-triiodothyronine to rapidly reverse the hypothyroid state. A whole body scan is performed 1 week after the therapy dose. This posttreatment scan allows for identification of metastatic disease not visualized on the diagnostic scan. Additional metastatic foci are noted in 10% to 26% of patients on the posttherapy scan compared to the diagnostic scan. Approximately 30–50 mCi of ^{131}I is used to ablate the thyroid remnant in a postsurgical patient who does not have metastatic disease; uptake is limited to the thyroid bed. For metastatic or recurrent disease, patients are generally treated with a 100–200 mCi dose of ^{131}I. Side effects from doses larger than 100 mCi include sialadenitis, xerostomia, and temporary oligospermia. **The recombinant TSH protocol** allows the patient to avoid

the discomfort of severe hypothyroidism and disrupting suppressive T4 therapy. The patient is on a low iodine diet for at least 2 weeks prior to the study but the L-thyroxine is only stopped 2 days before the procedures. Patients get intramuscular injections of recombinant TSH on days 1 and 2. Thyroglobulin and TSH levels are drawn and therapeutic dose of ^{131}I is given on day 3. The L-thyroxine dose and regular diet are restarted 3 days later and a whole body scan is performed a week after therapy dose. After ^{131}I ablative therapy, the patient is placed on suppressive L-thyroxine therapy. Suppression to below 0.1 mU/L is recommended for high-risk patients and below normal (0.1 to 0.5 mU/L) in the low-risk patient.

Long-term management is directed at early detection and treatment of recurrent disease. Patients can be considered low risk if the tumor did not have aggressive histology and was localized within the thyroid without evidences of local or distant metastasis and the diagnostic and/or posttreatment ^{131}I uptake was restricted to the thyroid bed. Intermediate risk patients have microscopic disease into the perithyroidal soft tissues or have aggressive histology or vascular invasion. High-risk patients have macroscopic tumor invasion, incomplete tumor resection or distant metastasis or ^{131}I uptake outside thyroid bed on a posttreatment scan.

Patients should be monitored at regular intervals with neck ultrasounds and clinical examination for new masses or lymphadenopathy and measurements of serum thyroglobulin, FT_4, and TSH. The frequency of ultrasound examination depends on patient's risk for recurrent disease and thyroglobulin status. It is helpful to get a baseline study at 2 to 3 months after surgery and then at 6 and 12 months and then yearly for at least 3 to 5 years. Suspicious lymph nodes and/or suspicious soft tissue in the neck should undergo FNA under ultrasound guidance and if disease is confirmed then additional surgery may be indicated.

Serum thyroglobulin levels have a high degree of sensitivity and specificity to detect persistent or recurrent thyroid cancer after total thyroidectomy and remnant ablation. Serum thyroglobulin levels should be measured by using the same immunometric assay every 6 to 12 months. Thyroglobulin antibodies in patient's serum can interfere with the assay making the result unreliable, and so they should be quantified with every measurement of serum thyroglobulin. A rise in thyroglobulin above 2 ng/ml (using a thyroglobulin assay with a functional sensitivity of <1.0 ng/ml) after thyroxine withdrawal or recombinant TSH treatment indicates persistent disease. This testing should be performed at approximately 12 months after ablation. Newer immunometric assays have functional sensitivities as low as 0.1 ng/mL and may detect persistent disease even while on suppressive therapy. Thus, in the low-risk patient where the 12 month assessment is negative, thyroglobulin of <0.1 ng/mL while on suppressive therapy combined with a normal neck ultrasound is reassuring and may obviate the need for repeat-stimulated thyroglobulin measurement.

Follow-up ^{131}I uptake scans are not routinely required in the low-risk patient with negative TSH-stimulated thyroglobulin level and neck ultrasound. Diagnostic uptake scans should be performed in moderate- or high-risk patients at 12 month intervals with concomitant radioactive treatments as necessary (Figure 42-8). Once a negative scan and negative thyroglobulin are achieved, the patient is likely to be disease free and may be subsequently followed with neck ultrasound and stimulated thyroglobulin measurements.

The amount of ^{131}I given for the treatment of thyroid cancer depends on the degree of disease, the response to previous treatments, and the amounts of ^{131}I administered in the past. With cumulative doses of up to 300 mCi, no permanent sterility has been reported in women and <10% of men have permanent sterility. Cumulative doses larger than 500 mCi have been associated with infertility, pancytopenia (in <4.0% of cases), and leukemia (in 0.3% of cases). However, cumulative doses over 800 mCi have been associated with permanent sterility in up to 60% of women and 90% of men. In patients with significant pulmonary metastasis, repeated ^{131}I treatment can rarely result in pulmonary pneumonitis and pulmonary fibrosis. Salivary gland damage, nasolacrimal duct obstruction, and secondary malignancies are risk factors of ^{131}I therapy. Surgical correction should be considered for lacrimal outflow obstruction. Long-term followup studies suggest a slightly increased ^{131}I dose-related risk for secondary malignancies such as bone, colorectal, salivary gland, and leukemia. There is no evidence, however, that these patients need more intensive screening for these malignancies than the general population. Radioiodine therapy is contraindicated in pregnancy and in breast-feeding women. Women receiving ^{131}I therapy should avoid pregnancy for 6 to 12 months.

^{131}I treatment is given either after L-thyroxine withdrawal or following recombinant TSH therapy. It should noted, however, that long-term outcome studies on the use of recombinant TSH for ^{131}I treatment for metastatic disease are not yet available.

Thyroid cancer with a negative scan but a positive thyroglobulin positive thyroid level poses a diagnostic dilemma. As thyroid cancer dedifferentiates, it can potentially lose the ability to concentrate iodine and thus lose responsiveness to radioactive iodine treatment. Once excessive iodine intake is ruled out, patients generally undergo further imaging such as ultrasound, MRI, CT scanning, 18 FDG-PET/CT scanning, or thallium or technetium-MIBI scanning to locate metastatic disease. Complete surgical removal of isolated symptomatic metastases has been associated with improved survival especially in patients under 45 years old. External beam radiation can be used to manage unresectable gross residual cervical disease, painful bone metastasis and CNS lesions not amenable to resection. Chemotherapy has modest benefit in patients with advanced radioiodine thyroid disease. Patients should be considered for clinical trials such as those using tyrosine kinase inhibitors targeting activated RET/PTC oncogene. If the patient does not qualify or does

Table 42–5. TNM Staging and Survival Rates for Adults with Appropriately Treated Differentiated Thyroid Carcinoma.

Stage	Description	5-year Survival Rate	10-year Survival Rate
1	Under 45: any T, any N, no M Over 45: T < 1 cm, no N, no M	99%	98%
2	Under 45: any T, any N, any M Over 45: T > 1 cm, no N, no M	99%	85%
3	Over 45: T beyond capsule, no N, no M Or: any T, regional N, no M	95%	70%
4	Over 45: any T, any N, any M	80%	61%

not wish to participate in clinical trials then treatment with doxorubicin alone or in combination with other agents may be considered.

Prognosis

The overall prognosis of well-differentiated thyroid cancer is assessed by the initial staging and the adequacy of treatment. Table 42–5 describes the TNM staging system as well as 5- and 10-year survival rates. In this system, the staging is related to the age of the patient, recognizing that for patients who are younger than 45 years of age at the time of diagnosis, papillary tumors are relatively indolent. Stage 1 patients have an excellent 5-year survival rate of 99% and a 10-year survival rate of 98%.

The treatment modality, including the type of surgery, the radioactive treatment, and adequate L-thyroxine suppressive therapy, also affects the prognosis. Patients with tumors > 1 cm who receive partial thyroidectomies have a mortality rate that is 2.2 times greater than that of patients who undergo total thyroidectomies. Patients who have never undergone radioablation carry a twofold increased mortality rate at 10 years compared with patients who receive radioablation. Adequate suppressive therapy decreases the mortality rate but must be weighed against the possible side effects of tachycardia, arrhythmias, angina, and osteoporosis.

FOLLICULAR CARCINOMA

General Considerations

Follicular carcinoma is the second most common thyroid cancer, accounting for 16% of all thyroid cancers.

Clinical Findings

Microscopically, follicular cancer forms small follicles that contain small, cuboidal cells with poor colloid formation. The distinction between carcinoma and adenoma requires the presence of capsular or vascular invasion. It is often difficult to distinguish a follicular carcinoma from a follicular adenoma on an FNA biopsy; therefore, a frozen section at the time of surgery is necessary. Like papillary carcinoma, follicular carcinoma retains the ability to synthesize thyroglobulin and concentrate iodine and is therefore responsive to radioactive iodine treatment. Rarely, follicular carcinoma synthesizes T_3 and T_4 and presents with hyperthyroidism and distant metastases. Follicular carcinoma tends to be slightly more aggressive than papillary carcinoma; it may spread to local lymph nodes or by the blood to bone or lung. Histologic variants, such as Hürthle cell and poorly differentiated carcinoma, rarely take up radioiodine and have a higher risk of metastases and recurrence.

Treatment & Prognosis

The treatment and prognosis of follicular carcinoma are the same as for papillary carcinoma (see the previous section).

MEDULLARY THYROID CANCER

General Considerations

Medullary thyroid cancer (MTC) represents only 5% of thyroid cancers. Papillary and follicular carcinomas involve thyroid epithelial cells; medullary carcinoma is a disorder of the parafollicular or C cells.

Clinical Findings

The neuroendocrine cells of MTC appear as sheets of cells with abundant, interspersed amyloid that stains Congo red. In addition to secreting calcitonin, medullary carcinoma can secrete histaminase, prostaglandins, serotonin, and other peptides. Local extension often occurs into the lymph nodes, surrounding muscle, and the trachea. In addition, medullary carcinoma can spread via the blood to the lungs and viscera. Treatment involves surgical resection, since radiation therapy has no effect.

MTC has a natural history that is more aggressive than papillary or follicular thyroid carcinoma. Patients with multiple endocrine neoplasia (MEN) type 2b have the most aggressive form, whereas the cancers found in patients with MEN 2a and familial medullary thyroid carcinoma (FMTC) are the least aggressive. This cancer also has a strong familial association; one third of cases are sporadic, a second

third are associated with MEN 2, and the other third of cases are familial without other associated endocrinopathies. MEN 2a is composed of medullary carcinoma, pheochromocytoma, and hyperparathyroidism, whereas MEN 2b consists of medullary carcinoma, pheochromocytoma, and multiple mucosal neuromas. All patients with a MTC should be screened for other endocrinopathies found in MEN 2. Familial MTC is a clinical variant of MEN 2A in which MTC is the only manifestation. To prove that kindred has FMTC, it is necessary to demonstrate that pheochromocytoma or primary hyperparathyroidism is not present in two or more generations.

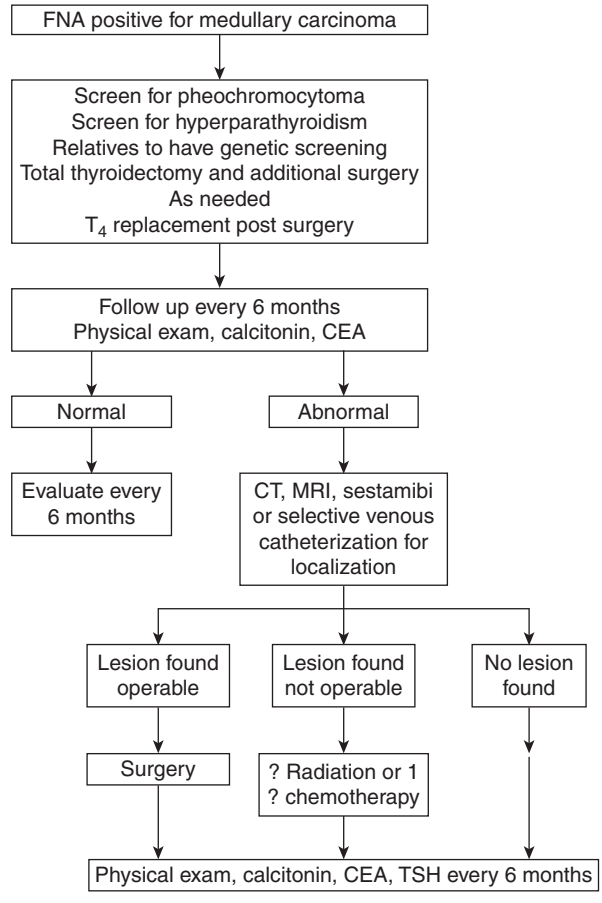
Germline RET mutations are present in MEN 2 and FMTC. Somatic RET mutations that occur later in life and are limited to C cells are present in 40% to 50% of sporadic MTC. All patients with MTC, MEN 2 or primary C-cell hyperplasia should be offered germline RET screening. All people with family history of MEN 2 or FMTC should be offered RET testing. For MEN 2b this should be done shortly after birth. For MEN 2a and FMTC this should be done before 5 years of age.

Treatment

Preoperative evaluation of patients presumed to have MTC should have serum measurements of calcitonin, antigen (CEA), serum calcium and albumin. Consideration should also be given to screening for pheochromocytoma using plasma or 24 hour urine metanephrines or normetanephrines. If the catecholamine measurements are consistent with a pheochromocytoma diagnosis then an adrenal MRI or CT scan is indicated. The pheochromocytoma should be surgically resected prior to surgery for MTC. Patients who have ultrasound evidence for LN involvement should also undergo a chest, neck and liver CT, or contrast-enhanced MRI.

Patients with MTC with no evidence of LN involvement or distant metastasis should undergo total thyroidectomy with prophylactic central compartment (level VI) neck dissection. Patients with local metastatic disease in the regional lymph nodes should also have lateral neck dissection. Since C-cell tumors are not TSH dependent, L-thyroxine replacement targets TSH levels between 0.5 and 2.5 mIU/L. There is no role of ^{131}I or chemotherapy in the treatment of medullary carcinoma. Patients should be monitored for the recurrence of disease with serum calcitonin or CEA measurements (Figure 42–9). Imaging modalities include MRI of the neck and chest, PET scanning, indium-labeled somatostatin scanning, or sestamibi scanning. In addition, family members should be screened for familial medullary carcinoma and the *RET* proto-oncogene associated with MEN 2a and 2b.

MEN 2 patients who present with palpable MTC have a low rate of surgical cure. Prophylactic thyroidectomy is therefore indicated in family members with germline RET mutations. The codon mutated is used to guide the timing of the surgery. Mutations at RET codons 883 and 918 are associated with the youngest age of onset and highest risk of metastasis and disease-specific mortality. Patients with these mutations should therefore undergo prophylactic thyroid surgery soon as possible in the first year of life. Patients with mutation at RET codon 634 should have thyroid surgery before the age of 5 years. For patients with mutation at RET codons 609, 611, 618, 620, and 630, surgery before the age of 5 is preferable but can be deferred if normal annual basal or stimulated calcitonin; normal annual neck ultrasound; less aggressive family history of MTC; and family preference. Patients with mutation at RET codons 768,790, 791, 804790, 791, 804, and 891 are at the least high risk and surgery can be deferred beyond 5 years of age provided normal annual basal or stimulated calcitonin; normal annual neck ultrasound; and less aggressive family history of MTC and family preference. Preimplantation and prenatal testing should be made available to carriers of RET mutations.



▲ **Figure 42–9.** Management of medullary carcinoma. CEA, carcinoembryonic antigen; TSH, thyroid-stimulating hormone.

ANAPLASTIC CARCINOMA

General Considerations

Undifferentiated (anaplastic) carcinoma represents 1% of all thyroid cancers. Histopathologic types include small cell, giant cell, and spindle cell carcinomas. Anaplastic carcinoma is the most aggressive form of thyroid cancer and rapidly expands by local extension into surrounding structures. It results in death in 6–36 months.

Clinical Findings

The typical presentation of anaplastic thyroid carcinoma is an older patient with a long history of goiter with sudden rapid expansion of the gland followed by compressive symptoms or vocal cord paralysis.

Treatment & Prognosis

Anaplastic thyroid carcinoma is resistant to all treatment modalities. Treatment is palliative and includes isthmectomy to prevent tracheal compression, and external-beam therapy plus suppressive L-thyroxine therapy. Although chemotherapy is generally not effective with anaplastic carcinoma, doxorubicin may be useful in patients who cannot undergo other forms of therapy. Anaplastic carcinoma carries a very poor prognosis because of the aggressiveness of the disease and a lack of responsiveness to treatment.

OTHER THYROID CANCERS

Other types of malignant thyroid disorders represent approximately 3% of all thyroid cancers. These include lymphomas, metastatic carcinomas, fibrosarcomas, squamous cell carcinomas, malignant hemangioendotheliomas, and teratomas. Lymphoma can present rapidly in patients with long-standing Hashimoto's thyroiditis, or it may develop in association with generalized lymphoma. The thyroid lymphoma associated with Hashimoto's thyroiditis can sometimes be difficult to distinguish from chronic thyroiditis. In the absence of systemic spread, thyroid lymphoma is responsive to radiation therapy. Common meta-static cancers of the thyroid include breast, renal cell, and bronchogenic cancers, as well as melanoma.

Cooper DS et al. American Thyroid Association (ATA) Guidelines Taskforce on thyroid nodules and differentiated thyroid cancer. Revised American Thyroid Association management guidelines for patients with thyroid nodules and differentiated thyroid cancer. *Thyroid* 2009;19(11):1167–214 [PMID: 19860577]. (Review of currently recommended approach to thyroid nodules.)

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NONMALIGNANT THYROID DISORDERS

HYPERTHYROIDISM & THYROTOXICOSIS

Thyrotoxicosis is a clinical syndrome that results from excessive levels of circulating thyroid hormone. The most common causes of thyrotoxicosis are due to overproduction of thyroid hormone by the thyroid gland, but other sources of thyroid hormone may exist, including exogenous ingestion of thyroid hormone or ectopic secretion (Table 42–6).

Patients with thyrotoxicosis classically present with a large number of symptoms related to hypermetabolism;

Table 42–6. Causes of Hyperthyroidism (in Order of Frequency).

Graves' disease
Toxic multinodular goiter
Solitary hyperfunctioning adenoma
Subacute thyroiditis (transient)
Exogenous thyroid hormone
Iodine-induced hyperthyroidism
Struma ovarii
Metastatic follicular thyroid carcinoma
Trophoblastic tumors
TSH-secreting pituitary adenoma
Pituitary resistance to thyroid hormone

Table 42–7. Signs and Symptoms of Hyperthyroidism.

Symptoms	Signs
Irritability	Tachycardia, atrial fibrillation
Insomnia	Systolic hypertension
Heat intolerance	Extremity tremor
Diaphoresis	Warm, moist skin
Heart racing and palpitations	Fine or thin hair
Weight loss with increased appetite	Lid lag or retraction
Diarrhea	Goiter with bruit
Oligomenorrhea, loss of libido	

these symptoms, listed in Table 42–7, include anxiety, insomnia, a racing heartbeat, palpitations, hand tremors, increased stool frequency, weight loss, heat intolerance, and increased perspiration. Older patients may exhibit "apathetic hyperthyroidism," which is characterized by weight loss, severe depression, and the potential for slow atrial fibrillation.

On physical examination, patients may be hyperkinetic with an inability to sit still; they may also present with fine tremor and hyperreflexia. Lid retraction is responsible for the characteristic "stare" and lid lag may be evident whereby the sclera can be seen above the iris when the patient is asked to gaze downward slowly. Lid retraction and lid lag are due to the hyperadrenergic state and should not be confused with exophthalmos, which is unique to Graves' disease. The patient's skin may have a velvety, moist texture, and the hair is thin and fine. Cardiovascular signs include tachycardia, widening of the pulse pressure with an increase in systolic pressure and a decrease in diastolic pressure, and a hyperdynamic precordium. Atrial fibrillation occurs in approximately 10% of patients with thyrotoxicosis. Examination of the neck may reveal a diffusely enlarged or multinodular goiter, a single nodule, or a painful and tender thyroid. A bruit may be present and is most often heard over the gland in Graves' disease.

The diagnosis is confirmed by laboratory analysis. Overt thyrotoxicosis typically has a suppressed TSH and elevated FT_4 and FT_3 concentrations. A normal T_4 but an elevated T_3 is consistent with T_3 toxicosis, usually seen in the early phase of toxic multinodular goiter and Graves' disease. The diagnosis of the etiology of thyrotoxicosis can be aided by the physical examination—the presence of ophthalmopathy, diffuse goiter, and pretibial myxedema is suggestive of Graves' disease. Additional laboratory tests, such as TSI (thyroid-stimulating immunoglobulin), anti-TPO, and ESR (erythrocyte sedimentation rate) can be helpful in diagnosing Graves' disease, the hyperthyroid phase of Hashimoto's disease, and viral thyroiditis. Radioactive thyroid uptake and scan are occasionally needed to confirm the cause of thyrotoxicosis.

GRAVES' DISEASE

General Considerations

Graves' disease is an autoimmune disorder characterized by the production of immunoglobulins that bind and activate the TSH receptor, which stimulates thyroid growth and hormone secretion. It tends to occur in women between the ages of 20 and 40, with an incidence of 1.9% in women. Females are five times more likely to be affected than males. There is a strong family predisposition in that 15% of patients have a close relative with the disorder.

Clinical Findings

In addition to the signs and symptoms of hyperthyroidism, several signs and symptoms are unique to Graves' disease, including ophthalmopathy, dermopathy, and osteopathy. Infiltrative ophthalmopathy is by far the most common sign. For unclear reasons, the increased inflammation and the accumulation of glycosaminoglycans cause swelling of extraocular and retroorbital muscles, as well as displacement of the eye forward (also known as proptosis or exophthalmos). Patients can experience eye irritation; excessive tearing worsened by cold air, bright lights, or wind; diplopia; blurred vision; and, rarely, loss of vision.

Other physical findings in Graves' disease include dermopathy and osteopathy. Glycosaminoglycans can accumulate in the dermis layer, causing thickening of the skin, especially over the anterior tibia (pretibial myxedema). Osteopathy may occur with subperiosteal bone formation and swelling. The extrathyroidal manifestations often have a course independent of the thyroid disease itself and can persist despite restoration of the euthyroid state.

Laboratory Tests

The diagnosis of Graves' disease can be made from evidence of ophthalmopathy on the physical exam, as well as a decreased TSH and an increased FT_4 or FT_3. If ophthalmopathy is absent, obtaining a measure of TSI can be helpful. TSI is specific for Graves' disease but the lack of a TSI elevation does not exclude the diagnosis. The presence of autoantibodies provides supportive evidence for Graves' disease. More than 95% of patients have anti-TPO antibodies and about 50% have antithyroglobulin antibodies. In the absence of eye signs or an elevated TSI, a radioactive scan and uptake can be performed to confirm the diagnosis of Graves' disease.

Treatment

There are three aspects in the treatment of Graves' disease: (1) the control of hyperadrenergic symptoms, (2) the short-term restoration of the euthyroid state, and (3) the long-term control of excess thyroid hormone production.

A. Control of Adrenergic Excess

To control the symptoms of adrenergic excess, beta-blockers—either propranolol or atenolol—are used. These agents should be instituted even before determining the cause of hyperthyroidism. Propranolol has the advantage of inhibiting peripheral T_4 to T_3 conversion, whereas atenolol is more convenient with once-daily dosing. A typical starting dose is 10–20 mg of propranolol—three to four times a day, or 25 mg of atenolol once daily. These drugs are then titrated up over a few days while the patient's pulse and blood pressure are monitored. The beta blockade is discontinued once the serum FT4 and T3 levels return to normal.

B. Restoration of Euthyroid State

Thionamides (methimazole or propylthiouracil) act by inhibiting TPO-mediated iodination of thyroglobulin to form T_4 and T_3 within the thyroid gland and are generally used to restore the patient to the euthyroid state before deciding on long-term management. Methimazole is the preferred drug in most circumstances because propylthiouracil has been associated with the increased risk of fulminant hepatitis resulting in death or need for liver transplantation. Also, in patients for whom ^{131}I treatment is planned, methimazole is preferable to propylthiouracil because propylthiouracil may inhibit radioactive iodine uptake for weeks or months after discontinuation. Typically, a patient is started on a daily 20–40 mg dose of methimazole for 1–2 months, and then titrated down to a maintenance dose of 5–10 mg. Titration of the drug dose is based on the measurement of TSH and FT_4, as well as on the signs and symptoms of hyper- or hypothyroidism.

Propylthiouracil should only be used if the patient is allergic to methimazole. The typical starting dose of propylthiouracil is 100–150 mg three times a day; after 1–2 months it is titrated down to 50–100 mg twice daily. It also is more protein bound and is therefore the preferred drug at time of conception and in the first trimester of pregnancy. Because of hepatotoxicity concerns, consider switching back to methimazole in the second and third trimesters. Although less propylthiouracil is excreted in breast milk than methimazole, both drugs are considered safe for use during breast feeding provided the doses are kept low. In pregnancy, if the initial dose of propylthiouracil is 300 mg or less and the maintenance dose is 50–150 mg daily, the risk of fetal hypothyroidism is extremely low. The thionamide doses are titrated to maintain total T4 at the upper limit of normal.

Both methimazole and propylthiouracil cause a rash in approximately 5.0% of patients. Agranulocytosis, which occurs in about 0.5% of patients, is usually heralded by a severe sore throat and fever. Patients should be counseled to stop the drug if they get a sore throat or fever and to see their physician. If the white blood cell count is normal, then the antithyroid drug can be resumed. Other serious side effects requiring discontinuation of drug include arthritis with both drugs; cholestatic jaundice with methimazole; angioneurotic edema, hepatocellular toxicity, and vasculitis with propylthiouracil.

C. Long-Term Therapy

The choice of long-term therapy is based on the age of the patient, the severity and duration of the hyperthyroidism, the size of the gland, and the potential for a future pregnancy. In the one randomized trial that assessed the efficacy of drug treatment, radioablation, and surgery, all three modalities were found to be equally effective. However, there are several guidelines for choosing a treatment modality.

1. Methimazole—Methimazole treatment is chosen for long-term therapy, particularly in adolescents and young patients with small glands and less severe disease. The drug is usually given for up to 18 months to allow the disease to remit spontaneously. This remission occurs in 30–40% of patients treated for 18 months. If the patient relapses after stopping the methimazole, then the patient has the option of going back on methimazole or consider radioactive iodine therapy or surgery.

2. Radioactive iodine—Radioactive iodine ablation is the treatment of choice in patients 21 years and older. From a survey performed by the American Thyroid Association, 69% of American thyroid specialists recommended radioablation as the therapy of choice. In contrast, only 22% and 11% of European and Japanese thyroid doctors recommended radioablation as a first-line therapy.

With this treatment modality, patients are dosed with radioactive iodine based on their uptake scan. Patients with severe hyperthyroidism, serious thyroid enlargement, or a history of heart disease should be adequately returned to the euthyroid state with methimazole prior to radioablation, with methimazole discontinued about 5 days prior to radioablation. Most patients subsequently become hypothyroid and require thyroid hormone replacement. Approximately 10% of patients have unsuccessful radioablation and may require a second dose. Radioactive iodine treatment is contraindicated in pregnancy, and it is important to advise women who may become pregnant in the near future that they should wait at least 6 months after ^{131}I treatment to allow for the resolution of any transient effects of the radiation on the ovaries. Alternative options should be offered to a female patient who cannot wait that long. Radioiodine therapy can exacerbate Graves' ophthalmopathy especially if the disease is severe or if the patient is a smoker. Concomitant glucocorticoid therapy can prevent exacerbation. Surgery may be a better option for such patients.

3. Thyroidectomy—Total or subtotal thyroidectomy should be considered in patients with a very large gland (ie, >150 g), those with severe Graves' ophthalmopathy, those who are allergic to antithyroid drugs, and the patient who wants to get pregnant soon. Patients should be given thionamides until a euthyroid state is achieved (approximately 6 weeks), and a saturated solution of potassium iodide—5 drops twice

daily for the 2 weeks before surgery. The preoperative iodine treatment decreases the vascularity of the gland and reduces intraoperative blood loss. The degree of the thyroidectomy is variable among surgeons but generally 2–3 g of thyroid tissue is left intact. If an experienced surgeon is available then total thyroidectomy is preferable because leaving behind too much tissue may result in disease recurrence. Total thyroidectomy is also preferred in patients with progressive exophthalmos.

Surgical complications include neck hematoma, recurrent laryngeal nerve injury, and hypoparathyroidism. A neck hematoma can cause airway compromise and must be evacuated immediately. In experienced surgeons the rate of hypoparathyroidism is less than 1%. Approximately 10% of patients develop transient post-operative hypocalcemia. Oral and intravenous calcium supplementation is sufficient to control the symptoms. The rate of recurrent laryngeal nerve injury leading to ipsilateral vocal cord paralysis is also about 1%. Bilateral recurrent laryngeal nerve injury can cause severe respiratory impairment and may require tracheostomy. It is now extremely rare after subtotal thyroidectomy.

Most patients require thyroid hormone replacement therapy postoperatively.

Complications

A. Thyroid Crisis (Thyroid Storm)

Thyroid crisis is an acute exacerbation of all symptoms of thyrotoxicosis. It occurs in patients with inadequately controlled thyrotoxicosis who undergo surgery, radioactive iodine treatment, parturition, and severe stressful illnesses such as infections, uncontrolled diabetes, and myocardial infarction. This disorder results from hypermetabolism and excessive adrenergic response. It is typically associated with Graves' disease but can also occur in patients with toxic nodular goiter.

Systemic symptoms include fever (38–41°C), flushing, and sweating. Cardiac symptoms and signs include tachycardia, atrial fibrillation, and congestive cardiac failure. Neurologic symptoms and signs include agitation, restlessness, delirium, and coma. Gastrointestinal symptoms include abdominal pain, nausea, vomiting, diarrhea, and jaundice.

Thyroid crisis is a medical emergency and should be treated promptly. Propranolol, either in a dose of 1–2 mg given as a slow IV injection, or in a dose of 40–80 mg administered orally, is given to control tachyarrhythmias. Methimazole is given at a dose of 20 mg every 6 to 8 hours. Propylthiouracil (250 mg every 6 hours) was traditionally favored because it partially blocked the peripheral conversion of T4 to T3. It is however no longer considered first line therapy because of its association with hepatocellular injury. If the patient cannot take oral medications, then 60 mg of methimazole every 24 hours or 400 mg of propylthiouracil can be administered rectally. An hour *after* a dose of methimazole or propylthiouracil has been given, hormone release can be retarded by giving an oral, saturated solution of potassium iodide (10 drops twice daily). The oral cholecystographic agents (sodium ipodate or iopanoic acid) similarly retard hormone release and also potently block T_4 to T_3 conversion, but they are not currently available in the United States. Sodium iodide (1 g) can be given intravenously over 24 hours. In addition, 50 g of hydrocortisone is administered intravenously every 6 hours, then tapered as clinical improvement occurs. Supportive measures include intravenous fluids and the management of electrolytes and nutrition. Aspirin should be avoided because it can displace T_3 from TBG.

B. Graves Ophthalmopathy

The American Thyroid Association has classified Graves ophthalmopathy into six classes: (1) Class 1, spasm of the upper eyelids; (2) Class 2, soft tissue involvement with periorbital edema and conjunctival chemosis; (3) Class 3, proptosis; (4) Class 4, muscle involvement that limits gaze; (5) Class 5, corneal involvement (eg, keratitis); and (6) Class 6, visual loss due to optic nerve involvement.

The treatment of Graves' ophthalmopathy involves (1) reversal of the hyperthyroid state; (2) symptomatic treatment with eye lubrication, glucocorticoids, or both; and (3) with severe symptoms, the surgical decompression of the orbit. Most patients have mild disease; one study found that approximately 65% of patients treated with thionamide therapy alone had no progression of eye disease, and only 8% demonstrated deterioration.

Restoration of the euthyroid state can be achieved by thionamide therapy, radioablation, and surgery. Radioablation can aggravate the ophthalmopathy, especially in smokers. Treatment with a short course of prednisone (40–60 mg/d) tapered over 4–6 weeks at the same time as ^{131}I treatment can prevent this exacerbation.

In most patients, symptomatic treatment involves alleviating corneal irritation and wearing dark glasses. Glucocorticoid therapy is indicated for worsening chemosis, diplopia, or proptosis. Surgical decompression is warranted for progressive eye disease despite glucocorticoids, optic nerve changes, corneal ulceration or infection, and cosmetic reconstruction. A loss of vision, which is heralded by a loss of color vision, is considered a medical emergency; the patient should be treated with high-dose glucocorticoids and surgical decompression. Orbital radiotherapy can also be used if glucocorticoid therapy is ineffective or if there is recurrence after the dose is tapered.

Bartalena L et al. Consensus statement of the European group on Graves' orbitopathy (EUGOGO) on management of Graves' orbitopathy. Thyroid. 2008;18(3):333–346 [PMID: 18341379]. (Evidence based recommendations on the treatment of thyroid orbitopathy.)

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Weetman AP. Graves' disease. *N Engl J Med*. 2000;343(17):1236 [PMID: 11071676]. (Comprehensive review of the pathogenesis, clinical signs and symptoms, diagnosis, and treatment of Graves' disease.)

OTHER FORMS OF THYROTOXICOSIS

1. Amiodarone-Lnduced Hyperthyroidism

General Considerations

The antiarrhythmic drug amiodarone contains 37.3% iodine and has a half-life of about 50 days. Although amiodarone-induced hypothyroidism is far more common than hyperthyroidism, 2% of patients on amiodarone will develop hyperthyroidism. The symptoms of amiodaroneinduced hyperthyroidism may be blunted by the antiadrenergic effects of amiodarone itself, and hyperthyroidism often develops years after starting this medication.

Etiology & Clinical Findings

There are two etiologies responsible for hyperthyroidism that manifests in the setting of amiodarone: (1) excess iodine in an underlying abnormal gland causes excessive hormone production and (2) thyroiditis caused by amiodarone itself. Thyroid ultrasound may be useful in differentiating between the two causes, with an increased Doppler flow in excess hormone production and a decreased Doppler flow in thyroiditis. However, many patients may have a mixed etiology, and it is often difficult to differentiate between the two forms.

Treatment

Patients may be treated with higher-dose thionamides, such as 40–60 mg of methimazole, and beta-adrenergic blockade. If there is inadequate control, a 40-mg daily dose of prednisone is often helpful, especially in cases of amiodarone-induced thyroiditis. Total thyroidectomy should be considered since it is curative, but patients often have a poor operative status.

Eskes SA, Wiersinga WM. Amiodarone and thyroid. *Best Pract Res Clin Endocrinol Metab.* 2009;23(6):735–751 [PMID: 19942150]. (Comprehensive review of amiodarone-induced hypothyroidism and hyperthyroidism.)

2. Subacute Thyroiditis

General Considerations

Subacute granulomatous thyroiditis is an acute inflammatory disorder of the thyroid gland presumed to be due to viral infection. Subacute granulomatous thyroiditis may also be referred to as de Quervain thyroiditis, subacute thyroiditis, and subacute nonsuppurative thyroiditis.

Clinical Findings

The classic signs and symptoms are fever, malaise, and soreness of the neck; the thyroid gland is extremely tender on examination. Patients need a changing pattern of thyroid function tests throughout the course of the disease. Initially, with thyroid follicle damage and the release of preformed thyroid hormones, TSH is decreased, with an increase in T_4 and T_3 and a low radioactive iodine uptake. After 2–6 weeks, patients enter a euthyroid phase as T_4, T_3, and TSH levels return to normal. A transient hypothyroid phase of 2–8 weeks ensues while thyroid hormone stores are exhausted and the thyroid follicles regenerate. Most patients return to the euthyroid state once the thyroiditis has resolved; however, a hypothyroid state may be permanent in 10% of patients.

Diagnosis

The diagnosis of subacute thyroiditis is made clinically. A markedly elevated ESR as high as 100 mm/h is strongly suggestive of the diagnosis. Additional helpful laboratory findings include negative thyroid autoantibodies.

Treatment

Patients are usually treated symptomatically with beta-blockers and nonsteroidal anti-inflammatories (NSAIDs); prednisone is usually reserved for more severe cases. Patients who become hypothyroid should be administered L-thyroxine.

3. Rare Forms Of Thyrotoxicosis

A. Thyrotoxicosis Factitia

Thyrotoxicosis factitia is a psychoneurotic disorder in which patients purposely take thyroid hormones, usually for weight control. In addition, patients may be given thyroid hormones by psychiatrists to facilitate the treatment of depression. Clinical findings include the absence of a goiter, a suppressed TSH level, mild elevation of T_4 and T_3, a negative radioactive iodine uptake level, and a low thyroglobulin level.

B. Struma Ovarii

Teratoma of the ovaries may contain functioning thyroid tissue, which results in hyperthyroidism. Radioactive iodine uptake in the neck is absent, but a whole body scan shows an increased uptake in the pelvis. Curative treatment involves resection of the teratoma.

C. Metastatic Follicular Carcinoma

Follicular thyroid carcinoma usually does not retain the ability to produce active hormone, but in rare instances, as in the presence of metastatic disease, follicular carcinoma can produce a hyperthyroid state. A radioactive body scan usually shows an increased uptake in the lungs or bones.

D. Hydatidiform Mole

Hydatidiform moles do not produce thyroid hormone; rather, they produce chorionic gonadotropin, which displays TSH-like activity. Clinical evidence of hyperthyroidism is

Table 42–8. Causes of Hypothyroidism (in Order of Frequency).

Primary Hypothyroidism
1. Hashimoto's thyroiditis
2. Iatrogenic:
   a. Radioactive iodine therapy for Graves' disease
   b. Subtotal thyroidectomy for Graves' disease or nodular goiter
3. Excessive iodide intake (kelp, radiocontrast dyes)
4. Transient hypothyroidism
   a. Subacute lymphocytic thyroiditis
   b. Subacute granulomatous thyroiditis
   c. Postpartum thyroiditis
5. Lithium, antithyroid drugs (methimazole, propylthiouracil); (rare)
6. Iodide deficiency (rare)
7. Inborn errors of thyroid hormone synthesis (rare)

Secondary Hypothyroidism
1. Hypopituitarism due to a pituitary adenoma
2. Pituitary ablative therapy

Tertiary Hypothyroidism
1. Hypothalamic dysfunction (rare)

usually not present, but a laboratory workup can reveal a suppressed TSH and a mild elevation of serum T_4 and T_3. Resection of the mole is curative.

HYPOTHYROIDISM

General Considerations

The failure of thyroid hormone production results in a generalized hypometabolic state and seriously impairs normal growth and development if it occurs early in life. Hypothyroidism may be due to a primary disease of the thyroid gland, or it may be secondary to a pituitary deficiency. Hypothalamic dysfunction, resulting in a TSH deficiency or peripheral resistance to the action of thyroid hormone, is a rare cause (Table 42–8).

Clinical Findings

In adults, the onset of symptoms of hypothyroidism is often insidious. These symptoms include fatigue, weight gain, intolerance to cold, and a delayed relaxation phase to deep tendon reflexes (Table 42–9).

Hashimoto's thyroiditis is the most common cause of hypothyroidism. It is an autoimmune disease characterized by lymphocytic infiltration, destruction of thyroid follicles, and fibrosis. Several autoantibodies are present, including anti-TPO, antithyroglobulin antibody, and TSH-receptor-blocking antibody. Thyroperoxidase antibodies remain positive for many years and are useful for diagnosis. There may or may not be a goiter. The goiter in Hashimoto's thyroiditis is usually moderate in size and firm in consistency. In older patients, the thyroid may be totally destroyed by the immune process, and the gland is found to be small on examination.

Table 42–9. Signs and Symptoms of Hypothyroidism.

Symptoms	Signs
Fatigue, weakness	Bradycardia
Cold intolerance	Delayed tendon reflexes
Dyspnea on exertion	Slowed movement and speech
Weight gain	Dry, rough skin, loss of eyebrows
Constipation	Nonpitting edema, periorbital edema
Hoarseness	Muscle stiffness, proximal weakness
Menorrhagia	Carotenemia
Rrare: Dementia	Rare: Pleural and pericardial effusions
	Depressed ventilatory drive
	Diastolic hypertension

Diagnosis

The diagnosis of suspected hypothyroidism is outlined in an algorithm listed in Figure 42–6. In primary hypothyroidism, the TSH is elevated with a low FT_4 level. In secondary hypothyroidism, the TSH level is low or inappropriately normal with a low FT_4 level. Secondary hypothyroidism may also present with other signs of pituitary deficiency, including hypogonadism and adrenal insufficiency.

Treatment

Treatment involves hormone replacement with L-thyroxine; the average replacement dosage in adults is 1.6 mcg/kg/d. In young, healthy adults, a starting dosage of 75–100 mcg can be used, followed by a dosing adjustment every 4–6 weeks. Elderly patients or patients with coronary artery disease should be started on much smaller doses of 12.5–25.0 mcg/d, and then increased by 12.5–25.0 mcg every 4–6 weeks until the TSH level normalizes between 0.5 and 2 mU/L. Once stabilized, patients should be monitored once or twice a year with TSH and FT_4. T_4 has a half-life of about 7 days and therefore needs to be given only once daily.

Desiccated thyroid is unsatisfactory because of its variable hormone content and should not be used. The use of T_3 is controversial. The current preparation is rapidly absorbed, has a short half-life, and a rapid biological effect. Patients who experience malabsorption or who ingest drugs such as calcium and iron, which impair T_4 absorption, may require an increase in T_4 dosing. Since the half-life of T_4 is long, it is not a problem omitting the drug for a few days if the patient is unable to take oral medications. Alternately, the patient can be given parenteral L-thyroxine at 75% of the usual oral dose.

MYXEDEMA COMA

General Considerations

Severe, untreated hypothyroidism can result in a hypothermic coma. It tends to occur in elderly patients and is frequently fatal (>20% incidence).

Clinical Findings

Myxedema coma is characterized by hypothermia, bradycardia, alveolar hypoventilation with CO_2 retention, hyponatremia, hypoglycemia, and either stupor or coma. The diagnosis is often difficult because the coma and hypothermia may be due to other causes, such as stroke. Heart failure, pneumonia, excessive fluid administration, and sedatives or narcotic use can precipitate myxedema coma.

Treatment

Treatment consists of L-thyroxine administered intravenously, at an initial loading dose of 300–400 mcg, followed by 80% of the calculated full replacement dose intravenously daily. Ventilatory support may be required for hypoventilation and hypercarbia. Hyponatremia is treated with fluid restriction. Active rewarming is contra-indicated, because it may induce vasodilation and vascular collapse. The patient should be screened for concomitant adrenal insufficiency by a cosyntropin stimulation test. Until the cortisol results are available, the patient should be treated with hydrocortisone (100-mg IV bolus followed by 50 mg intravenously every 6 hours).

Biondi B, Cooper DS. The clinical significance of subclinical thyroid dysfunction. *Endocr Rev*. 2008;29(1):76–131 [PMID: 17991805]. (Review focusing on the prevalence, natural history, and potential consequence of subclinical hypothyroidism and subclinical thyrotoxicosis.)

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43

Parathyroid Disorders

Michael C. Singer, MD & David J. Terris, MD, FACS

The parathyroid gland is a key regulator of calcium homeostasis. While hyperparathyroidism is now most often diagnosed in asymptomatic patients, untreated it can have devastating effects on multiple organ systems. Primary hyperparathyroidism, the most common cause of hypercalcemia in nonhospitalized patients, is treated surgically in most cases.

EMBRYOLOGY & ANATOMY

During the fifth week of gestation, the parathyroid glands form from the third and fourth branchial pouches. The glands derived from the third pouches descend caudally in the neck along with the thymus gland (formed from the third branchial arch), while the glands from the fourth pouches remain stationary. Knowledge of this embryologic migration, which results in the glands arising from the fourth pouches to be superiorly located and those from the third pouches to be inferior, is critical when searching for ectopically located glands.

The superior parathyroid glands are typically closely associated with the posterolateral aspect of the superior poles of the thyroid gland. The inferior glands, which are more variable in positioning, are most commonly found near the inferior poles of the thyroid gland. These are sometimes embedded within the superior aspect of the thymus gland or within the thyrothymic ligament.

Deviation from the standard migratory pattern during embryogenesis can lead to aberrantly located glands in approximately 15 to 20% of patients, although this has been reported to be higher in individuals with renal hyperparathyroidism. Aberrant glands can occur in any location along their migration course and have been identified from the carotid bifurcation to the level of the aortic arch.

While the majority of people have four parathyroid glands, approximately 2 to 5% have five or more glands. A similar percentage has fewer than four glands.

The blood supply to parathyroid glands is fairly constant. Both the superior and inferior glands are fed from branches of the inferior thyroid artery. Occasionally, superior glands are supplied by an anastomotic branch from the inferior to the superior thyroid artery or are fed by both arteries. These arteries enter the glands at their hila, an anatomic characteristic which distinguishes them from surrounding fat. The arterial branches supplying the glands can be variably positioned relative to the recurrent laryngeal nerve.

Normal parathyroid glands, often bean shaped, appear a distinct yellowish brown, often described as caramel in color. Manipulation of the glands and their blood supply during surgery will change the color to a darker mocha brown. Healthy glands weigh 30 to 40 mg on average.

Physiology

Parathyroid hormone (PTH) impacts calcium homeostasis by targeting the kidneys, skeletal system, and gastrointestinal tract. The parathyroid chief cells are responsible for the production and storage of PTH. Hormone release by parathyroid glands is directly controlled by feedback inhibition of the glands by serum calcium.

PTH acts to raise calcium levels by several mechanisms. It influences the kidneys to increase calcium reabsorption, promotes resorption and calcium release by the bones and enhances absorption of calcium in the intestines by increasing renal activation of vitamin D.

HYPERPARATHYROIDISM

Hyperparathyroidism is the most common disorder of parathyroid function. Hyperparathyroidism is categorized as primary, secondary or tertiary depending on the etiology. Primary and tertiary hyperparathyroidism are treated surgi-

cally while secondary hyperparathyroidism is usually managed medically.

PRIMARY HYPERPARATHYROIDISM

ESSENTIALS OF DIAGNOSIS

- Elevated serum calcium level
- Elevated serum PTH level
- Must differentiate between primary, secondary and tertiary hyperparathyroidism.

Primary hyperparathyroidism is due to a primary defect in the parathyroid glands, such that elevated serum calcium fails to inhibit additional PTH release. Approximately 0.3 to 1% of the general population develops primary hyperparathyroidism. Rare prior to puberty, its incidence peaks in women in their fourth to seventh decades.

Pathogenesis

In a majority of primary hyperparathyroidism patients, dysfunctional calcium sensing receptors on the surface of chief cells is the cause. Single adenomas are present in 80 to 85% of cases, double adenomas in 2 to 3%, and multigland hyperplasia in 12 to 15%. Parathyroid carcinoma is a rare cause of primary hyperparathyroidism.

Clinical Findings

The introduction over 30 years ago of accurate and mechanized laboratory tests for serum calcium levels has allowed for earlier and more frequent detection of primary hyperparathyroidism. Historically, patients presented with the classic constellation of "groans, bones, stones, and psychiatric overtones". Currently, the vast majority of patients are diagnosed on routine lab testing and are asymptomatic. Long-standing, untreated primary hyperparathyroidism can lead to early death, often from cardiac dysfunction.

In addition to generalized fatigue and weakness, multiple systems can be impacted:

- Gastrointestinal: Abdominal pain, constipation, nausea, vomiting, peptic ulcer, and pancreatitis.
- Rheumatologic: Bone pain, osteoporosis, arthralgia, myalgia, and gout.
- Renal: Nephrolithiasis, polyuria, polydipsia, and renal failure.
- Psychiatric: Depression, dementia, and confusion.
- Cardiovascular: Hypertension and cardiac arrhythmias.

Diagnosis

A. Laboratory

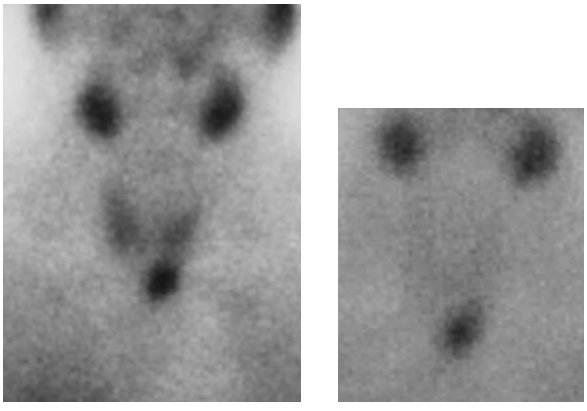
While there are numerous physiological derangements that can occur in primary hyperparathyroidism, elevated calcium and PTH levels are fundamental to the diagnosis. Several additional laboratory tests can contribute to making an accurate diagnosis.

- Hypercalcemia: An elevated calcium level is a hallmark of the diagnosis. While an elevated serum calcium level is almost always present and adequate for diagnosis, in some situations, only the physiologically active ionized calcium is elevated. In the blood, approximately 50% of calcium is bound to protein, typically albumin, 5% is complexed with phosphate or citrate and the remainder is ionized. In the setting of hypoalbuminemia, serum calcium levels can be normal while the ionized fraction is elevated.
- Hyperparathyroidism: The introduction of new assays has allowed accurate assessments of intact PTH levels. In primary hyperparathyroidism, PTH levels can range from the high end of normal to markedly elevated level. In the setting of hypercalcemia, a PTH level at the high end of normal should be considered inappropriate and needs further diagnostic workup.
- Hypophosphatemia: Increased PTH levels promote renal excretion of phosphate. Approximately 50% of patients with primary hyperparathyroidism have below normal serum phosphate levels.
- Normal to elevated urine calcium: A 24 h total urine calcium level and calcium clearance can help in differentiating familial hypocalciuric hypercalcemia (FHH) from primary hyperparathyroidism, in which normal to elevated urine calcium levels are present. Inappropriately low urine calcium excretion suggests FHH.

B. Radiologic

The development of effective imaging modalities for identifying hyperfunctioning parathyroid glands has promoted the performance of directed, or minimally invasive, parathyroidectomies.

- Radionuclide Scanning: The localization ability of Technetium 99m sestamibi scintigraphy is based on its preferential uptake by parathyroid cells, due to their high mitochondrial activity. (Figure 43–1) Delayed images taken 2 to 3 h after injection are sensitive in up to 90% of single adenoma cases, with over 90% specificity. Sestamibi imaging is also effective in cases of double adenoma. However, it has significantly reduced accuracy in cases of four-gland hyperplasia. Its physiologic basis aids in identification of ectopic glands. More recently, some have used this technique in combination with single-photon emission computed tomography and report improved three-dimensional localization.



A B

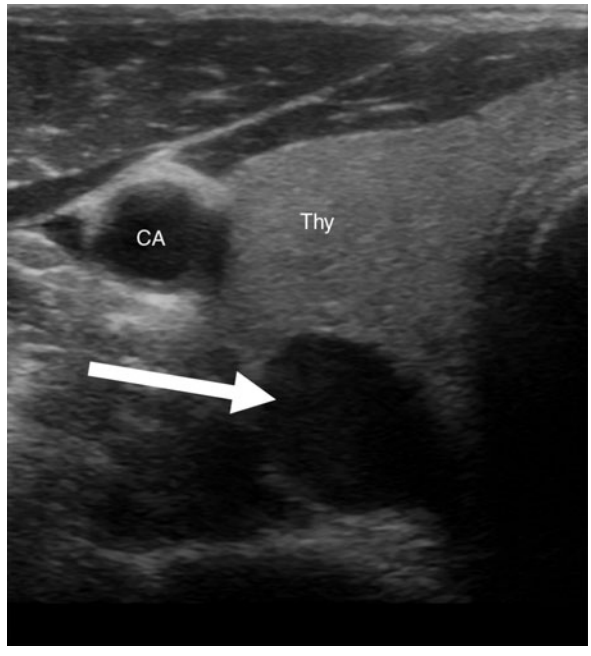
▲ **Figure 43–1.** Images from a ^{99m}technetium-sestamibi scan 15 min after injection: **(A)** in a patient with primary hyperparathyroidism showing uptake in the salivary glands, thyroid gland, and a left inferior parathyroid adenoma. A delayed image obtained at 2 h **(B)** reveals washout from the thyroid, but retention in the mitochondrial-rich parathyroid adenoma.

- Ultrasound: High-resolution ultrasonography (US) can be used for localization of parathyroid adenomas. (Figure 43–2) US is a noninvasive, easily performed and inexpensive modality to evaluate primary hyperparathyroidism patients. In skilled hands, its sensitivity and specificity are high. Its usefulness is limited in cases of deeply placed ectopic glands.
- Magnetic resonance imaging: Magnetic resonance imaging is usually used as an adjuvant modality in cases of ectopic glands or re-exploration for persistent hyperparathyroidism.

C. Treatment

Surgical intervention is the treatment of choice for primary hyperparathyroidism. Prior to routine screening of serum calcium levels, patients often presented with significant complications of their disease. However, currently most patients are asymptomatic when identified. There are some who argue that primary hyperparathyroidism does not progress in many asymptomatic patients and they can be observed for progression of their disease. Most experts, however, support parathyroidectomy for all patients irrespective of their symptoms. Parathyroidectomy is effective at alleviating symptoms and in preventing additional sequelae.

For patients who are not operative candidates supportive medical therapy can be utilized. Recently, selective angiography with embolization of parathyroid adenomas has been used successfully in some instances.

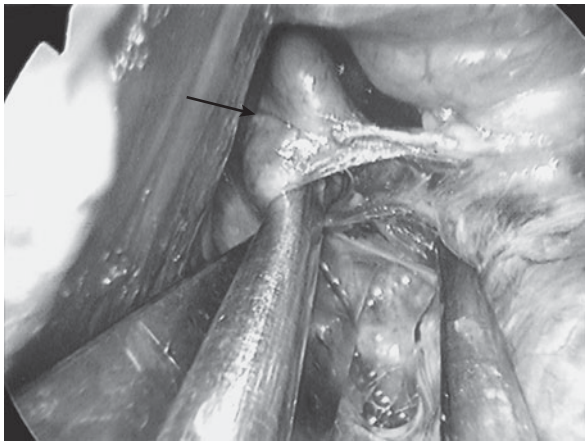


▲ **Figure 43–2.** Transverse image from a B-mode ultrasound image of the thyroid bed demonstrating a large, ovoid hypoechoic lesion consistent with a parathyroid adenoma (white arrow). Also seen are the carotid artery (CA) and the thyroid gland (Thy).

D. Surgery

The gold standard for management of primary hyperparathyroidism has been bilateral neck exploration with four-gland examination. This approach is effective for cases of single adenomas, double adenomas, and four-gland hyperplasia. A horizontal cervical incision is made through the skin and platysma muscle. Subplatysmal flaps are then elevated and strap muscles are divided in the midline and retracted. The thyroid gland is retracted medially to allow for serial identification and examination of all four parathyroid glands. Additional dissection may be required if a gland is ectopically located. Depending on the appearance of the glands, several excisional options exist. If one or two glands appear abnormal, as with a single or double adenoma, they can be removed. If there is suspicion of four-gland hyperplasia, either a total or subtotal parathyroidectomy can be performed.

Total parathyroidectomy requires excision of all four parathyroid glands. After removal, in order to prevent lifelong hypoparathyroidism, a portion of a gland is reimplanted. The tissue to be reimplanted is cut into 1 to 2 mm pieces and then placed in a pocket created in the sternocleidomastoid muscle or in a presternal subcutaneous pocket. A clip or suture is placed to mark the reimplantation site in the muscle for easy identification if revision surgery is required.



▲ **Figure 43–3.** Endoscopic appearance of a right superior parathyroid adenoma (black arrow).

Alternatively, a subtotal parathyroidectomy can be performed, in which 3½ glands are removed. The remaining half of the most normal-appearing gland is left in place with an intact blood supply. Preference is given to leaving an inferior gland, since re-exploration (if necessary) will incur lower risk to the recurrent laryngeal nerve.

Directed parathyroidectomy, including minimally invasive approaches, is now widely practiced (Figure 43–3). These focused techniques became feasible with the introduction of imaging studies that provided accurate preoperative localization of hyperfunctional or enlarged parathyroid glands. Rather than explore and examine all parathyroid glands, localization permits dissection and excision of the pathologic gland only. These procedures, which require minimal dissection and time, can be performed under local anesthesia if dictated by patient preference.

Several other innovations have enhanced the performance of directed parathyroidectomy. Assays that rapidly measure PTH levels, which have a half-life of 2 to 5 min, allow for intraoperative assessment of the efficacy of surgery. Numerous protocols for the use of intraoperative PTH have been described. Typically, a 50% reduction in PTH level 5 to 10 min after removal of the gland, with a fall into the normal range, is considered a positive outcome. Some surgeons utilize a preoperative injection of methylene blue or sestamibi to aid in focusing their dissection. Abnormal parathyroid glands will stain strongly with methylene blue, although it should be used cautiously because of the possibility of neurologic reactions, particularly in patients taking SSRI's. For radioguided procedures, a radioprobe is used to detect the gland with above average uptake of the radio-tagged sestamibi and then to direct dissection for its removal. Based on surgeon preferences, these different modalities can be used in various combinations to perform the most efficient and successful surgery.

In the past, patients were hospitalized after surgery to monitor their calcium levels until they stabilized. Currently, most patients undergoing parathyroidectomy, particularly targeted procedures, are discharged the same day. These patients are routinely started on oral calcium supplementation to mitigate transient postoperative hypocalcemia.

Regardless of the technique utilized, the success rate for primary surgery exceeds 90%. Recurrent or persistent hyperparathyroidism occurs in the remainder, with unsuccessful surgeries often due to unrecognized double adenomas or four gland hyperplasia or ectopically located glands. Revision surgery achieves cure in about 85 to 90% of cases.

E. Pathology

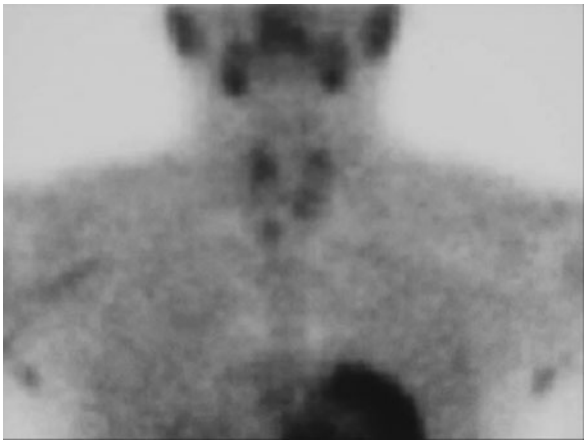
Adenomas are typically composed of large numbers of relatively uniform, polygonal chief cells. The presence of normal appearing parathyroid tissue, which often can be detected as a thin, compressed rim at the periphery of the gland, confirms an adenoma. A large number of oxyphil cells are often present and adenomas can occasionally consist of these cells only.

Hyperplasia affects all four glands, causing all to be grossly enlarged. As opposed to adenomatous lesions, in hyperplasia all tissues are involved and no normal gland is found.

F. Complications

The risk of complications from parathyroidectomy is low. The potential complications include the following:

- Temporary hypocalcemia and hypoparathyroidism: In many patients the hyperfunctional tissue has suppressed the activity of the normal glands. Consequently, patients may become temporarily hypoparathyroid and hypocalcemic until their normal glands regain their function. Typically, calcium levels will reach a nadir at 48 to 72 h after surgery. If a total parathyroidectomy with autotransplantation is performed, patients may remain hypoparathyroid until the implanted glandular tissue revascularizes and starts to function. This may take 3 to 6 months.
- Hungry bone syndrome: Certain patients with long-standing hyperparathyroidism can become severely hypocalcemic as the bone repletes its calcium deposits after surgery. Patients can develop parathesias, tetany, and seizures if not aggressively supplemented with calcium. In addition to hypocalcemia, these patients also can have hypophosphatemia and hypomagnesemia, which require supplementation. Older patients, patients with elevated preoperative alkaline phosphatase levels, and those with large adenomas are at increased risk of developing this complication.
- Permanent hypoparathyroidism: In rare instances, in patients who underwent total parathyroidectomy and autotransplantation, the implanted tissue never becomes



▲ **Figure 43–4.** Images from a ^{99m}technetium-sestamibi scan 2 h after injection in a patient with renal hyperparathyroidism showing uptake in each of four hyperplastic parathyroid glands. Note that the right inferior parathyroid gland has descended into an ectopic location in the anterior mediastinum.

functional and patients develop permanent hypoparathyroidism.

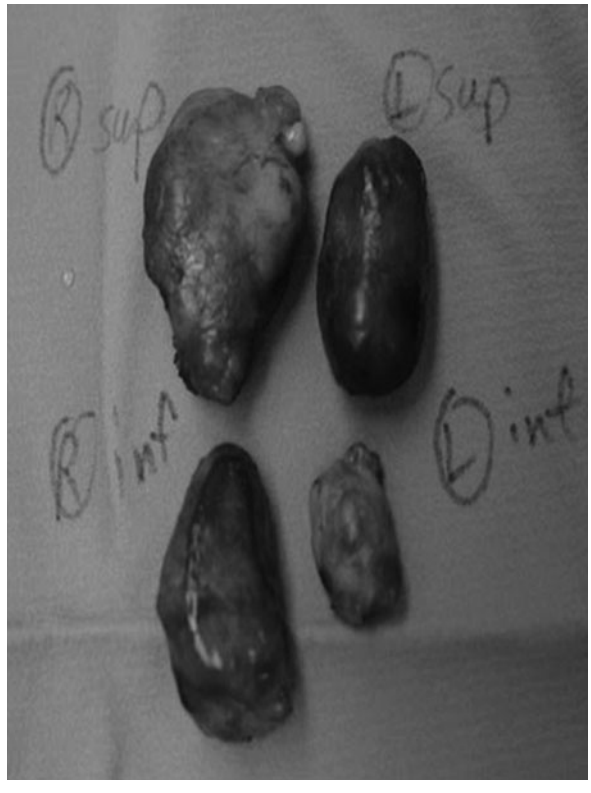
- Recurrent laryngeal nerve injury: The rate of temporary or permanent dysfunction after parathyroidectomy is approximately 1%.
- Postoperative hematoma or infection: These are rarely occurring complications.

SECONDARY HYPERPARATHYROIDISM

In secondary hyperparathyroidism PTH levels are elevated in response to chronic hypocalcemia. While any disorder that results in hypocalcemia can lead to secondary hyperparathyroidism, chronic renal failure and vitamin D deficiency are the most common causes. Stimulation of the parathyroid glands by chronic hypocalcemia results in hyperplasia of all glands. In contrast to primary hyperparathyroidism, treatment is medical. The critical elements are correction of the hypocalcemia, repletion with vitamin D analogues and addressing the underlying cause (Figures 43–4 and 43–5).

TERTIARY HYPERPARATHYROIDISM

The parathyroid glands are chronically stimulated in secondary hyperparathyroidism. Tertiary hyperparathyroidism occurs when the cause of the stimulation is corrected, and the glands remain autonomously hyperfunctional. This disorder often requires subtotal or total parathyroidectomy, although selective parathyroidectomy may be appropriate.



▲ **Figure 43–5.** The parathyroid glands in patients with renal hyperparathyroidism are often asymmetrically hyperplastic and inhomogeneous in appearance.

Familial Hypocalciuric Hypercalcemia

An autosomal dominant disease, FHH can be a diagnostic challenge. Due to an inactivating mutation in the gene for the calcium sensing receptor, the parathyroid glands and kidneys are less sensitive to calcium, which leads to inappropriate PTH production and renal calcium reabsorption. In these patients, PTH and calcium levels are usually at the high end of normal or only mildly elevated. The course of the disease is most often benign, due to the relatively mild hyperparathyroidism and these patients should just be observed. Diagnostically, a low urinary calcium clearance will differentiate between FHH and primary hyperparathyroidism.

Carcinoma

Parathyroid carcinoma is the cause of less than 1% of primary hyperparathyroidism and is often difficult to diagnose prior to surgery. A high index of suspicion must be maintained in patients with extremely elevated calcium and PTH levels. A palpable mass is reportedly present in up to half of patients with carcinoma.

Histologically, parathyroid carcinoma is difficult to differentiate from adenomatous change. Diagnosis requires either capsular or local invasion, nodal or distant metastases or local recurrence after excision.

If a preoperative diagnosis is made or if intraoperative findings, such as local tissue invasion or adhesiveness, suggest carcinoma, wide local excision of the gland with surrounding tissue is indicated. An ipsilateral hemithyroidectomy should be performed with removal of tissue from the tracheoesophageal groove and central compartment. If any palpable neck adenopathy is present, a modified radical or selective neck dissection should be included in the resection. Recurrence or persistence of disease is common, even after many years, and treated with re-excision of any resectable tumor. Medical interventions have not been successful at controlling parathyroid carcinoma.

MULTIPLE ENDOCRINE NEOPLASIAS

Hereditary multiple endocrine neoplasia (MEN) syndromes often involve the parathyroid glands. These are transmitted in an autosomal dominant pattern with variable expression and should be considered in any patient who presents with multiple endocrine organ neoplasias or has a family history of endocrine organ neoplasias.

Hyperparathyroidism from parathyroid hyperplasia occurs in the following:

- MEN 1 (Werner's syndrome): Includes parathyroid hyperplasia, pituitary adenomas, and pancreatic islet cell tumors.
- MEN 2A (Sipple's syndrome): Includes medullary thyroid carcinoma, pheochromocytomas and parathyroid hyperplasia.

HYPOPARATHYROIDISM

Hypoparathyroidism is a rare entity that results in chronic hypocalcemia. Iatrogenic sources, almost always parathyroid or thyroid surgery, are the most frequent cause. Less frequently, congenital abnormalities of the third and fourth pharyngeal pouches, such as DiGeorge syndrome, can be responsible for the hypoparathyroidism. Lifelong supplementation with calcium and vitamin D is necessary.

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We would like to acknowledge Karsten Munck, MD and David W. Eisele, MD for their contribution to this chapter in the previous editions of CDT.

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44 Anatomy & Physiology of the Ear

John S. Oghalai, MD, &
William E. Brownell, PhD

Mechanical events resulting from sound, gravitational forces, and rotational acceleration are detected by the cochlea and vestibular organs within the inner ear. Sound is a mechanical vibration (eg, as produced by a vibrating piano string). This vibration sets up small oscillations of air molecules that, in turn, cause adjacent molecules to oscillate as the sound propagates away from its source. Sound is called a pressure wave because when the molecules of air come closer, the pressure increases (**compression**); as they move further apart, the pressure decreases (**rarefaction**).

A sound is characterized by its frequency and intensity. The **frequency** of a sound is its pitch. Middle C on a piano has a frequency of 256 cycles per second, whereas high C (seven white keys to the right) has a frequency of 512 cycles per second (Figure 44–1). People with normal hearing can tell the difference between two sounds that differ in frequency by less than 0.5%. To appreciate how small a difference this is, one needs only to realize that middle C differs from C sharp by more than 5%. Human hearing is limited to sound waves between 20 and 20,000 Hz. Many other mammals can hear ultrasound (>20,000 Hz), and some, such as whales, approach up to 100,000 Hz.

The **intensity** of a sound determines its loudness and reflects how tightly packed the molecules of air become during the compression phase of a sound wave. The ear can detect sounds in which the vibration of the air at the tympanic membrane is less than the diameter of a hydrogen molecule (< 0.24 nm). The mammalian ear has the ability to discriminate a wide range of intensities—over a 100,000-fold difference in energy (120 dB).

To maximize the transfer of sound energy from the air-filled environment to the fluid-filled inner ear, land animals evolved external ears as sound collectors and middle ears as mechanical force amplifiers (Figure 44–2).

The task of the cochlea is to analyze environmental sounds and transmit the results of that analysis to the brain. The inner ear first determines how much energy is present at different frequencies that make up a specific sound. The cochlea can do this because of its **tonotopic organization**, whereby different frequency tones stimulate different areas of the cochlea. This mapping of frequency information is just one of the several strategies that the ear uses to code incoming information. The frequency analysis of environmental sounds begins in the external ear.

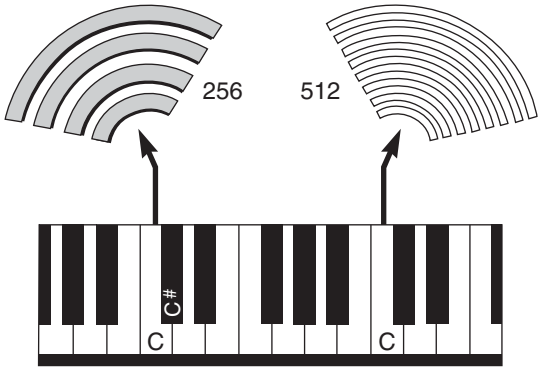
EXTERNAL EAR

1. Pinna

The external ear consists of the pinna and the external auditory canal. The pinna (Figure 44–3) is a three-layered structure. The central framework consists of elastic cartilage surrounded by a layer of skin. There is minimal subcutaneous tissue between the skin and the perichondrium. Physiologically, the pinna acts to funnel sound waves into the ear canal. The intricate shape of the pinna affects the frequency response of incoming sounds differently, depending on the vertical position from which the sound originated. This information is used by the brain to localize the sound source in three-dimensional space. Overall, the shape of the external ear provides approximately 20 dB of gain to sounds in the middle frequency range (2–4 kHz).

2. External Auditory Canal

The external auditory canal consists of a lateral cartilaginous portion and a medial bony portion. Each portion of the canal takes up approximately half of its length. The tragus forms the anterior cartilaginous canal. Directly in front of it lies the parotid gland. The facial nerve exits the stylomastoid foramen 1 cm deep to the tip of the tragus (the tragal pointer). Within the anterior and inferior portions of the cartilaginous ear canal, there are small fenestrations through the cartilage called the **fissures of Santorini.** Infection of the ear canal



▲ **Figure 44–1.** The pressure waves of sound are represented by the advancing concentric lines radiating away from the vibrating source. Middle C has a frequency of 256 cycles per second, while upper C (one octave higher) has a frequency of 512 cycles per second.

(otitis externa) can spread to the parotid gland through these fissures and may lead to skull base osteomyelitis. The tympanic portion of the temporal bone forms most of the bony ear canal. Anterior to the bony canal is the temporomandibular joint. The skin of the ear canal is thicker in the cartilaginous canal and contains glands that secrete cerumen (ear wax). The skin of the bony ear canal is very thin and fixed to the periosteum. No cerumen is secreted in the bony ear canal.

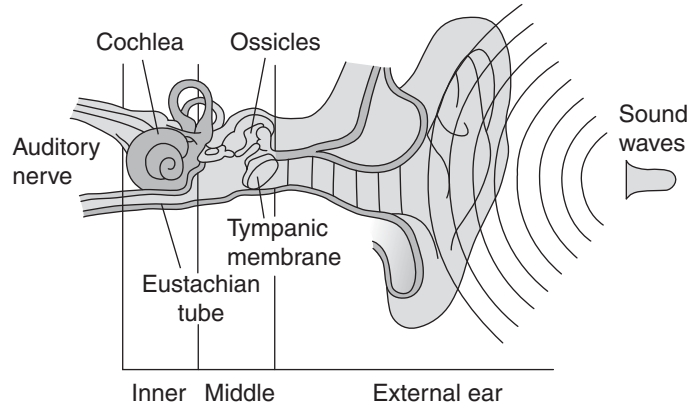
The great auricular nerve (from nerve roots C2 and C3) provides sensory innervation to the skin overlying the mastoid process as well as to most of the pinna. Cranial nerves V (the trigeminal nerve), VII (the facial nerve), and X (the vagus nerve) innervate the external auditory canal.

MIDDLE EAR

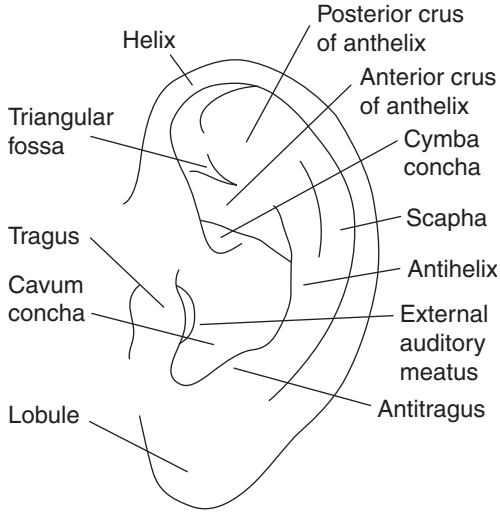
1. Tympanic Membrane

The tympanic membrane consists of three layers: outer, middle, and inner. The outer layer arises from the ectoderm, which consists of squamous epithelium. The inner layer originates from the endoderm and consists of cuboidal mucosal epithelium. The middle layer originates from the mesenchyme and is called the middle fibrous layer. The middle fibrous layer of the tympanic membrane consists of both radial and circumferential fibers. These fibers are important in maintaining the strength of the tympanic membrane as well as in aiding the proper vibration of the tympanic membrane with different frequency sounds.

The tympanic membrane has an oval shape and is approximately 8 mm wide and 10 mm high (Figure 44–4). The tympanic membrane is sloped so that the superior aspect is lateral to the inferior aspect. In addition, the tympanic membrane is tented medially by the long process of the malleus (manubrium). Around the circumference of the tympanic membrane is the fibrous annulus, which sits in the tympanic sulcus, a groove in the bone at the medial end of the external auditory canal. The annulus is incomplete superior to the anterior and the posterior malleal folds. The pars flaccida is above the anterior and posterior malleal folds while the pars tensa is inferior to the folds. The pars flaccida is also known as the **Shrapnell membrane.** The middle fibrous layer of the pars flaccida is weaker than that of the pars tensa. This area of the tympanic membrane can easily retract inwardly when the middle ear pressure is less than the environmental air pressure and is often the starting point of an attic cholesteatoma. Blood vessels enter the tympanic membrane through the superior external auditory canal skin (the vascular strip) as well as circumferentially from around the fibrous annulus.



▲ **Figure 44–2.** Anatomy of the ear. The external ear collects sound pressure waves and funnels them toward the tympanic membrane. The middle ear ossicles transmit the sound waves to the inner ear (cochlea). The middle ear acts to match the impedance difference between the air of the external environment to the fluid within the cochlea. This permits maximal sound transmission.



▲ **Figure 44–3.** Anatomy of the pinna. The pinna consists of a cartilaginous framework covered by skin.

2. Middle Ear Cavity

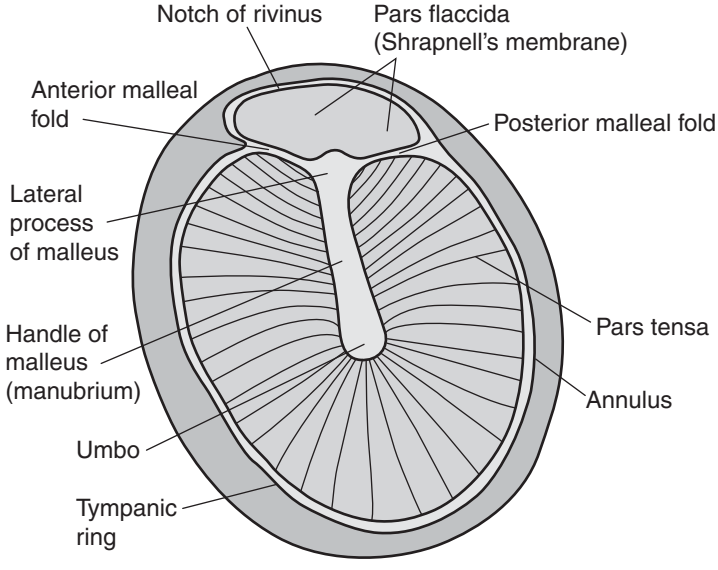
The middle ear cavity (Figure 44–5) originates embryologically from the first branchial pouch. It is connected to the nasopharynx via the eustachian tube. Posterior to the middle ear cavity are the mastoid air cells, which connect with the attic through the aditus ad antrum. The middle ear cavity and mastoid air cells are lined with ciliated mucosal epithelium. Anatomically, the middle ear space can be divided into five portions based on their relationship to the tympanic annulus: the mesotympanum, hypotympanum, attic, protympanum, and retrotympanum (see Figure 44–5). The retrotympanum includes the sinus tympani and facial recess.

The blood supply in the middle ear and mastoid originates from the internal and external carotid arteries. Vessels off the external carotid artery include the anterior tympanic artery and the deep auricular artery (branches of the internal maxillary artery), the superior petrosal and superior tympanic arteries (branches of the middle meningeal artery), and the stylomastoid artery (a branch of the occipital artery that runs up the stylomastoid foramen). In addition, the caroticotympanic artery, a branch of the internal carotid artery, forms a plexus over the promontory of the middle ear.

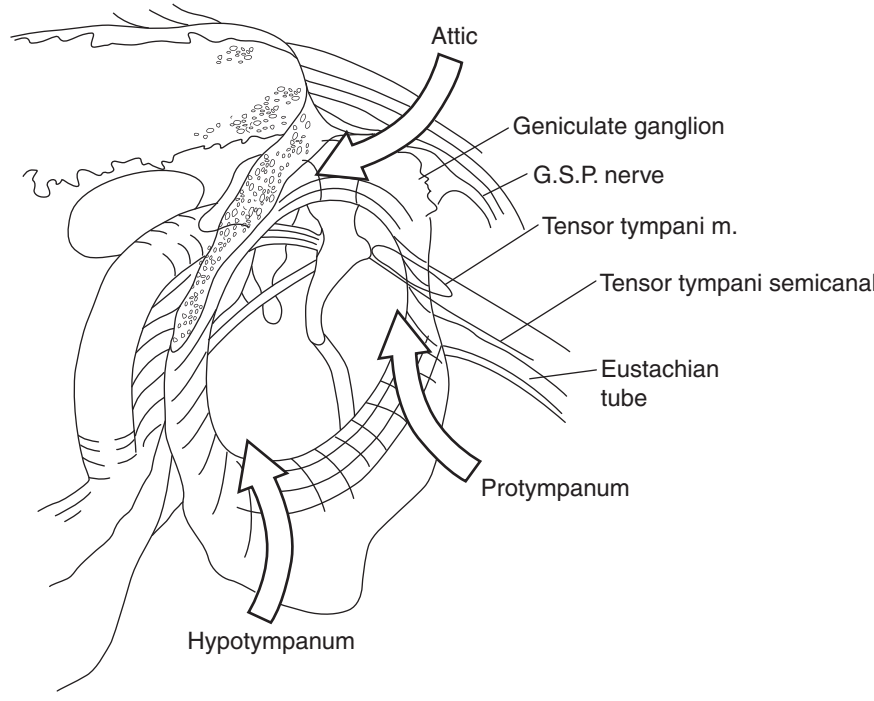
3. Ossicular Chain

There are three ossicles (Figure 44–6): the malleus, the incus, and the stapes. The malleus has a long process, a short process, and a head. The malleus is bonded to the tympanic membrane from the tip of the long process (the umbo) to the short process. The head of the malleus articulates with the body of the incus in the attic.

The short process of the incus is tethered to the posterior wall of the middle ear cavity for structural support and the long process is connected to the stapes capitulum. The distal portion of the long process is known as the lenticular process. The blood supply to the ossicular chain is most tentative at the lenticular process and is the first portion of the ossicular chain to be resorbed in patients with chronic otitis media, producing ossicular discontinuity.



▲ **Figure 44–4.** Anatomy of the tympanic membrane (a left ear).

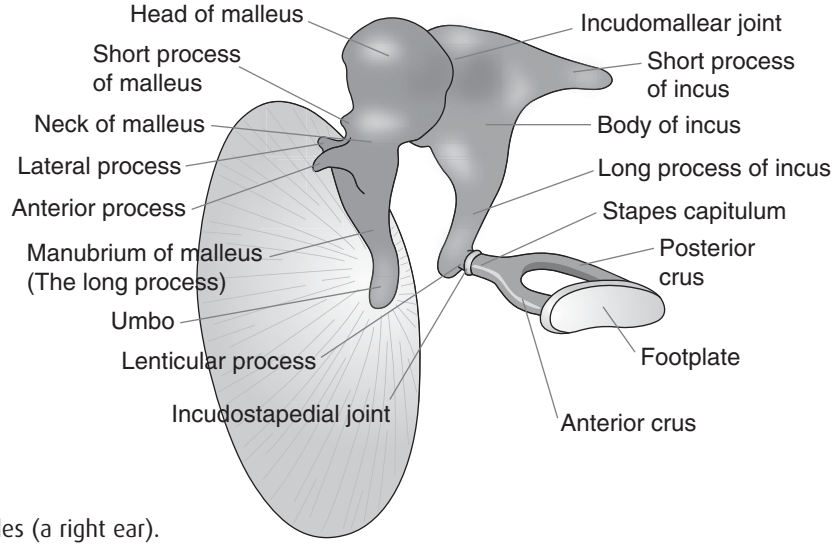


▲ **Figure 44–5.** Spaces of the middle ear (a right ear). The mesotympanum is the portion of the middle ear directly behind the tympanic membrane. The attic, protympanum, and hypotympanum are superior, anterior, and inferior to the mesotympanum, respectively. The facial recess and sinus tympani are posterior to the mesotympanum (also see Figure 44–8). GSP, greater superficial petrosal.

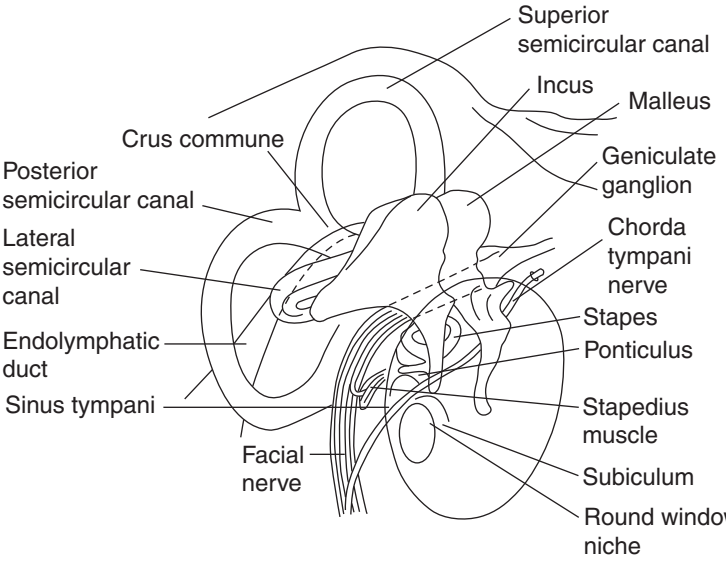
The stapes consists of a footplate and a superstructure. The superstructure includes the anterior and posterior crus, which are attached at the capitulum. The footplate sits within the oval window.

The stapedius muscle (Figures 44–7 and 44–8) originates from the pyramidal eminence. The tensor tympani muscle is anchored by the cochleariform process where it turns 90° and becomes a tendon that connects to the malleus. The ponticulus is a ridge of bone between the round window and the oval window. The subiculum is a ridge of bone just anterior to the round window. The promontory is the medial wall of the middle ear cavity. Medial to the promontory is the cochlea.

The embryologic development of the ossicles is complex. The ossicular portions found in the attic are formed from



▲ **Figure 44–6.** The middle ear ossicles (a right ear).



▲ **Figure 44–7.** Relationship of the middle ear structures with the inner ear (a right ear).

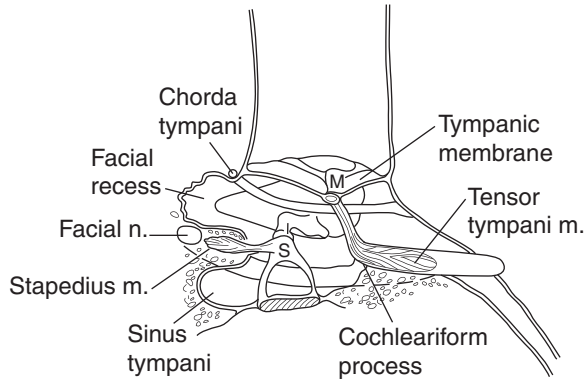
the first branchial arch. This includes the head of the malleus and the body and short process of the incus. The ossicular portions that are found within the mesotympanum originate from the second branchial arch. This includes the long process of the malleus, the long process of the incus, and the stapes superstructure. The stapes footplate originates from the otic capsule (the primordial otocyst), rather than from a branchial arch. The ossicles are full-sized cartilage models by 15 weeks of gestation, and endochondral ossification is complete by 25 weeks. The middle ear is adult sized at birth.

4. Nervous Structures

The facial nerve is the major nerve traversing the middle ear cavity (Figure 44–7). After entering the temporal bone via the internal auditory canal, the labyrinthine segment courses to the geniculate ganglion, immediately superior to the cochlea. The facial nerve then turns (first genu) and runs horizontally through the middle ear space (the tympanic portion of the facial nerve). The nerve lies superior to the oval window and the bone is often missing (dehiscent facial nerve) at this point. The nerve then turns again (second genu) and runs vertically (the vertical portion of the facial nerve). The nerve exits the temporal bone through the stylomastoid foramen, which is medial to the digastric muscle but lateral to the styloid process.

There are three branches of the facial nerve within the temporal bone. The greater superficial petrosal nerve (Figure 44–5) branches off at the geniculate ganglion and delivers parasympathetic nerves to the lacrimal gland and to the minor salivary glands of the nose. Another branch of the facial nerve goes to the stapedius muscle. Finally, the chorda tympani nerve branches off from the vertical portion of the facial nerve and runs underneath the tympanic membrane, medial to the malleus, before exiting the middle ear space through the petrotympanic fissure. It joins up with cranial nerve V3 and supplies both taste to the anterior two thirds of the tongue as well as parasympathetic innervation to the sublingual and submandibular glands. The cell bodies of these nerves are found in the geniculate ganglion.

Cranial nerve IX (the glossopharyngeal nerve) has a branch that runs across the tympanic promontory called the tympanic nerve or Jacobson's nerve. It innervates the mucosa of the middle ear space and Eustachian tube as



▲ **Figure 44–8.** The facial recess and sinus tympani (a right ear viewed from below). Mallues (m); staples (s).

well as provides parasympathetic innervation to the parotid gland. There is also a branch of the vagus nerve within the middle ear cavity called Arnold's nerve, which supplies innervation to the external auditory canal. Patients often cough when their ear canal is cleaned because of the referred sensation to the throat.

5. The Facial Recess and the Sinus Tympani

Understanding the area around the second genu of the facial nerve is critical for conducting safe middle ear surgery (Figure 44–8). The bony ear canal ends at the level of the annulus. The space medial to the end of the ear canal, but lateral to the facial nerve, is the facial recess. Medial to the facial nerve is another pocket of space called the sinus tympani. It is impossible to visualize the sinus tympani by looking either through the ear canal or through an opening made through the mastoid. Residual cholesteatoma is often found here because of remnants left behind (and not seen) during primary surgery.

Physiology of the Middle Ear

The middle ear provides an acoustic impedance match between the environmental air and the fluid-filled inner ear. The middle ear amplifies the airborne sound vibration in two ways. First, the large surface area of the tympanic membrane, compared with the small surface area of the stapes (14:1), imparts an increase in vibrational amplitude. Second, the lever arm effect of the malleus and incus imparts a further increase in vibrational amplitude (1.3:1.0). Thus, the total middle ear gain is between 20 and 35 dB. In addition, the mass and stiffness of the ossicular chain affect its frequency response. Overall, the middle ear acts as a band-pass filter, with a maximum energy transfer over the range of 1–10 kHz.

Changing the mass and stiffness of the middle ear modulates its frequency response, which can be observed clinically. For example, the stapedius and tensor tympani muscles contract through a neural reflex arc mediated by loud sounds (>80 dB). They act to stiffen the ossicular chain and protect the inner ear from noise damage, particularly at low frequencies. In contrast, cholesteatoma formation in the middle ear can contact the ossicular chain, increasing the total mass, causing a predominantly high-frequency conductive hearing loss.

The middle ear is aerated through the eustachian tube to keep it at the same pressure as that of the ear canal. If the eustachian tube is blocked (eg, by edema of the nasopharynx secondary to allergy, adenoid hypertrophy, nasopharyngeal tumor, etc.), the middle ear pressure becomes lower than atmospheric pressure, pulling the tympanic membrane inward. As the tympanic membrane is richly innervated, this can be painful. The occasional opening of the eustachian tube, with a resultant change in middle ear pressure, can cause a patient to experience a popping sensation, pain, and a mild fluctuation in the sensation of hearing. If the tube becomes chronically blocked, a serous middle ear effusion with conductive hearing loss can develop.

INNER EAR

Development

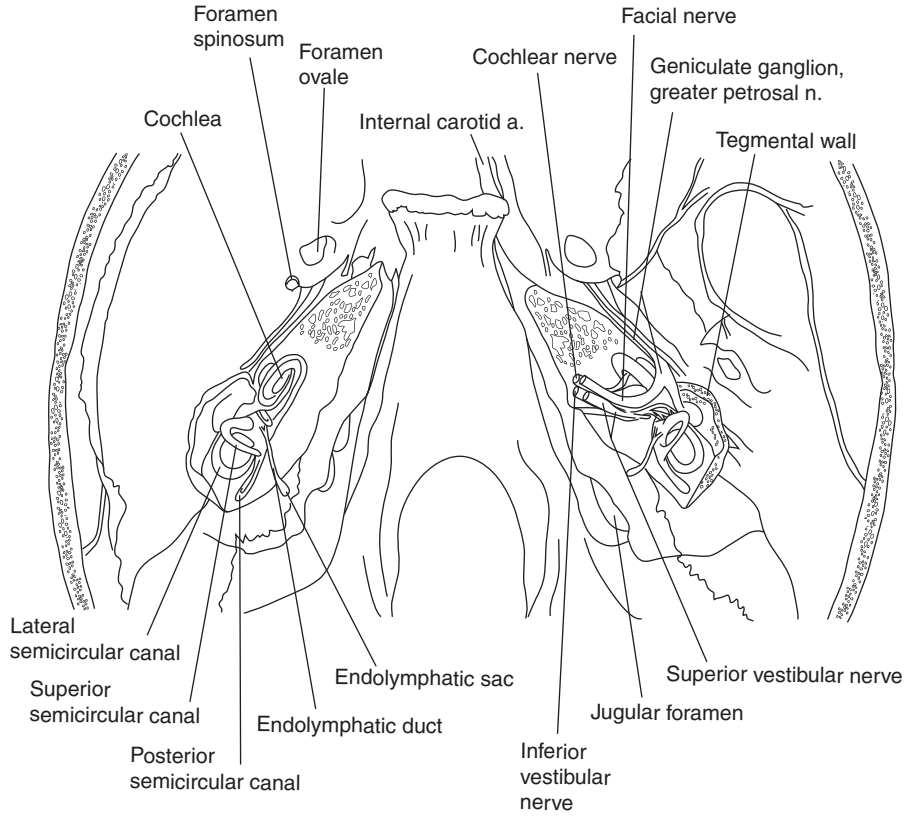
The inner ear begins at 3 weeks gestation as a thickening of the ectoderm on the side of the embryo. This otic placode invaginates to form the otic pit. It then pinches off and begins to enlarge, forming the otocyst. Beginning in weeks 5–6, the otocyst elongates and partitions itself into what will become six different sensory structures (three semicircular canals, two otolithic organs, and one cochlea) and the endolymphatic duct and sac (Figure 44–9). By 12 weeks, the formation of the membranous labyrinth is complete and the sensory cells have differentiated. By 16 weeks, cartilage has formed around the membranous labyrinth. By 23 weeks, this has undergone complete endochondral ossification to form the adult-size otic capsule. By 26 weeks, the human inner ear is sending auditory information to the brain.

1. Fluid Compartments

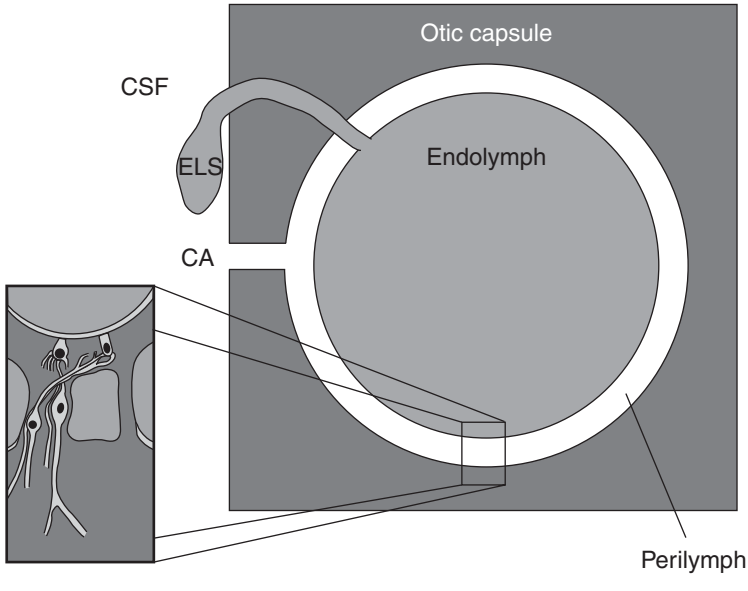
The inner ear is divided into two fluid-filled chambers, one inside the other (Figure 44–10). The fluid in the two chambers differs on the basis of the kind of salt that each contains. The fluid in the outer or bony chamber is filled with a sodium salt solution called **perilymph**, which resembles cerebrospinal fluid. The inner or membranous chamber is filled with a high potassium salt solution called **endolymph**, which resembles intracellular fluid. Marginal cells in the stria vascularis (see Figure 44–21) actively pump potassium into the membranous chamber to maintain the difference in the sodium and potassium concentrations. The difference in the chemical composition between perilymph and endolymph provides the electrochemical energy that powers the activities of the sensory cells. The inner ear is unique because the sensory cells rely on energy provided by other cells. In virtually all other systems, whether it is heart muscles, the brain, or the retina of the eye, the principal cells must combine nutrients and oxygen to produce the energy they use to perform their functions.

2. Hair Cell Function

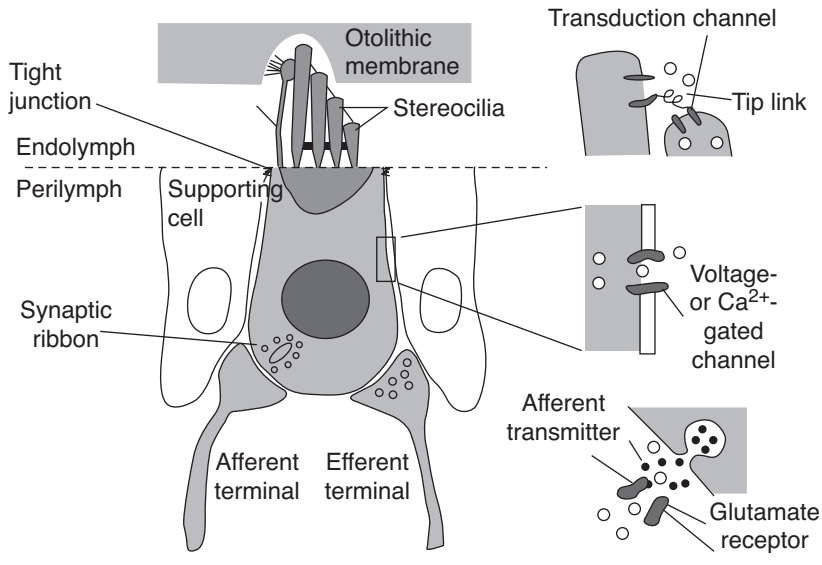
Hair cells (Figure 44–11) are the sensory receptor cells of hearing and balance and are the most important cells in the inner ear. Their name derives from the fact that they have about 100 stereocilia at their apical end. Individual stereocilia are packed with a filamentous actin cytoskeleton. Hair cells are specialized mechanoreceptors that convert the mechanical stimuli associated with hearing and balance into neural information for transmission to the brain.



▲ **Figure 44–9.** The location of the inner ears within the skull base.



▲ **Figure 44–10.** Schematic diagram showing the organization of the inner ear organs of hearing and balance. The inner ear contains two fluid chambers, a membranous and a bony chamber. The membranous chamber is filled with endolymph while the bony chamber is filled with perilymph. CA, cochlear aqua x duct; CSF, cerebrospinal fluid; ELS, endolymphatic sac.



▲ Figure 44–11. A stereotypical hair cell. The sensory cells are called hair cells because of their stereocilia. Each hair cell has a tuft of stereocilia arranged in rows that increase in length toward one side of the cell. A single kinocilium sits in front of the longest stereocilia. Neurotransmission from the hair cells to afferent neurons occurs at their basal pole. Some hair cells also receive efferent input that regulates their sensitivity. Voltage- and calcium-gated ion channels in the basolateral hair cell membrane shape the electrical response of the hair cell to mechanical stimuli.

The conversion of one type of energy to another is called **transduction**.

The stereocilia of each hair cell are arranged in a precise geometry. This arrangement is asymmetrical and polarized because the stereocilia are arranged in rows of short, intermediate, and tall stereocilia. A single kinocilium is located adjacent to the tallest row. It has a 9/2 microtubule organization similar to motile cilia found elsewhere in the body. The kinocilium is thought to establish the morphologic polarization of the stereocilia bundle and is not required for mechanoelectrical transduction. It is present in embryonic cochlear hair cells but is resorbed by the time cochlear hair cells mature.

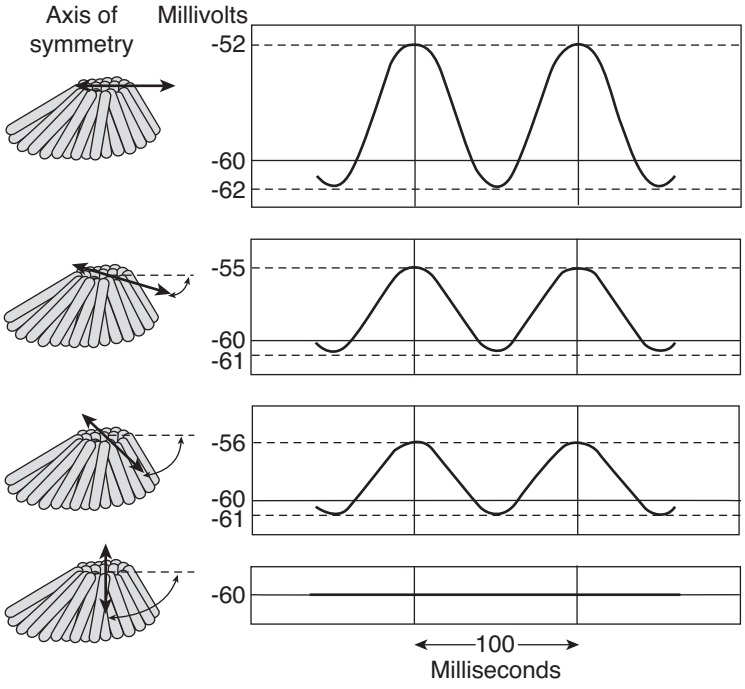
There is a stepwise progression from the shortest row to the tallest row. The organization of the bundle from short to tall rows is related to the functional consequences of bending the bundle on the cell's membrane potential. The mechanoelectrical transduction channels that are in the stereocilia are tethered to adjacent stereocilia by "tip links" (see Figure 44–11). The deflection of the stereocilia toward the tallest row causes shearing between the stereocilia, which causes the tip links to pull on the transduction channels, opening them. Deflection in the other direction releases the tension of the tip link, causing the transduction channels to close. Bending the bundle in the direction of the tallest row leads to the entry of K^+ and Ca^{2+} ions into the hair cell through channels that open at the tips of the stereocilia. This causes the hair cell to depolarize. Bending the bundle in the opposite direction promotes channel closure and results in hair cell hyperpolarization.

Within the stereociliary bundle, there is movement of the bundle back and forth parallel with the axis of symmetry through the kinocilium. Movement in this direction produces a maximal receptor potential (change in the intracellular voltage). As the bundle is moved at larger angles away from this axis, the receptor potential is reduced. In Figure 44–12, note that the receptor potential is asymmetric, with larger depolarizing swings compared with hyperpolarizing swings. This is because the current–voltage characteristics of the hair cell are nonlinear and are shaped by the various voltage- and calcium-dependent ion channels in its basolateral plasma membrane. The lowest tracing (see Figure 44–12) demonstrates that deflection of the stereociliary bundle perpendicular to the bundle's axis of symmetry produces no receptor potential.

Hair cells have synapses located at their basal pole. When a hair cell is mechanically stimulated, it releases a chemical that modulates the electric activity of the afferent neurons (Figure 44–13). This neurotransmitter release is regulated by changes in the membrane potential of the hair cell in response to bending its stereocilia bundle. Efferent synapses at the termination of the fibers originating in the brainstem are also present. The neural signals from the brain conveyed by these efferent fibers modulate the gain (amplification) of the hair cells they innervate.

3. The Organs of Hearing and Balance

The inner ear sensory epithelia are among the smallest organs in the body, containing less than 20,000 sensory cells. (By comparison, about 1 million photoreceptors are in the eye.) The inner ear organs must be small because any increase in their size would increase their mass. An increase in mass would increase the mechanical force required to



▲ **Figure 44–12.** Mechanoelectrical transduction in the hair cell stereocilia (Used, with permission, from Estate of Bunji Tagawa).

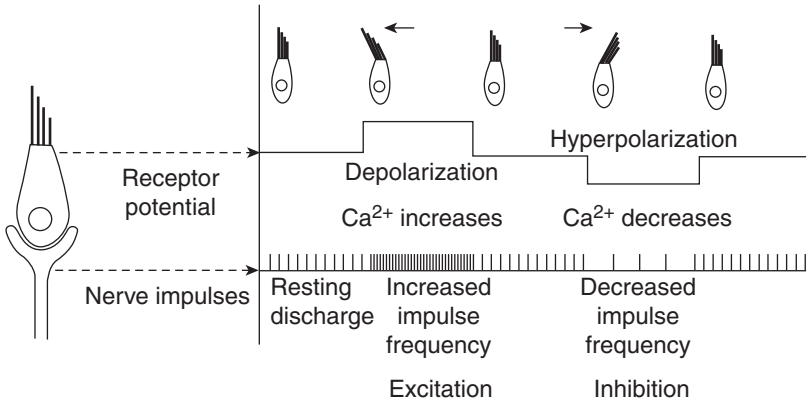
stimulate them. Any increase in the driving force would represent a decrease in the sensitivity of the system (a hearing loss). The small number of cells in the hearing organ means that the loss of even a small number affects hearing.

Inner ear sensory organs differ in a way the stereocilia bundles of the hair cells are mechanically bent. The hair cells in each organ are grouped in one of three types of sensory epithelia. The maculae (Figures 44–14 and 44–15) and the cristae (Figure 44–16) are the sensory epithelium of the vestibular system (balance) and the organ of Corti (Figure 44–17) is the sensory epithelium of the cochlea. There are two maculae (the saccule and the utricle), three cristae, and one organ of Corti on each side of the head.

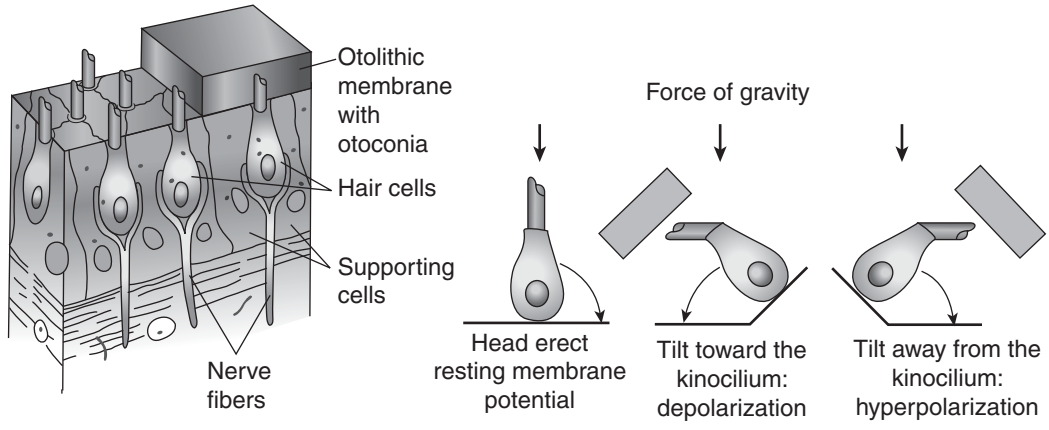
VESTIBULAR SYSTEM

Anatomy & Physiology of the Vestibular Organs

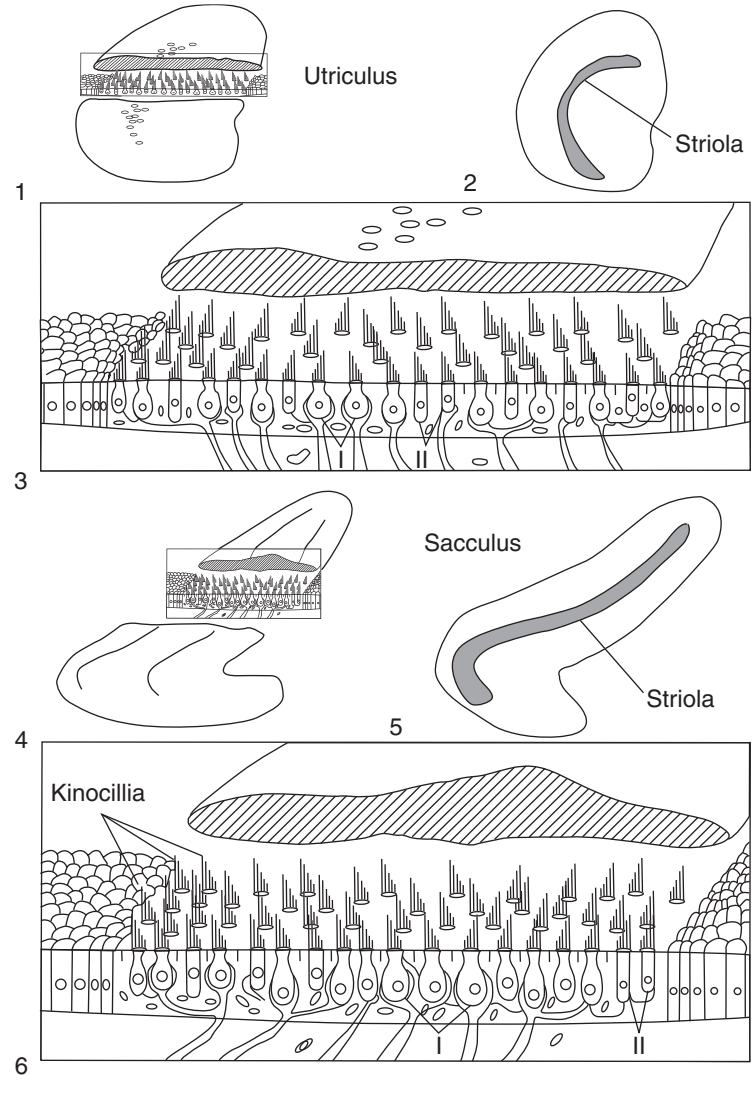
The maculae (see Figure 44–15) of the otolithic organs are responsible for sensing gravity (linear acceleration). The maculae are flat, ovoid structures that are covered with hair



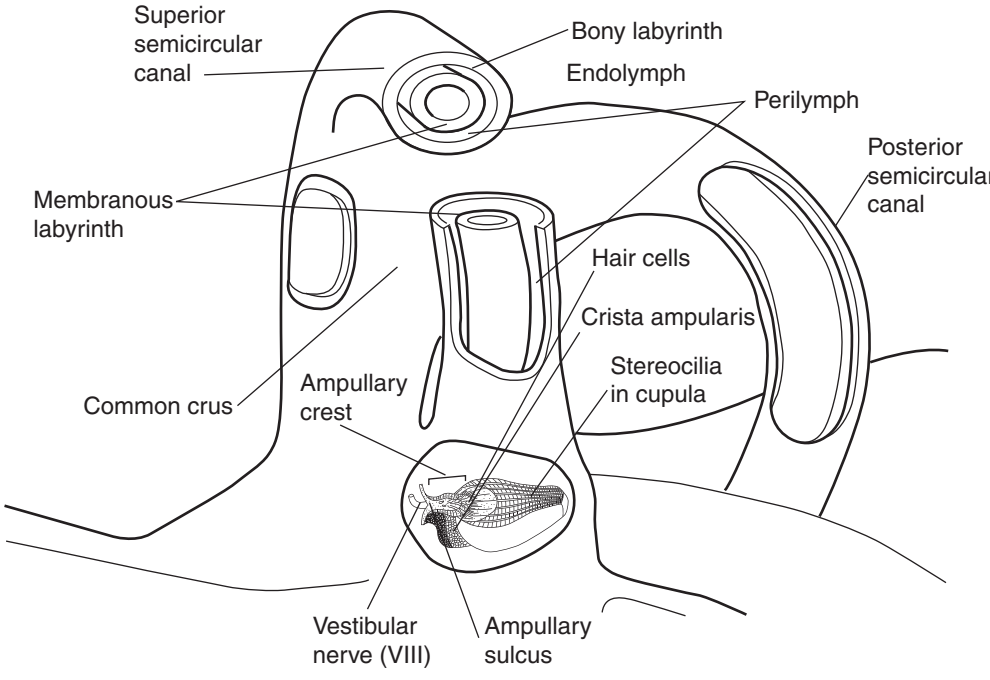
▲ **Figure 44–13.** Modulation of afferent nerve fiber activity by stereociliary bundle deflection. The normal afferent eighth nerve has a resting spontaneous discharge rate. Depolarization of the hair cell leads to an increase in this rate and hyperpolarization leads to a decrease in this rate.



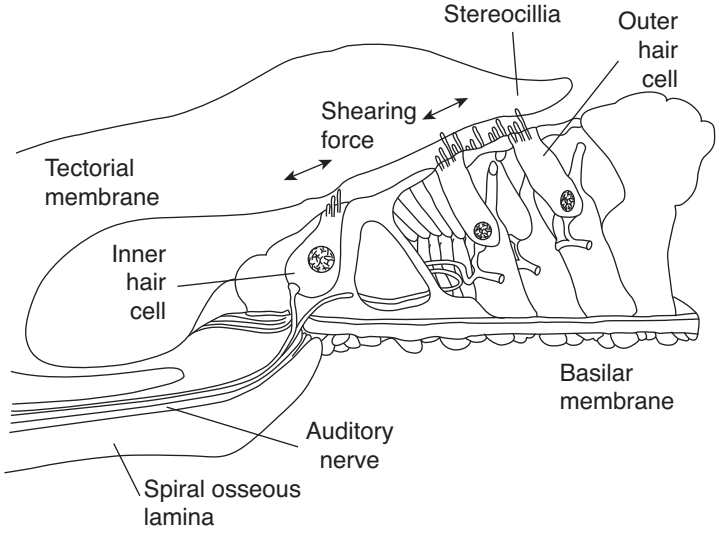
▲ **Figure 44–14.** Organization and physiology of the maculae.



▲ **Figure 44–15.** Organization of the utricle and saccule.



▲ **Figure 44–16.** The semicircular canals and ampullae. Hair cells sit on the crista, and their stereocilia are embedded in the gelatinous cupula. Angular acceleration (head rotation) causes the endolymph within the semicircular canal to bend the cupula, resulting in stereociliary deflection. The three semicircular canals (lateral, superior, and posterior) are perpendicular to one another, permitting detection of head rotation in any direction.



▲ **Figure 44–17.** The organ of Corti. The central axis of the spiraling cochlea is to the left of the drawing. Eighth nerve fibers pass through a bony shelf (the spiral osseus lamina) on their way to the hair cells.

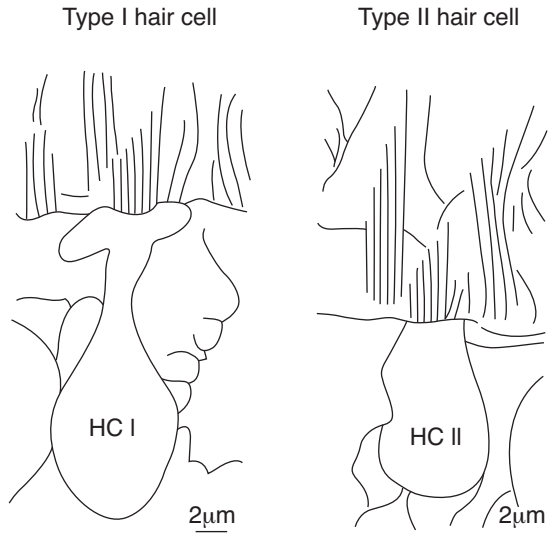
cells across their surface. The stereocilia of the hair cells protrude upward and are embedded in the gelatinous otolithic membrane, which contains calcium carbonate crystals called **otoconia**. Otoconia have a density greater than water, so when the head is tilted from side to side, gravity causes a shearing force between the otolithic membrane and the surface of the maculae. This results in a bending of the stereocilia. Deflection toward the longer stereocilia causes the transduction channels to open and hair cell depolarization to occur. Deflection toward the shorter stereocilia causes the transduction channels to close and the cell to hyperpolarize.

The utricle and saccule take advantage of this bidirectional coding because there are hair cells oriented in both directions across their surface. In this way, a single macule can produce both excitatory and inhibitory signals with a change in the head position. The striola is defined as a thinning in the center of the otolithic membrane in the utricle and a thickening in that of the saccule (see Figure 44–15). This roughly defines the area on the sensory epithelium that divides hair cells oriented in one direction from those oriented in the opposite direction. Both the utricle and the saccule have a gently-curved shape. Two-dimensional information is able to be detected by a single otolithic organ because of the distributed orientation of the hair cell stereociliary bundles in all directions.

Hair cells have a mechanism for adjusting their set points, which is particularly important to the otolithic organs. When a steady-state head tilt occurs, hair cell stereocilia are deflected and a receptor potential occurs within the cell. However, over the next few seconds, the intracellular potential partially returns to normal levels, which is termed *adaptation*. It permits the hair cell to respond to further changes in the head position rather than resting unresponsively in a fully deflected position. Molecular motors within the stereocilia are thought to be activated in a manner that maintains an optimal tension in the tip links between adjacent stereocilia.

The ampullae (see Figure 44–16) of the semicircular canals are responsible for sensing head turning (angular acceleration). The semicircular canal ampulla contains the crista, which has a shape similar to a horse saddle. Hair cells lie on the surface of the crista. The stereocilia protrude upward off the surface of the crista and into a gelatinous material called the **cupula**. With a turn of the head, the inertia of the endolymph within the semicircular canal causes the cupula to move, deflecting the hair cell stereocilia and stimulating transduction. The three semicircular canals (lateral, superior, and posterior) are perpendicular to one another and thereby provide sensory signals from any type of head rotation.

Each semicircular canal is paired with one in a parallel plane on the opposite side of the head (see Figure 44–9). For instance, both lateral canals are in the same plane, the left posterior canal is in the same plane as the right superior canal, and the right posterior canal is in the same plane as the left superior canal. One vestibular organ gives an excitatory response, and the other vestibular organ gives an inhibitory response for rotation in a given plane. This paired input is then integrated by the brainstem to control balance. The kinocilia of the hair cells in the lateral semicircular canals are oriented toward the utricular side; therefore, the displacement of the cupula toward the vestibule provides an excitatory response (**ampullopetal endolymph flow**). In contrast, the kinocilia of the superior and posterior semicircular canals are oriented toward the canal side. Therefore, the displacement of the cupula toward the canal provides an excitatory response (**ampullofugal endolymph flow**).

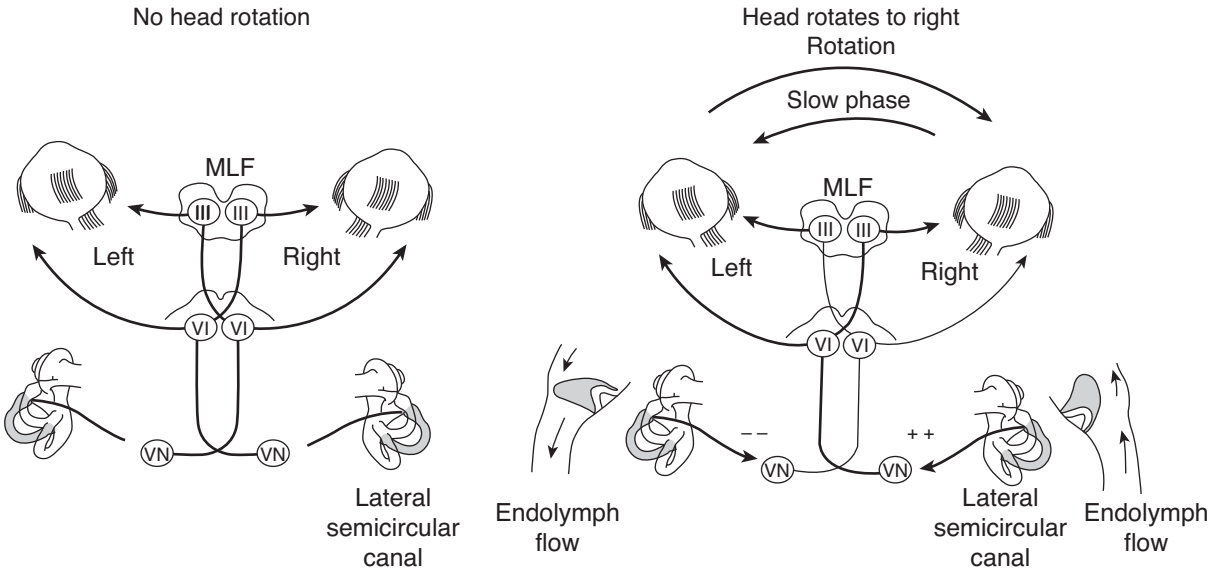


▲ **Figure 44–18.** Vestibular hair cells. Type I hair cells (left) are of flask shape with a narrow neck, whereas Type II hair cells (right) are more cylindrical.

Within the otolithic organs and the semicircular canals are two different types of hair cells, Type I and Type II (Figure 44–18). Physiologically, these cells act differently, although both are mechanoreceptor cells that transduce the head position and send this information to the brain.

Neurophysiology

Vestibular eighth nerve fibers project to the ipsilateral vestibular nuclei. The neural signals coming from the semicircular canals start the vestibuloocular reflex (Figure 44–19). The **vestibuloocular reflex** is critical to the ability to visually fixate on an object while one's head is turning. In contrast, keeping one's head still while trying to follow a moving target with the eyes is predominantly under cortical and cerebellar control. This is a much slower, multisynaptic,

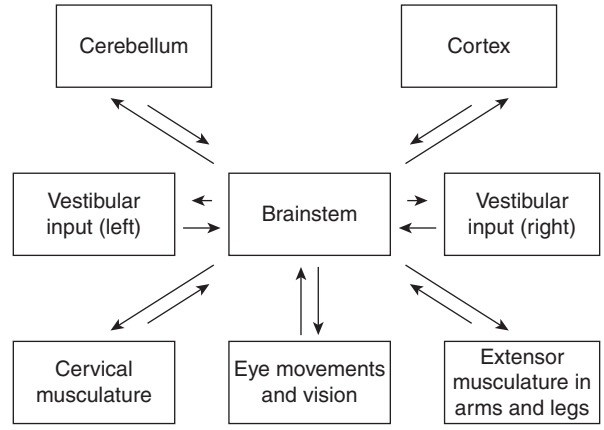


▲ **Figure 44–19.** The vestibuloocular reflex. Horizontal head rotation stimulates the ipsilateral lateral semicircular canal and inhibits the contralateral canal. A three-neuron reflex arc involving the abducens (VI) and oculomotor (III) brainstem nuclei leads to stimulation of the contralateral lateral rectus muscle and stimulation of the ipsilateral medial rectus muscle. The corresponding antagonistic muscles (the contralateral medial rectus and ipsilateral lateral rectus) are inhibited. MLF, medial longitudinal fasciculus; VN, vestibular nucleus.

response compared with the three-neuron reflex arc of the vestibuloocular reflex.

An excitatory response from one semicircular canal results in an excitatory signal that crosses the midline of the brainstem via a second neuron to the contralateral abducens nucleus. The abducens nucleus then sends inputs via the sixth cranial nerve (the abducens nerve) to the lateral rectus muscle in the contralateral eye, causing the eye to deviate away from the side of the vestibular excitation. In addition, the abducens nucleus sends an excitatory input via the medial longitudinal fasciculus to the ipsilateral ocular motor nucleus. This controls the ipsilateral medial rectus muscle, causing the ipsilateral eye to deviate away from the side of the vestibular excitation. Because this input is paired, inhibitory signals from the other ear cause precisely the opposite response.

Balance is a complex interplay among input from the inner ear, the eyes, and musculature in the body and cervical spine. These signals are integrated in the brainstem, the cerebellum, and the cortex (Figure 44–20). The utricle and saccule send information regarding the head position to the brain and to the spinal cord, relaying changes in orientation to the antigravity musculature. These vestibulospinal reflexes are important for postural maintenance, equilibrium, and resting muscular tone. The cerebellum modulates these effects as well. The muscles responsible



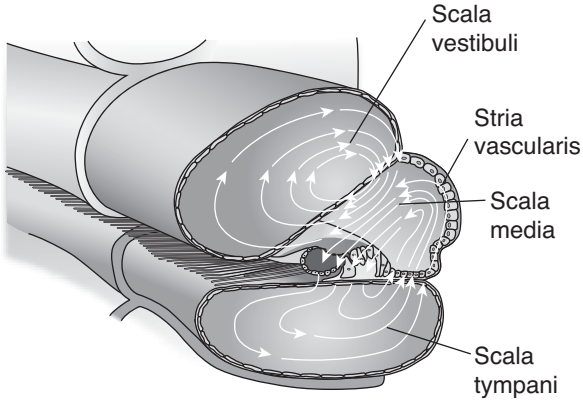
▲ **Figure 44–20.** Balance control involves the vestibular system, the cervical musculature, the visual system, and the extensor musculature. The cerebellum and cortex provide control over the sensory integration and motor control process that occurs predominantly in the brainstem. Normal balance processes act to keep the head upright. When falling asleep (for example, during a lecture), the loss of cortical input reduces the tonic output of the vestibulospinal pathways, causing your head to fall forward.

for postural control include the abdominal and paraspinal muscles around the hip, the hamstrings and quadriceps in the thigh, and the gastrocnemius and tibialis anterior in the calf. The vestibulospinal reflexes are carried by many distinct vestibulospinal tracts. The most important is the lateral vestibular spinal tract. Fibers within this tract cause a monosynaptic excitation of the ipsilateral extensors and disynaptic inhibition of contralateral extensors. Hence, a unilateral labyrinthine lesion causes increased contralateral extensor activation. For example, patients who have an acoustic neuroma and decreased vestibular input from one side tend to fall toward the side of the lesion because of the contralateral extensor activation.

AUDITORY SYSTEM

1. The Cochlea

The cochlea achieves a greater mechanical sensitivity than the vestibular organs. The energy required for this process is provided by the stria vascularis (Figure 44–21). This structure forms the outer wall of the scala media and sits within the spiral ligament. It is highly vascular and metabolically active in order to maintain the high potassium concentration within the scala media. There are tight junctions between the apex of the hair cells and the surrounding supporting cells that form the barrier (the reticular lamina) between the endolymph and the perilymph. The stria vascularis acts as a battery whose electrical current powers hearing. In addition to elevated potassium concentrations, it creates a positive potential within the endolymph relative to the perilymph.



▲ **Figure 44–21.** Cross-section of the cochlea. There are three fluid-filled chambers: the scala vestibuli and scala tympani are connected at the apex of the cochlea and contain perilymph; the scala media contains endolymph. The stria vascularis maintains the endolymphatic potential and drives the silent current (arrows) that provides the energy for hearing.

This increases the electrochemical gradient that drives a constant flow of K^+ ions from the endolymph into the hair cells. This "silent current" is modulated as hair cell stereocilia are deflected. Potassium ions are recycled back to the stria vascularis by diffusion through the perilymph and through supporting cells via gap junctions. The gap junction proteins are called connexins, and mutations of their genes result in sensorineural hearing loss. Connexin mutations are the most common mechanism of genetic hearing loss.

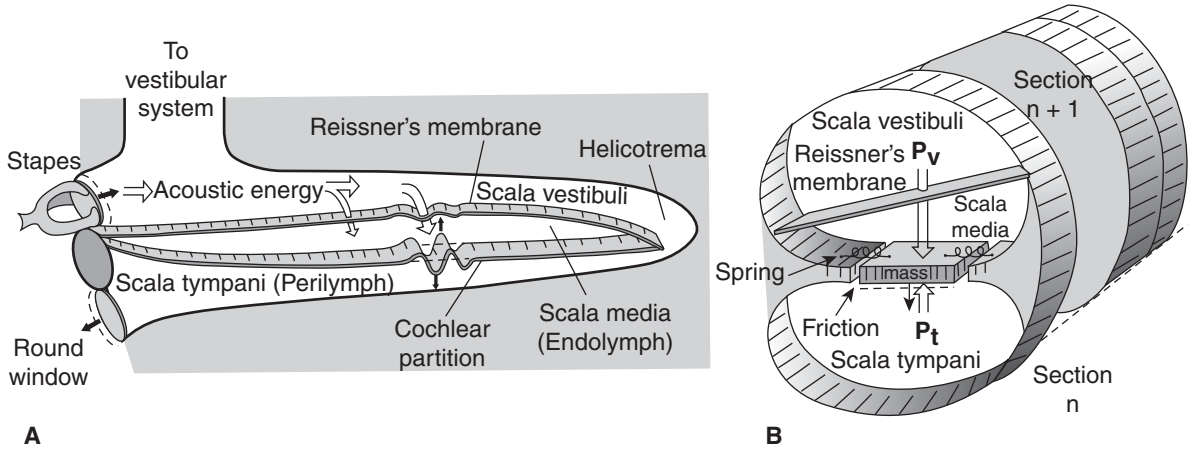
▶ Passive Mechanics Within the Cochlea

The hair cells in the organ of Corti vibrate in response to sound. Differential movements between the basilar membrane and the tectorial membrane bend the stereocilia bundle (see Figure 44–17). In this figure, the flexible basilar membrane is anchored to the bony shelf on the left and a ligament (not shown) on the right. A single flask-shaped inner hair cell is shown on the left, and three rows of cylindrically shaped outer hair cells are seen on the right. The tips of the outer hair cell stereocilia are embedded in a gelatinous mass called the **tectorial membrane,** which lies on top of the organ of Corti. When sound is transmitted to the inner ear, the organ of Corti vibrates up and down. Since the basilar membrane is attached to bone and ligament at its two ends, the area of maximal vibration is near the third (furthest right) row of outer hair cells. The basilar membrane is fixed at the osseous spiral lamina, whereas the tectorial membrane is fixed at a different position. Movement of the basilar membrane up and down, induced by sound waves within the cochlear fluids, causes a shearing force to deflect the hair cell stereocilia.

The cochlea acts as both a passive and an active filter. Passive filtering produces a traveling wave in response to sound vibrations (Figure 44–22). The location of the peak of the traveling wave changes with the frequency of the sound played into the ear. The change in location results from the tonotopic organization of the organ of Corti. There are systematic differences in its mass and stiffness along its length that determine the frequency response at any specific location. At the base of the cochlea (the high-frequency region), it has a lower mass and a higher stiffness. In contrast, at the apex of the cochlea (the low-frequency region), the organ of Corti has a higher mass and a lower stiffness. Sound vibrations that enter the cochlea at the stapes footplate propagate along the length of the cochlear duct and are maximal when they match the characteristic frequency at a specific location.

▶ Active Processes Within the Cochlea

Analyses of the cochlea based only on passive mechanical properties such as mass and stiffness cannot explain the exquisite frequency selectivity of human hearing or the frequency selectivity that is measured from individual



▲ **Figure 44–22.** The traveling wave. The basilar membrane varies in mass and stiffness along the length of the cochlea (here shown unrolled). This creates a tonotopic organization in which different segments of the basilar membrane are most sensitive to different frequencies. The pressure wave introduced from movement of the stapes propagates up the cochlea and is dissipated at its characteristic frequency place. The cochlea can be modeled as having multiple sections, each with a distinct mass and stiffness of the basilar membrane. (Adapted, with permission, Geisler CD. *From Sound to Synapse: Physiology of the Mammalian Ear.* New York: Oxford University Press, 1998.)

auditory nerve fibers. The frequency selectivity of the cochlea is enhanced by an amplification mechanism within the cochlea. The amplification process generates sounds called otoacoustic emissions that can be measured with a sensitive microphone in the ear canal. They are routinely measured in the clinic to assess hearing. The outer hair cell is the amplifier. It elongates and shortens in response to the receptor potential generated by the stereocilia. This is called **electromotility**. The function of the outer hair cell in hearing is to refine the sensitivity and frequency selectivity of the mechanical vibrations of the cochlea.

2. Outer Hair Cells

Pressurization of the Outer Hair Cells

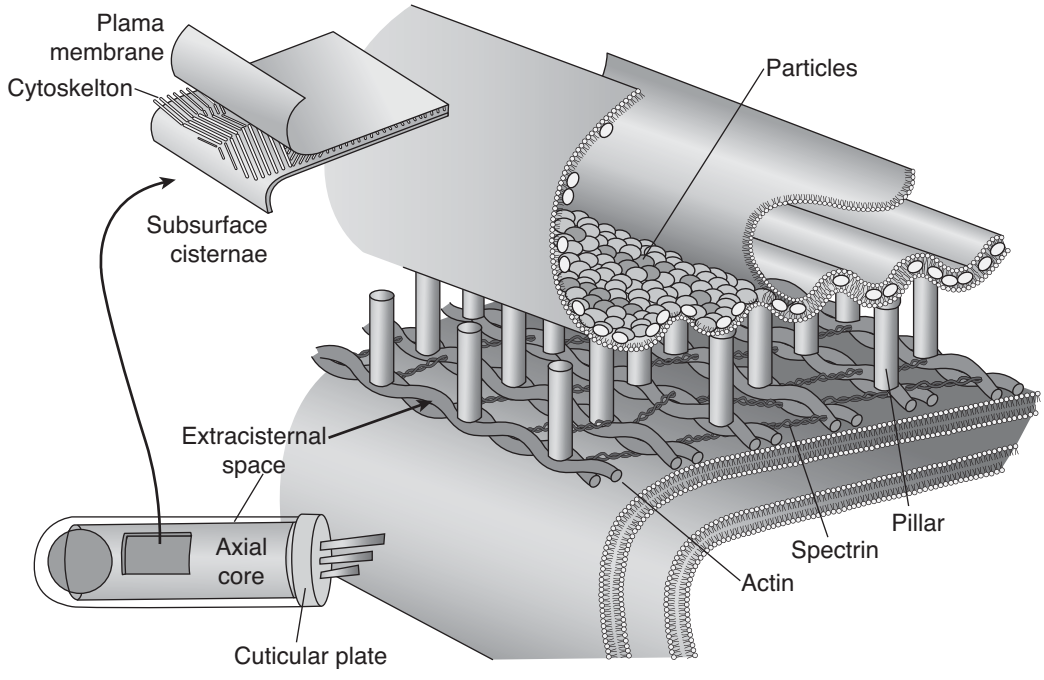
Most cells have a cytoskeleton to maintain cell shape. Because such an internal skeleton would impede electromotility, a central cytoskeleton is missing in the cylindrical portion of the outer hair cell, thereby improving the cell's flexibility. The outer hair cell must be more than flexible; it must also be strong enough to transmit force to the rest of the organ of Corti. As a result, outer hair cells are pressurized.

Most cells do not tolerate internal pressure because their membrane is weak. The outer hair cell plasma membrane is reinforced with a highly organized actin–spectrin cytoskeleton just underneath the plasma membrane (Figure 44–23). The shape of the outer hair cell is maintained by a pressurized fluid core that pushes against an elastic wall. The lateral wall of the outer hair cell is about 100 nm thick and contains the plasma membrane, the cytoskeleton, and an intracellular organelle called the subsurface cisternae. Particles sit within the plasma membrane and may be related to electromotility. The cytoskeleton consists of actin filaments that are oriented circumferentially around the cell and that are crosslinked by spectrin molecules. Pillar molecules tether the actin–spectrin network to the plasma membrane. The plasma membrane may be rippled between adjacent pillar molecules.

Electromotility of Outer Hair Cells

Outer hair cells have a cylindrical shape (Figure 44–24). They vary in length from approximately 12 μm at the basal or high-frequency end of the cochlea to >90 μm at the low-frequency end. Their diameter at all locations is approximately 9 μm. Their apical end is capped with a rigid cuticular plate into which the stereocilia are embedded, and their synaptic end is a hemisphere (compare with the typical hair cell shown in Figure 44–11).

Each of these three regions (flat apex, middle cylinder, and hemispheric base) has a specific function. The stereocilia at the apex of the cell are responsible for converting the mechanical energy of sound into electrical energy. Synaptic structures are found at the base of the hair cell and are responsible for converting electrical energy into chemical energy by modulating the release of neurotransmitters. The apex and the base of the outer hair cell perform functions that are common to all hair cells. The elongated cylindrical portion of the outer hair cell is where electrical energy is converted into mechanical energy. This function is unique to the



▲ **Figure 44–23.** Anatomy of the outer hair cell. The outer hair cell is cylindrical and is divided in three parts. The top part is capped with a cuticular plate into which the stereocilia are inserted. The base of the cell is hemispheric. It contains the cell nucleus and synaptic structures (not shown). The central part of the cell is cylindrical.

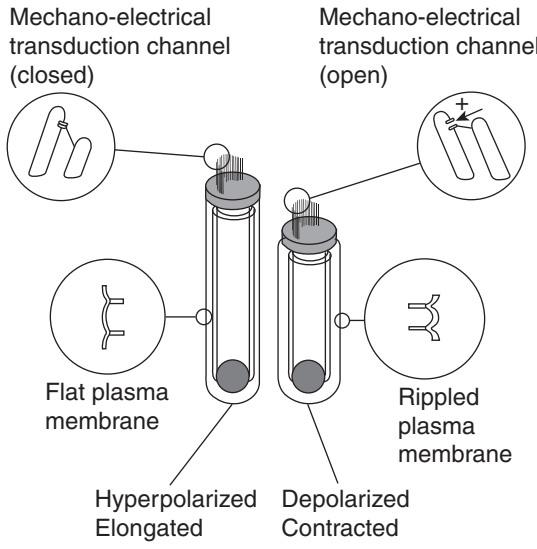
outer hair cell. No other hair cell is able to change its length at acoustic frequencies in response to electrical stimulation. These length changes can be greater than 1% of the cell's original length if the electrical stimulation is large.

The electromotility of the outer hair cells is based on a novel membrane-based motor mechanism in the plasma membrane of the cells' lateral walls. The membrane protein *prestin* and intracellular chloride ions are required for the motor to work. The mechanical force generated by the membrane is communicated to the ends of the cell by means of an elegant cytoskeletal structure immediately adjacent to the plasma membrane (see Figure 44–23). This motor mechanism is a biological form of piezoelectricity similar to that used in sonar or ultrasound imaging. Both cochlear and vestibular hair cells from humans have similar properties to those of rodents, the animal models in which most research has been done.

Humans are able to discriminate between sounds that are very close in frequency because the outer hair cell acts as the cochlear amplifier. The role of the outer hair cell in hearing is both sensory and mechanical. When the organ of Corti begins to vibrate in response to the incoming sound, each hair cell senses the vibration through the bending of its stereocilia. The bending results in a change in the voltage within the outer hair cell, causing electromotility. If the resulting mechanical force is at the natural frequency of that portion of the cochlea, then the magnitude of the vibration increases. If the electromotile force is at a different frequency, the vibrations decrease. The intact system has greater sensitivity and frequency selectivity than when the outer hair cells are missing or damaged.

One consequence of having an active system is that oscillations can occur even when no energy is coming into the system from the outside. This happens in the cochlea, and the resulting sound vibrations can be measured in the ear canal. These are called spontaneous otoacoustic emissions and are observed only in living ears. Other types of otoacoustic emissions can be measured as well, including distortion product, otoacoustic emissions, and transient evoked otoacoustic emissions. These can be triggered as needed by playing certain types of sound stimuli into the ear and are therefore more useful clinically than the measurement of spontaneous otoacoustic emissions. Measuring otoacoustic emissions has become an important diagnostic tool for determining if outer hair cells are working, particularly in newborn hearing screening (see Chapter 45, Audiologic Testing).

Sensorineural hearing loss is a common clinical problem and has many possible causes, including noise exposure,



▲ **Figure 44–24.** Outer hair cell electromotility. When the mechanoelectrical transduction channels are closed (cell on the left), the outer hair cell is hyperpolarized and elongated. When the channels are open (cell on the right), the outer hair cell is depolarized and shortened. The plasma membrane may flatten and ripple during this process, although this concept is hypothetical. These length changes occur at speeds of up to 100 kHz, and function to amplify the sound pressure waves (the cochlear amplifier). (Adapted, with permission, Synder KV, Sachs F, Brownell WE. The outer hair cell: A mechanoelectrical and electromechanical sensor/actuator. In: Barth FG, Humphrey JAC, Secomb TW, eds. *Sensors and Sensing in Biology and Engineering.* Wien: Springer-Verlag, 2003.)

ototoxicity, and age-related hearing loss (presbycusis). The common site of pathology for all of these conditions within the inner ear is the outer hair cell (see Figure 44–24). The attachments of outer hair cell stereocilia to the tectorial membrane can be broken, even with mild noise exposure. This reduces the ability of outer hair cell electromotility to provide a positive feedback, leading to a temporary hearing loss. With further damage, the actin core of the outer hair cell stereocilia can fracture. With enough trauma, hair cell death occurs and a permanent hearing loss results because mammalian cochlear hair cells do not regenerate. After outer hair cells begin to degenerate, further structures within the cochlea die as well, including inner hair cells, supporting cells, and auditory nerve cells.

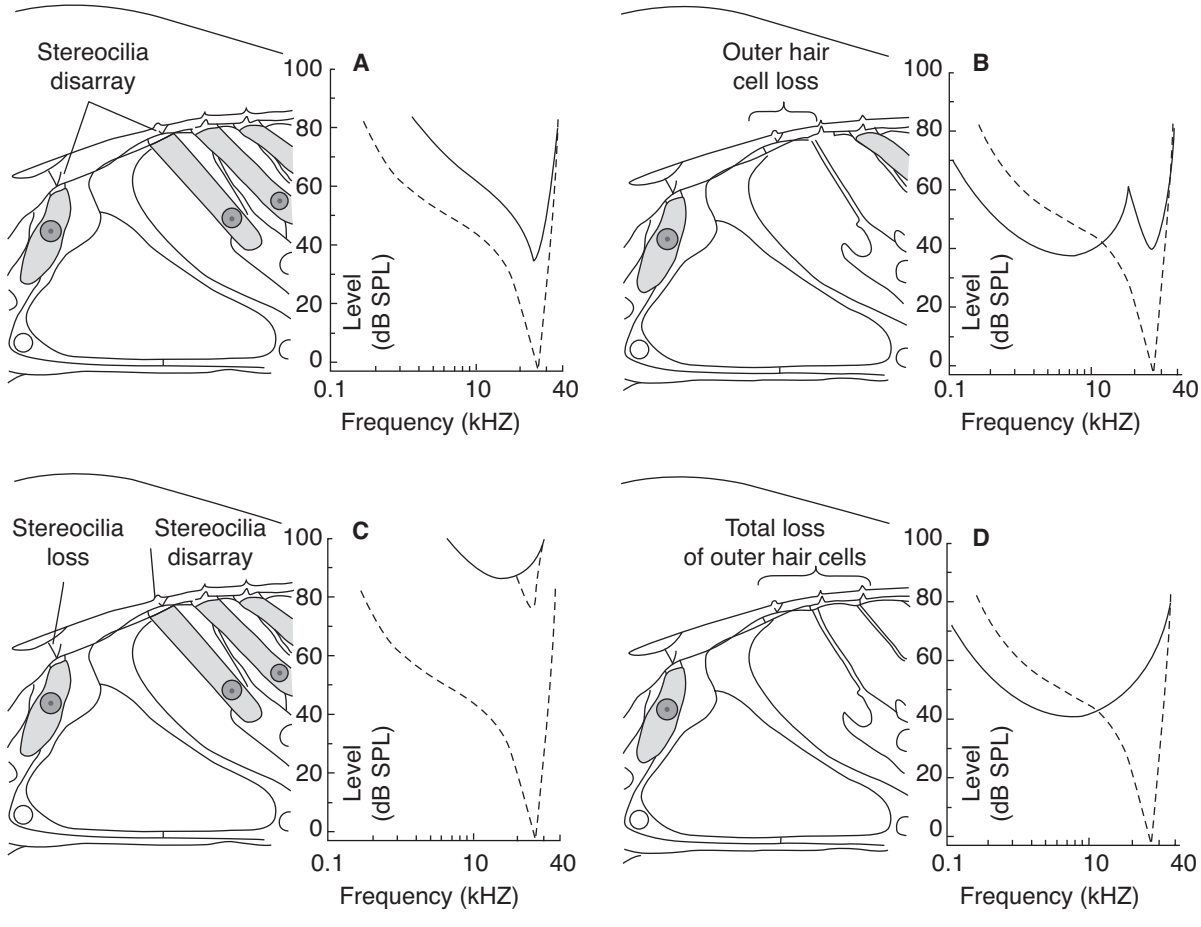
A low level of trauma that produces disarray of both inner and outer hair cell stereocilia proportionally elevates eighth nerve tuning curve thresholds (Figure 44–25**A**). When outer hair cells are lost, only the sharp peak of the tuning curve is lost (Figure 44–25**B and D**). Loss of inner hair cells produces a dramatic elevation in tuning curve thresholds (Figure 44–25**C**). Outer hair cell damage blocks the cochlear amplifier, but the passive tuning properties of the cochlea are retained. In contrast, inner hair cell damage reduces cochlear function overall. In summary, outer hair cells are responsible for the cochlear amplifier, whereas inner hair cells provide afferent input.

THE CENTRAL PATHWAYS: BRAINSTEM NUCLEI AND THE AUDITORY CORTEX

Input from both cochleae are integrated, and the acoustic environment is reconstructed in the brainstem and auditory cortex. This begins with the conversion of mechanical vibrations of the organ of Corti into changes of inner hair cell membrane potentials. Synaptic transmission to the afferent eighth nerve fibers (the auditory nerve) modulates the ongoing action potential discharge of the fiber. As a result of the faithful link between basilar membrane mechanics and the afferent fiber, each auditory nerve fiber is tuned to a particular characteristic frequency (see Figure 44–25). In this way, the central nervous system knows that there is energy at that specific frequency entering the ear.

Auditory brainstem-evoked response (ABR) is a clinical test to verify that the pathway from the cochlea to the midbrain is intact. Electrodes placed on the scalp (similar to those used with an electroencephalogram) can measure the electrical signals being relayed from the cochlea to the auditory cortex. By playing a "click" into the ear, a large number of auditory nerve fibers are excited simultaneously. This is called the compound action potential, and is Wave 1 of the ABR (see Chapter 45, Audiologic Testing). ABR Waves 2, 3, 4, and 5 represent the sequential activation of neurons as the signal is passed up the brainstem (distal auditory nerve, cochlear nucleus, superior olivary complex, and lateral lemniscus). Each wave should occur within a certain timeframe after the previous wave. If delayed, a conduction block can be diagnosed, which may represent brainstem pathology. The most common conduction delays are measured between Waves 1 and 3 and Waves 1 and 5, which may suggest the presence of an acoustic neuroma that is slowing conduction along the eighth cranial nerve. Many other types of pathology, including other cerebellopontine angle tumors, multiple sclerosis, chronic meningitis, and brainstem malformation, need to be included in the differential diagnosis. In most instances, an abnormal ABR indicates the need to order an MRI with and without gadolinium contrast to evaluate for retrocochlear pathology.

In all sensory systems, an important part of the neural code is determined by what location of the sensory organ is stimulated. In the case of the eye, a spot of light falls on a few photoreceptors and they excite nerves that map a representation of the visual world in the brain. In the ear, the acoustic world is coded by a one-dimensional representation of frequency. This frequency map then projects to the brain, which



▲ **Figure 44–25.** Various forms of hair cell damage found with noise trauma and their effect on eighth nerve tuning curves. The dotted lines represent normal turning curves and the solid lines are pathologic. (Adapted, with permission, Kiang NY, Liberman MC, Sewell WF, Guinan JJ. Single unit clues to cochlear mechanism. *Hear Res.* 1986;171.)

reconstructs the three-dimensional acoustic "world". Parts of the auditory cortex contain a true three-dimensional representation of the outer world so that the sound of a twig snapping behind an individual excites nerve cells in one location while a twig snapping on the right of an individual excites nerve cells in another spatially precise location. The analysis of speech appears to take place in parts of the brain that are highly developed only in humans. The amazing machinery that accomplishes the reconstruction of the acoustic world relies on the delicate structures of the inner ear that deconstruct the original sounds.

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Weitzel EK, Tasker R, Brownell WE. Outer hair cell piezoelectricity: Frequency response enhancement and resonance behavior. *J Acoust Soc Am.* 2003;114:1462. [PMID:14514199] (Describes how outer hair cell piezoelectric behavior benefits high-frequency mammalian hearing.)

45 Audiologic Testing

Robert W. Sweetow, PhD &
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Otolaryngologists often rely on audiologic test results to determine the course of treatment for a given patient. Many of the tests constituting the diagnostic audiologic battery of 20 years ago have now been replaced with newer procedures with greater specificity, sensitivity, and site of lesion accuracy. This is exemplified by the fact that the terms "sensory" or "neural" can now frequently replace the term "sensorineural." In addition, audiologic tests have gone beyond the realm of identifying anomalies in structure to identifying anomalies in function. The logical extension of this advancement is to provide the audiologist and otolaryngologist with information related to prognosis and rehabilitation.

Audiologic tests can be classified according to measures of hearing threshold, suprathreshold recognition of speech, assessment of middle ear function, assessment of cochlear function, determination of neural synchrony and evaluation of vestibular function. The test correlates associated with these measures are pure-tone audiometry, speech recognition, the immittance battery, otoacoustic emissions, electrophysiology, videonystagmography, and rotary chair assessment. The latter two procedures are discussed elsewhere in this textbook.

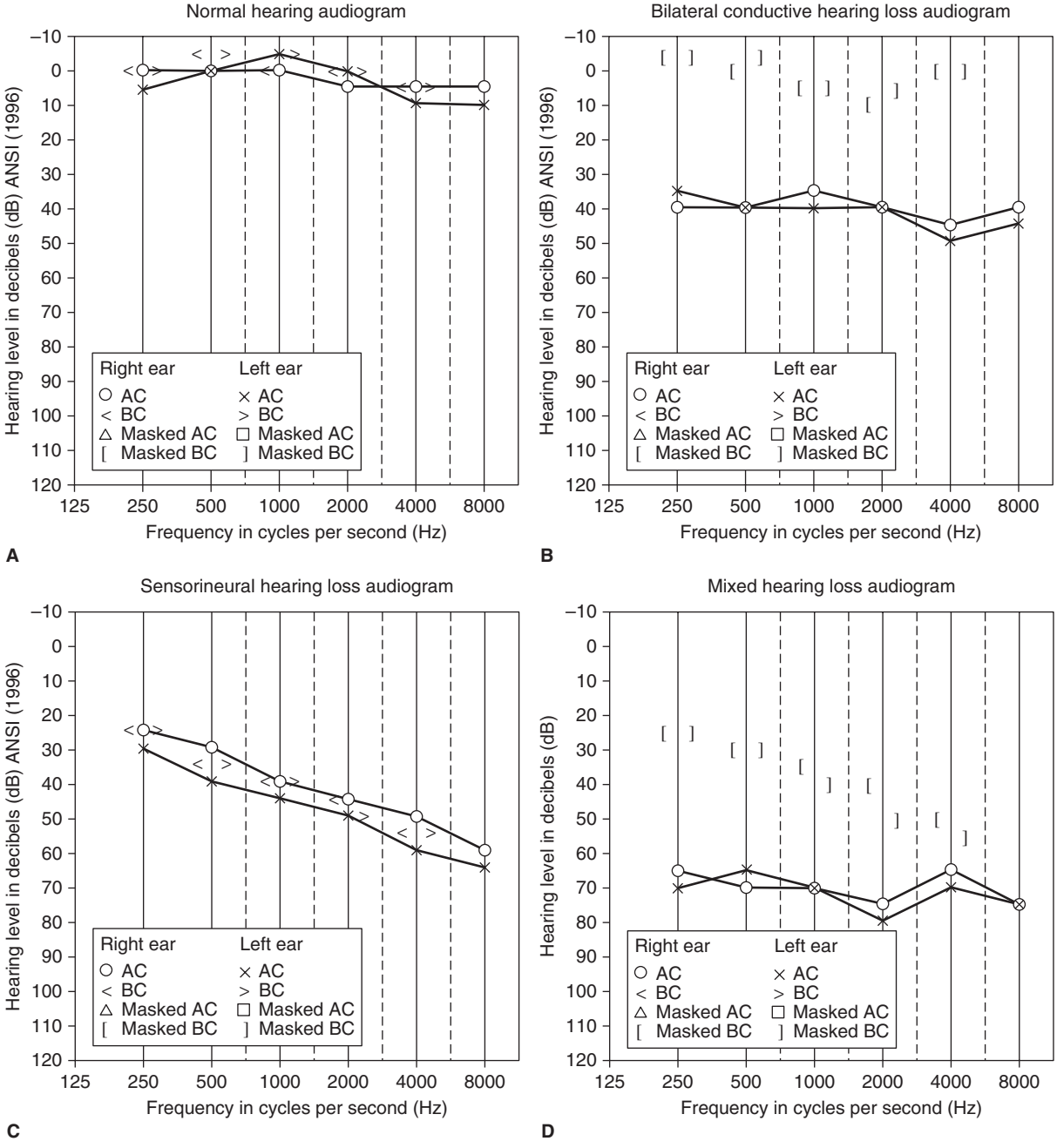
Audiologic test results should always be interpreted in the context of a battery of tests because no single test can provide a clear picture of a specific patient. In addition, the combination of objective and subjective (behavioral) tests provides a cross-check of the results. There are no age restrictions for audiologic testing; it is now possible and recommended to test newborns within days of birth.

AUDIOMETRY

The **audiogram** is a graph that depicts threshold as a function of frequency. **Threshold** is defined as the softest intensity level that a pure tone (single frequency) can be detected 50% of the time. Intensity is designated on a normalized decibel hearing level (HL) scale that takes into account the differences in human sensitivity as a function of frequency. The typical range of frequencies tested does not cover the entire range of human hearing (20–20,000 Hz). Instead, the range includes the frequencies considered to be essential for understanding speech (250–8000 Hz). Most testing is administered at discrete octave frequencies. However, when threshold differences between adjacent octaves exceed 15 dB, inter-octave frequencies should be tested. This is particularly true at 3000 and 6000 Hz, where "notches" in audiometric configuration often typify noise-induced hearing loss. Thresholds are measured clinically in 5-dB steps. There is a test-retest variability of ±5 dB. Therefore, a change of 10 dB may not necessarily represent a true threshold shift.

Thresholds can be obtained using **air conduction** (AC) or **bone conduction** (BC). Sound transmission via earphones, foam inserts, or loudspeakers requires the movement of air molecules; therefore, it is termed air conduction. This testing assesses the entire auditory system from the outer ear to the auditory cortex. Testing through loudspeakers (sound field) cannot isolate differences between ears. The advantages of insert earphones over over-the-ear (supra-aural) earphones include the prevention of collapsing ear canals, greater attenuation from ambient noise, and greater interaural attenuation (the loss of sound energy that occurs as the signal travels from one ear to the other either around the head or through the bones of the skull). Interaural attenuation is also referred to as "crossover." The amount of interaural attenuation varies as a function of the transducer type and frequency; it is typically 0 dB for bone conduction, 40–60 dB for supra-aural earphones, and 55–70 dB for insert earphones. AC thresholds are marked on the audiogram with an "O" for the right ear and an "X" for the left ear. BC thresholds are obtained using a small vibrator placed on the forehead or on the mastoid bone. Thresholds are typically indicated on the audiogram with the symbols "<" and ">" (unmasked) or "[" and "]" (masked). Because the skull vibrates as a whole, BC thresholds primarily reflect the contribution of the inner ear, mostly bypassing the function of the outer and the middle ear. The comparison of AC thresholds and BC thresholds provides an initial

differentiation between conductive, mixed, and sensorineural involvement. Sensorineural hearing loss is characterized by equivalent air and bone conduction (ie, air–bone gaps of less than 10 dB). Conductive hearing loss is characterized by BC thresholds within normal limits, with a concurrent gap between the poorer AC and better BC thresholds of 10 dB or more. A mixed hearing loss contains air–bone gaps with the bone conduction thresholds outside of the normal range. Figure 45–1 (A–D) shows audiograms depicting normal hearing and these three types of hearing loss.



▲ **Figure 45–1.** Examples of audiograms: **(A)** normal hearing thresholds, **(B)** conductive hearing loss, **(C)** sensorineural hearing loss, and **(D)** mixed hearing loss.

Both air and bone conduction thresholds may be obtained using an approach that ascends or descends in intensity but are typically determined using a bracketing technique. If tones are presented at high intensity levels, both air- and bone-conducted stimuli can evoke vibrotactile sensations. For AC, vibrotactile thresholds may occur at 90 dB HL at 250 Hz, and at 110 dB HL at 500 and 1000 Hz. For BC, vibrotactile thresholds may occur at 30–35 dB HL at 250 Hz, 55 dB HL at 500 Hz, and 65–70 dB at 1000 Hz. Therefore, patients with severe hearing loss may appear to respond at lower (softer) levels than their true auditory thresholds. For that reason, the tester should ask the patient whether the stimulus was heard or felt when approaching the aforementioned intensity levels. Furthermore, BC greater than approximately 45–60 dB HL in the lower frequencies and 70–75 dB HL in the mid and higher frequencies cannot be measured due to equipment output limits for bone-conducted stimuli. Thus, listeners with severe or profound losses may have real, but nonmeasurable, air–bone gaps, and one must not automatically assume that a profound hearing loss is exclusively sensorineural. This is one of several reasons why a battery of diagnostic test results should always be considered, as opposed to any single measure.

MASKING

One of the most important yet confusing aspects of hearing testing is to ensure that the auditory function of each ear is measured independently. In some situations, a noise is presented to the non-test ear to prevent it from responding to a signal presented to the test ear. This is referred to as masking. Masking is required for AC whenever the difference between the air conduction presentation level and the non-test ear BC thresholds exceeds approximately 40 dB for the lower frequencies and 60 dB for the higher frequencies. For BC testing, masking should be used whenever there is any difference in the AC and BC thresholds, since there is essentially no interaural attenuation by bone conduction. When the masking presented to the non-test ear crosses over to the test ear, a masking dilemma results. Usually, this occurs when a patient has a large bilateral conductive hearing loss. The use of insert earphones greatly minimizes these occurrences because of the greater interaural attenuation they provide. Failure to mask appropriately may have potentially serious medical and audiologic consequences.

CATEGORIES OF HEARING LOSS

Table 45–1 provides a general guideline for interpreting degrees of hearing loss based on audiometric findings. Levels should be categorized somewhat more stringently for children.

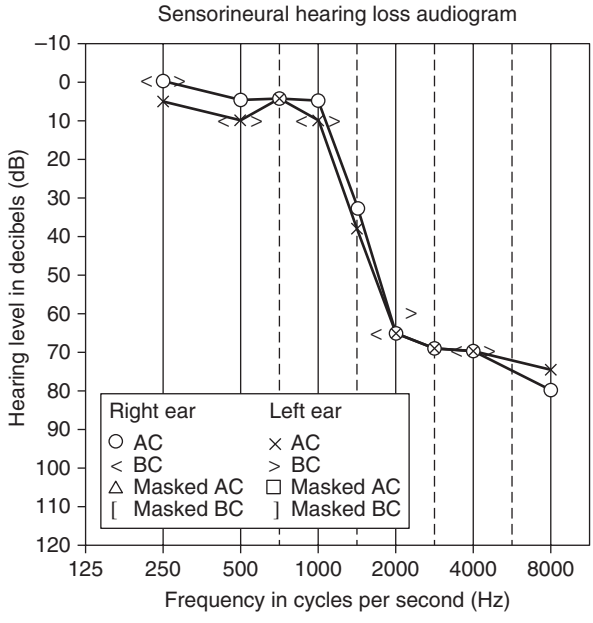
Table 45–1. Guidelines for Interpreting Hearing Loss.

Hearing Threshold	Interpretation
0–25 dB	Hearing within normal limits
26–50 dB—Mild hearing loss	Has difficulty with soft sounds, background noise, and when at a distance from the source of the sound
51–70 dB—Moderate hearing loss	Has significant difficulties with normal conversational level speech and relies on visual cues
71–90 dB—Severe hearing loss	Cannot hear conversational speech and misses all speech sounds Can hear environmental sounds, such as dogs barking and loud music
91+ dB—Profound hearing loss	Hears only loud environmental sounds, such as jackhammers, airplane engines, and firecrackers

SPEECH TESTING

One commonly used speech measure is the speech reception threshold (SRT). The SRT is the lowest intensity level at which a patient can correctly repeat 50% of common bisyllabic words such as "hotdog" or "baseball." These results should correspond with pure tone thresholds. However, caution must be exercised in using the SRT as the only indication of hearing sensitivity. An example of how the SRT can provide misleading information is shown in Figure 45–2. Note that for this patient, the SRT is 5 dB, well within the range of normal hearing. This value reflects the normal auditory sensitivity at 500 and 1000 Hz. Further inspection of the audiogram illustrates that this patient has a moderate hearing loss above 1000 Hz and will have considerable difficulty hearing in many acoustic environments. The only true purpose of the SRT is to validate the pure-tone findings. A variation of the SRT is the **speech detection threshold (SDT)** or **speech awareness threshold (SAT),** which is the softest level at which a person detects (as opposed to understands) the presence of speech sounds. Pure-tone testing and SRT, SAT, or SDT yield information about hearing sensitivity. Most listening is actually done at suprathreshold levels. Therefore, to define a person's true auditory capacity, measures reflecting suprathreshold listening and clarity must be included. **Word recognition testing** (formerly referred to as *speech discrimination testing*) assesses a patient's ability to identify monosyllabic words. A list of words are typically presented to the patient at approximately 40 dB above the SRT, or at a comfortable listening level if 40 dB is either too loud for the patient or incongruous with the audiometric configuration.

The type and degree of hearing loss can often affect word recognition scores. Given the relatively low face validity of



▲ **Figure 45–2.** An example of an audiogram in which the SRT could give misleading information regarding a patient's hearing. Note that the patient has normal hearing to 1000 Hz, which then drops to a moderate hearing loss in the high frequencies.

monosyllabic word testing (because we do not typically listen to single-syllable words all day), the audiologist can further define hearing by assessing conversational speech or sentence recognition both in quiet and in noise. This information can provide the most useful prognostic data for the rehabilitation plan.

NONORGANIC (FUNCTIONAL) HEARING LOSS

Pseudohypacusis is defined as functional hearing loss. Occasionally, patients willfully or subconsciously exaggerate their hearing loss. The signs in test behavior that suggest a functional component include (1) inconsistent responses, (2) significant differences between the thresholds obtained using ascending and descending administration of test stimuli, (3) a discrepancy of more than 8 dB between the SRT and the pure-tone average of 500–2000 Hz, and/or (4) a positive Stenger test. The **Stenger test** may be used to identify unilateral or asymmetrical functional hearing loss. It is based on the concept that when both ears are stimulated simultaneously by a tone equal in frequency and phase, the auditory percept is lateralized to the ear with better hearing. Systematic manipulation of the relative intensities delivered to each ear provides the audiologist with an estimate of the true threshold in the ear that has a more significant hearing loss. When speech stimuli are used, the test is called a **Speech Stenger test** or a **Modified Stenger test.** Other objective measures that may disclose functional involvement include acoustic reflexes, auditory brainstem responses, and otoacoustic emissions. These tests are discussed later in this chapter.

Martin, FN. Pseudohypacusis. In Katz J, Burkard RF, Medwetsky L (editors): *Handbook of Clinical Audiology*. Lippincott Williams and Wilkins. Philadelphia, PA, 2002. (A review of diagnostic procedures for possible functional hearing loss.)

ACOUSTIC IMMITTANCE TESTING

Acoustic immittance testing consists of tympanometry, acoustic reflexes, and static compliance. These tests measure the function of the tympanic membrane, middle ear, and acoustic reflex arc pathway. They are not direct measures of hearing sensitivity.

TYMPANOMETRY

Tympanometry is based on the amount of sound reflected back from the tympanic membrane when an 85-dB sound pressure level (SPL) low-frequency (226-Hz) probe tone is introduced into the sealed ear canal and pressure in the ear canal is varied. When the pressure in the ear canal corresponds with the pressure in the middle ear cavity, the tympanic membrane is at its most compliant point and thus absorbs, rather than reflects, the most sound. The **tympanometric peak,** or maximum flow of acoustic energy into the middle ear, occurs when the pressure in the ear canal and middle ear is equal. If eustachian tube function is normal, peak pressure occurs near 0 daPa. If the middle ear is not properly aerated, the middle ear pressure will be negative (>100 daPa). Thus, the ear canal pressure corresponding to the tympanometric peak provides an estimate of middle ear pressure. For infants and neonates, tympanograms should be obtained using a higher-frequency probe tone (660 or 1000 Hz) due to resonant differences in small ear canals.

Classification

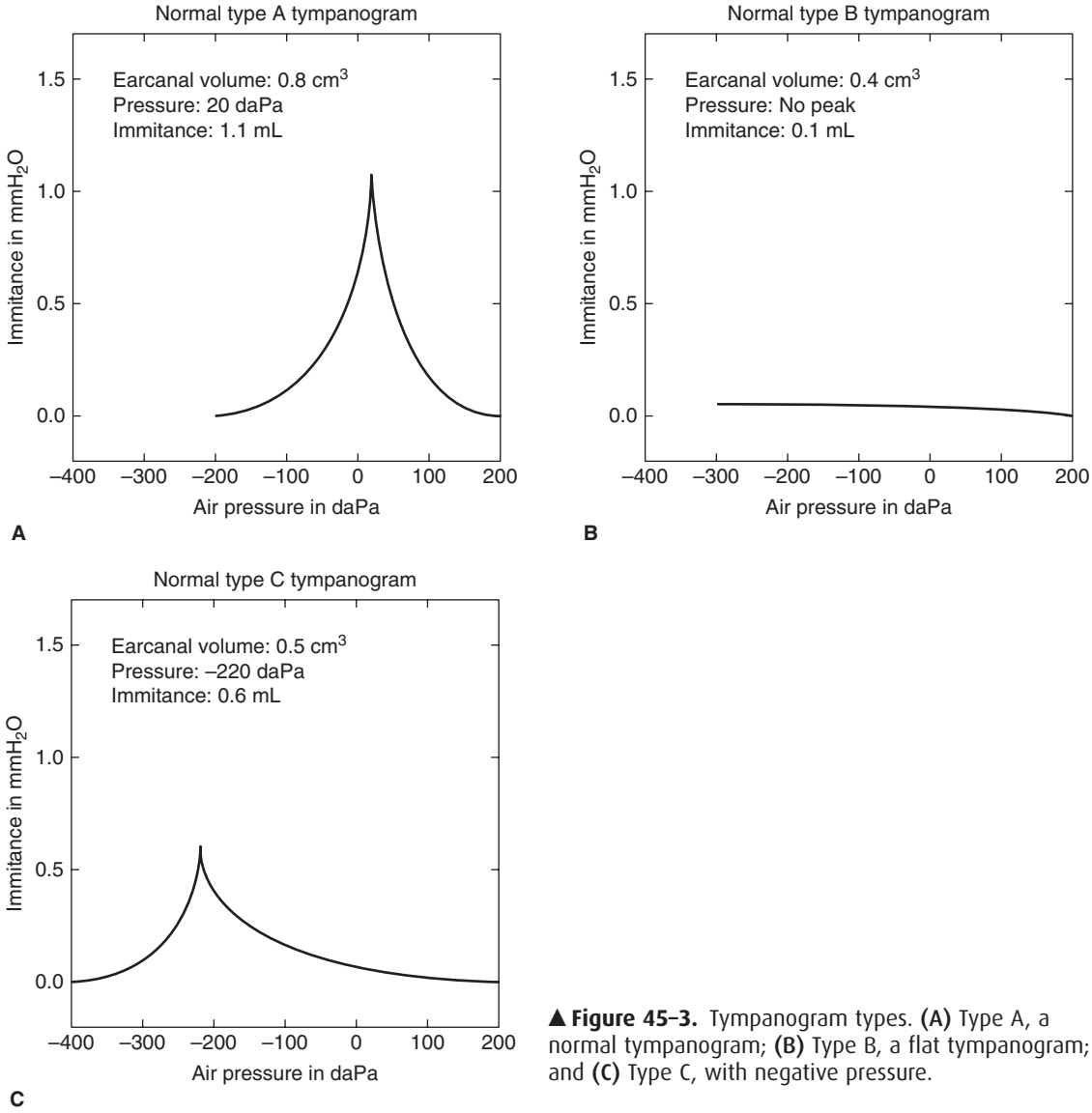
Traditionally, tympanograms have been classified as Type A, B, or C (Figure 45–3). Some clinicians prefer describing the tympanogram in a more specific narrative form.

A. Type A

Type A tympanograms have normal peak height (reflecting compliance) and pressure. Variations of the Type A tympanogram may be normal in pressure but shallow (A_S), reflecting otosclerosis or middle ear effusion, or may be peaked very high (A_D), reflecting ossicular discontinuity or a monomeric eardrum.

B. Type B

The Type B tympanogram is flat in appearance, indicating lack of compliance. The volume measurement that is simultaneously performed with tympanometry helps to



▲ **Figure 45–3.** Tympanogram types. **(A)** Type A, a normal tympanogram; **(B)** Type B, a flat tympanogram; and **(C)** Type C, with negative pressure.

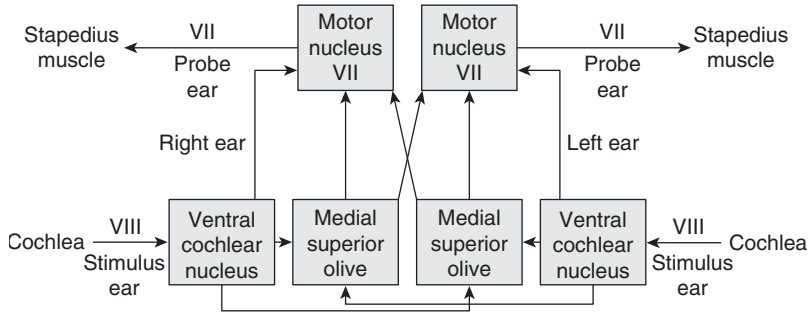
differentiate between a flat tympanogram suggesting an intact eardrum with middle ear effusion versus a perforated eardrum or ear with a patent ventilating tube.

C. Type C

The Type C tympanogram has negative peak pressure suggesting inadequate aeration of the middle ear space.

ACOUSTIC REFLEX

An acoustic reflex occurs when the stapedius muscle contracts in reaction to a loud sound. Acoustic reflex thresholds refer to the softest intensity levels that can trigger the response. They usually occur at 70–90 dB *above* the patient's hearing threshold. When the stapedius muscle contracts, it stiffens the ossicular chain, thus decreasing compliance. The change in compliance coincident with the presentation of an intense acoustic signal is measured with the same instrument used for tympanometry. Because monaural stimulation results in contraction of the muscles in both ears, the reflex can be measured either ipsilaterally or contralaterally. When the reflex is recorded in the stimulated ear, it is called an ipsilateral reflex; if it is recorded in the opposite ear, it is called a contralateral reflex. The following four stimulus-probe configurations can be measured: (1) right ipsilateral (stimulus to the right ear, probe to the right ear); (2) right



▲ **Figure 45–4.** The acoustic reflex arc.

contralateral (stimulus to the right ear, probe to the left ear); (3) left ipsilateral (stimulus to the left ear, probe to the left ear); and (4) left contralateral (stimulus to the left ear, probe to the right ear). Figure 45–4 depicts the acoustic reflex arc. Knowledge of this pathway allows the clinician to compare the results of the various testing configurations to interpret the findings.

Patients with mild or moderate cochlear (sensory) hearing loss yield contralateral and ipsilateral acoustic reflex thresholds at approximately the same intensity levels as those with normal hearing. Acoustic reflexes are absent in the presence of a severe or profound hearing loss. A significant conductive hearing loss typically eliminates the response on either ear whenever the affected side is stimulated. This is because the stimulating sound is not loud enough to trigger the reflex when the affected ear is stimulated, and the middle ear abnormality (eg, otosclerosis or middle ear effusion) prevents the stapedius muscle from contracting even when the opposite (normal) ear is stimulated. Therefore, any disorder of the stapedius muscle can also cause absent acoustic reflexes. Thus, the only reflex that will occur for a unilateral conductive loss is the ipsilateral reflex to the normal ear. A bilateral conductive loss eliminates the reflex in all four conditions. A lesion of cranial nerve VIII can eliminate both the contralateral and ipsilateral acoustic reflexes whenever the affected side is stimulated (ear effect). However, contralateral and ipsilateral reflexes are usually present when the normal ear is stimulated. For pathologies affecting the central crossed pathways, reflexes are present in both ipsilateral conditions, but may be absent in the two contralateral conditions. A lesion of the seventh nerve (eg, Bell palsy) can eliminate the acoustic reflex whenever the affected side is measured (probe effect), regardless of which ear is stimulated. This pattern can be distinguished from the conductive pattern because in a conductive loss, both the measured and the stimulated ear typically show absent contralateral reflexes. In seventh nerve pathology, the acoustic reflex also can help to determine whether the lesion is proximal or distal to the branching of the stapedius muscle. If the lesion is proximal to the stapedius muscle, acoustic reflexes are absent; if the lesion is distal to the muscle, reflexes are present. Any central nervous system depressant, including alcohol, can depress the amplitude of the response. A functional hearing loss may be suspected if reflexes occur below or at the volunteered pure-tone thresholds. When hearing loss exceeds 70 dB HL, it becomes difficult to determine whether absent reflexes are due to a cochlear or a retrocochlear hearing loss.

ACOUSTIC REFLEX DECAY

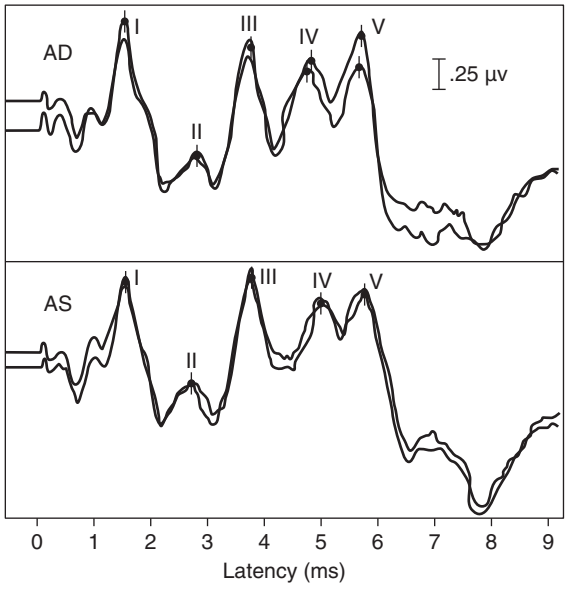
The measurement of acoustic reflex decay may be useful when a retrocochlear lesion is suspected. For this procedure, a 500- or 1000-Hz signal is presented to the ear contralateral to the probe ear, at 10 dB above the patient's acoustic reflex threshold for 10 seconds. If the response amplitude decreases more than 50%, it is considered abnormal (positive) and suggestive of a lesion on cranial nerve VIII. Usually, acoustic reflex decay is only measured contralaterally at 500 or 1000 Hz, because higher frequencies and ipsilateral stimulation may show decay even in normal subjects. The sensitivity and specificity of reflex decay are not as high as the auditory brainstem response (ABR) for identifying vestibular schwannomas. Also, care must be taken in deciding whether or not to administer decay testing, especially in patients with tinnitus or hyperacusis, because of the intense stimulus levels that are often required.

Harris PK, Hutchison KM, Moravec J. The use of tympanometry and pneumatic otoscopy for predicting middle ear disease. *Am J Audiol* 2005;14(1):3 [PMID: 16180966]. (Article describes tympanometry and multi-frequency tympanometry. Assesses the predictive potential of tympanometry for otitus media.)

ELECTROPHYSIOLOGY

AUDITORY BRAINSTEM RESPONSE

Auditory brainstem response (ABR) testing objectively assesses the neural synchrony of the auditory system from the level of the eighth nerve to the midbrain. The obtained results can be extrapolated to provide information regarding hearing sensitivity and also can be used for **neurodiagnostic** purposes. To administer the ABR test, electrodes are placed on the patient's head, and a series of sounds are presented.



▲ **Figure 45–5.** An example of a normal auditory brainstem response.

The patient must remain still and, with children, it may be necessary to sedate to obtain valid results. The diagnostic (not screening) test procedure typically requires 30–60 minutes. The ABR consists of a series of 5–7 waves that occur within the first 10–15 ms following the stimulus. These potentials are shown in Figure 45–5. Waves I and II are thought to be generated in the eighth nerve of the stimulus ear; Waves III–V are thought to be generated in the brainstem and midbrain. For neurologic purposes, the latencies (**absolute**, **interwave**, and **interaural**) and amplitudes (absolute and relative) of Waves I, III, and V are analyzed. Clicks are the most commonly used stimuli because their abrupt rise time and broad spectrum enhance **neural synchrony**; however, the results are dominated by the high-frequency region.

The other primary use of electrophysiologic measures is to estimate the auditory thresholds for AC and BC in patients who are unwilling or unable to provide accurate behavioral audiometric thresholds. For these patients, the lowest intensity level at which Wave V can be visualized and repeated is considered the threshold. ABR is frequently used for newborn hearing screening, because it provides accurate information in a relatively short amount of time. For better definition across the frequency range, **frequency-specific** stimuli, such as tone pips, are used. Because tonal signals have a slower rise–fall time than clicks, the wave morphology may be degraded, making threshold identification more difficult. Normative values from research centers for gender and age are available; however, to be accurate, each clinic should establish its own equipment-specific normative values. More recent additions to the electrophysiologic battery include **ASSR** (Auditory Steady State Response), which allows for a potentially more rapid means of establishing frequency-specific thresholds, stacked ABR (a more sensitive and specific method for the detection of small tumors), and **CHAMP** (cochlear hydrops analysis masking procedure) for detection of Meniere disease.

ABR Interpretation

Interpretation of the ABR depends on knowledge of the relevant recording and subject variables. Age and gender, as well as the type, degree, and configuration of the hearing loss, may substantially affect the latencies and amplitudes of the ABR. The following statements summarize the expected outcomes:

A. Normal Hearing

The latencies for Waves I, III, and V are within the normal range, and the interaural (between ears) latencies are equal (within 0.2–0.3 ms).

B. Conductive Hearing Loss

The absolute latencies of all waves are prolonged, but the interwave latencies are not substantially affected. This pattern occurs regardless of the stimulus intensity. The configuration of the hearing loss may also contribute to variability in the latencies.

C. Cochlear Hearing Loss

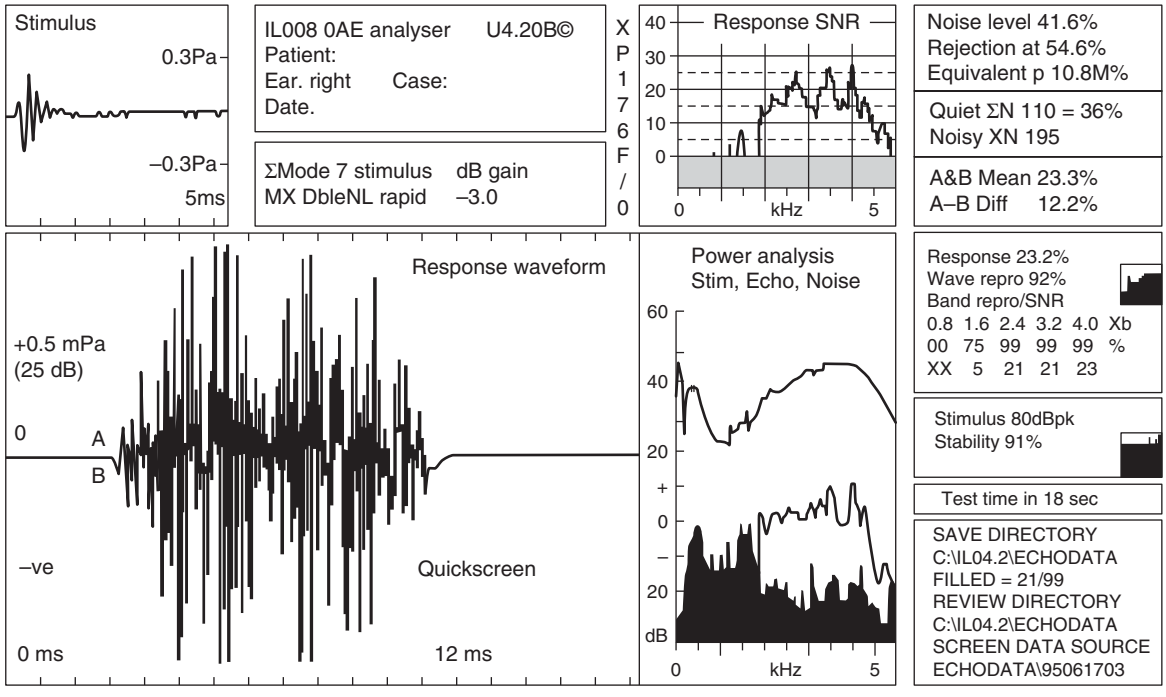
The degree and configuration of the hearing loss may affect the latencies of Waves I, III, and V. A relatively flat hearing loss of less than 60 dB HL should not impact the ABR latencies, but high-frequency hearing loss may reduce the amplitudes and prolong the absolute latencies of the waves, without increasing the interwave I–V latency difference when stimuli are presented at high intensities.

D. Retrocochlear Hearing Loss

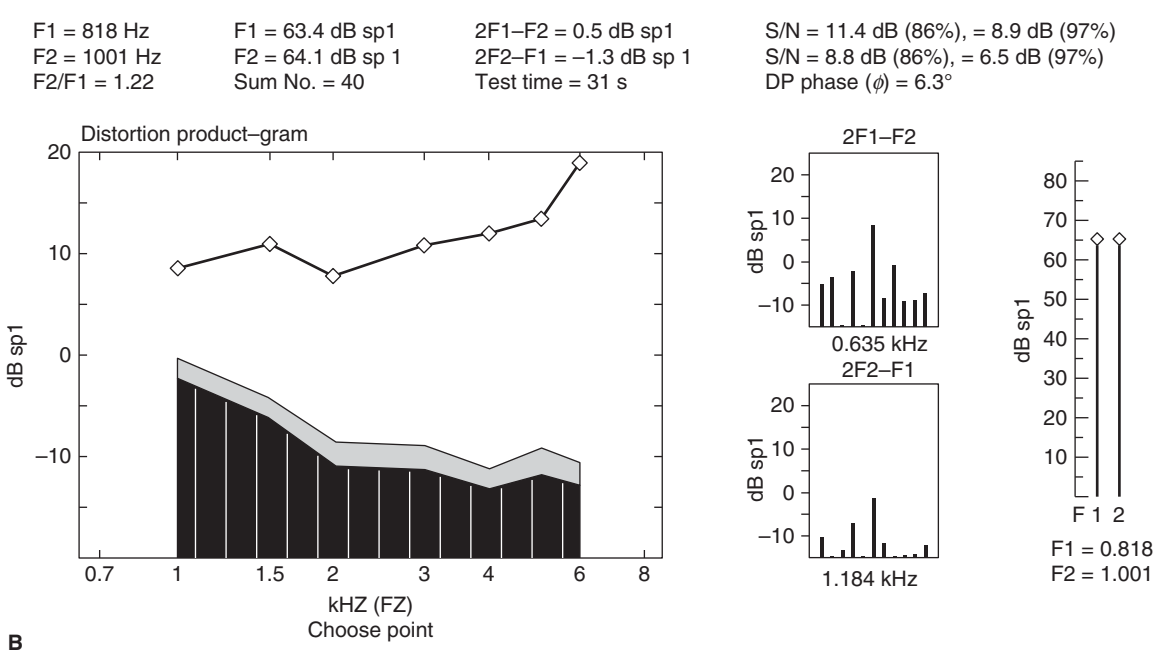
A variety of effects on the latencies and morphology of the ABR may occur. These may include the absence of waves, prolonged absolute or relative latencies (2 or 3 standard deviations beyond the mean), or prolonged interaural latencies. Wave I may be within normal limits, but the absolute latency for Wave V, and consequently the I–V interwave latency, is prolonged beyond the normal limits.

ELECTROCOCHLEOGRAPHY

Electrocochleography (ECOG or ECochG) evaluates the electrical activity generated by the cochlea and the eighth cranial nerve, occurring during the first 2–3 ms subsequent to a stimulus. The active electrode is placed in the ear canal, on the tympanic membrane, or through the tympanic membrane on the promontory; the reference electrode is placed



A



B

▲ **Figure 45–6.** Examples of otoacoustic emissions. **(A)** In transient evoked otoacoustic emissions, the patient has normal hearing to 4000 Hz; and **(B)** in distortion product otoacoustic emissions, the patient has normal hearing.

on the vertex or the contralateral earlobe or mastoid. The closer the active electrode is to the cochlea, the larger the response. The principal potentials that are evoked through ECOG are the cochlear microphonic, the summating potential, and the compound action potential. Most commonly, only the summating potential and the compound action potential are of interest. The main application of the ECOG is to help determine if a patient has Meniere disease. The amplitude of the summating potential (reflecting activity of the hair cells) is compared with that of the compound action potential (reflecting whole nerve activity). If the ratio is larger than normal (0.3–0.5), it is considered indicative of Meniere disease. The procedure is considered valid only the patient is symptomatic.

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OTOACOUSTIC EMISSIONS

Otoacoustic emissions (OAEs) are objective, noninvasive, and rapid measures (typically less than 2 minutes) used to determine cochlear outer hair cell function. It is believed that OAEs are a by-product of the **biomechanical motility** of the outer hair cells. Emissions are recorded from a small microphone placed in the ear canal via a soft probe. A good probe fit and low ambient and patient noise levels are essential to record OAEs because the OAE response is very small (usually <20 dB SPL).

OAEs are usually detected in the presence of normal or near-normal hearing. Using current measurement protocols, emissions typically are not detected if there is a conductive or sensorineural hearing loss greater than 25–30 dB HL. Although produced in the cochlea, a pathology in the outer or middle ear may obliterate OAE because of the reduction in stimulation signal intensity and also because the signal must travel distally through the middle and outer ear to be measured by the recording microphone.

The three main types of OAE are spontaneous, transient evoked, and distortion product.

SPONTANEOUS OTOACOUSTIC EMISSIONS

Spontaneous otoacoustic emissions (SOAEs) occur even in the absence of a stimulus. SOAEs are the product of a healthy cochlea; however, they are found in less than half of the normal hearing population and, therefore, cannot be used in hearing screening. They have limited clinical use at this time.

TRANSIENT EVOKED OTOACOUSTIC EMISSIONS

Transient evoked otoacoustic emissions (TEOAEs) occur when the ear is stimulated by transient or brief signals, such as clicks. Even though the stimulus is broadband, the TEOAE can provide frequency-specific data. As the traveling wave progresses through the cochlea, the basal (high frequency) turn of the cochlea is first to be stimulated by the click and responds earliest, followed by the more middle- and low-frequency (apical) portions, thus allowing the response to be analyzed in both the frequency and time domain.

DISTORTION PRODUCTION OTOACOUSTIC EMISSIONS

Distortion production otoacoustic emissions (DPOAEs) are produced when two tones of different, but related, frequencies (F1 and F2) are presented to the cochlea simultaneously. F2 is usually 1.21 times the frequency of F1 and is typically presented 10 dB higher in intensity. In response to these two tones, the normal cochlea generates novel tones, called distortion products, at frequencies related to F1 and F2. This is due to the **nonlinearity** of the healthy cochlea. The information obtained from DPOAE is frequency specific because tonal stimuli are used to generate the response. Although the results are correlated with the audiometric configuration, the relationship is not precise. Figures 45–6A and 45–6B show examples of TEOAE and DPOAE recorded from a patient with normal hearing.

The clinical applications of OAE are significant. Because OAEs are specific to cochlear function, they can be very useful in differentiating between cochlear and retrocochlear lesions in sensorineural hearing loss. Even though OAEs assess cochlear outer hair cell function, the results are often used in predicting the likelihood of hearing impairment. As such, OAE testing is commonly used in newborn hearing screening because of its speed and noninvasive nature. It is also used in confirming pure-tone test results obtained from young children, in patients for whom a functional hearing loss is suspected, for audiometric configuration confirmation, for ototoxic drug monitoring, and in hearing aid candidacy. More recently, OAEs, in conjunction with ABR, can be used in identifying individuals with **auditory neuropathy,** also termed auditory dyssynchrony.

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Lonsbury-Martin BL, Martin GK. Otoacoustic emissions. Curr Opin Otolaryngol Head Neck Surg 2003;11(5):361 [PMID: 14502067]. (Review of otoacoustic emissions.)

46 Vestibular Testing

Bulent Satar, MD

PATIENT HISTORY

Before performing any vestibular test, taking a thorough medical history and ascertaining the patient's symptoms constitute the first steps in caring for a patient with a vestibular disorder. Sometimes the patient history alone may suggest a diagnosis.

Symptoms

Taking a patient history should include determining the patient's symptoms, including balance, hearing, vision, somatosensation, and motor function. The first task for a neurotologist is to allow the patient to describe what he or she senses. The clinician may help the patient in choosing the correct terms to describe his complaints.

A. Vertigo

Vertigo can be described as an unreal sense of rotationary movement. It should be distinguished from dizziness, which describes any kind of altered sense of orientation. A history of vertigo is of great value in identifying the presence of vestibular pathology but not in localizing its origin. Vertigo results from impaired tonic symmetry in the inputs of the vestibular nuclei. Therefore, a vestibular lesion can occur anywhere within the vestibular end-organs, the vestibular nuclei, the cerebellum, the pathways connecting these structures in the brainstem, and, rarely, within the cortex.

The differentiation between peripheral and central nervous system (CNS) lesions may be based on detailed features of vertigo, even though these features may not apply to every patient. The clinician should determine whether the vertigo occurs in episodes or continuously. If it is episodic, it should be ascertained how often the episodes occur and how long they last. In peripheral causes, vertigo occurs in episodes with an abrupt onset. It disappears in varying time periods, from seconds to days, based on the underlying pathology. The origin of intensive, episodic vertigo that lasts up to a minute is more likely **benign paroxysmal positional vertigo** (BPPV) if it is provoked with particular positions. Another cause of brief but recurrent vertigo or dizziness, especially if precipitated by body straining, is **perilymph fistula**. Vertigo that lasts 2–20 minutes is consistent with a **transient ischemic attack**, which affects the posterior circulation if it is associated with visual deficits, ataxia, and localized neurologic findings. **Meniere disease** causes recurrent vertigo attacks that can last between 20 minutes and 24 hours. An isolated attack of vertigo that lasts more than 24 hours is suggestive of **vestibular neuronitis**. Autonomic symptoms such as nausea, vomiting, and sweating are common presenting symptoms. Generally, the more intense symptoms a patient has, the more likely it is that the vertigo is caused by a peripheral lesion.

B. Lightheadedness

Lightheadedness describes the sensation of unsteadiness and falling or the symptoms similar to those preceding syncope, such as blurred vision and faded facial color. It should be distinguished from both vertigo and visual disorientation. Most often, lightheadedness occurs with nonvestibular causes such as cardiac or vasovagal reflex.

C. Imbalance

Imbalance is described as the inability to maintain the center of gravity. It causes the patient to feel unsteady or as if about to fall. The causes may be sensory or motor.

D. Other Symptoms

The physician should also ascertain the presence of other associated symptoms such as hearing loss, tinnitus,

and facial weakness. A positive history of precipitating factors (eg, rapid head movement) may lead the clinician to variants of BPPV. However, identifying the factors that induce vertigo may not be helpful in distinguishing peripheral lesions from CNS lesions because vertigo precipitated by rapid head movements may result from either decompensated peripheral vestibular lesions or CNS lesions. The physician should ascertain whether the patient has a history of falling with no loss of consciousness; this symptom may be associated with Meniere syndrome. Determining whether noise is a precipitating factor may be useful in identifying **Tullio phenomenon**. A history of brief episodes of vertigo induced by Valsalva-like maneuvers, which increase middle ear pressure, may be indicative of a perilymph fistula, Chiari malformation, or dehiscence of the superior semicircular canal (SCC). Figure 46–1 shows downbeating nystagmus induced by hyperventilation in a patient with superior canal dehiscence syndrome.

Drug Use

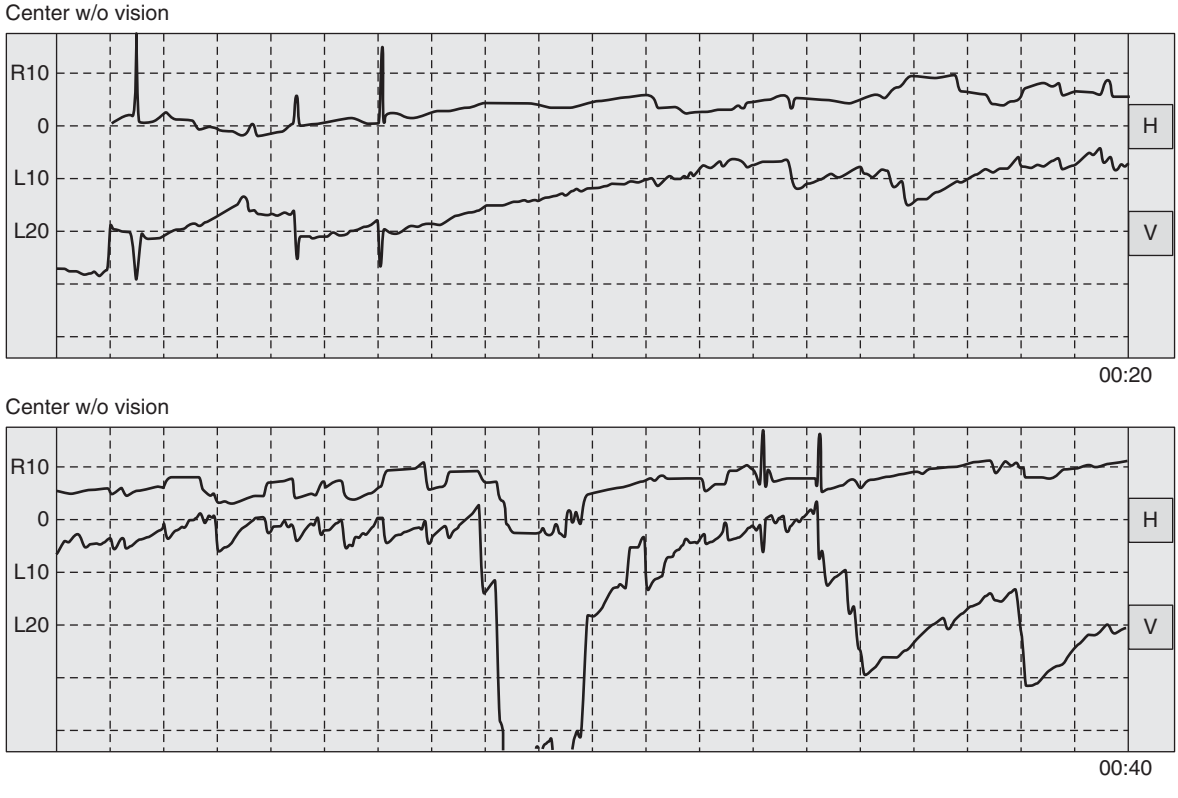
Determining the patient's drug history and current drug use (prescription or other) is crucial in evaluating dizziness. Vestibulotoxic drug intake may cause bilateral vestibular end-organ damage, which results in oscillopsia.

Psychological Factors

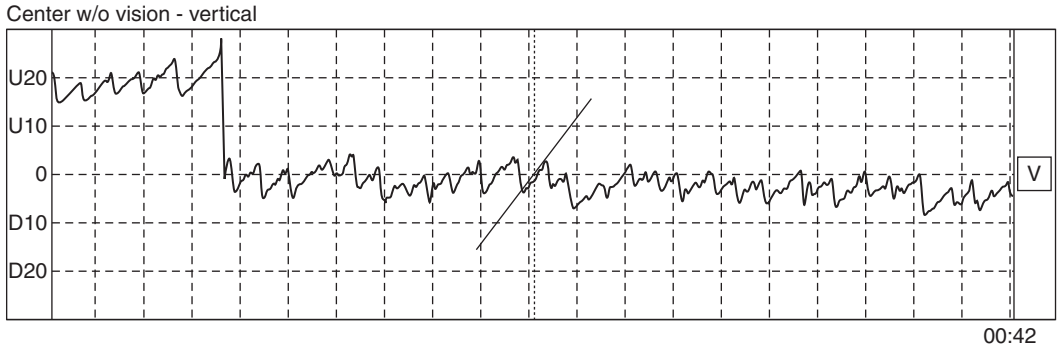
The clinician should also query patients about psychological factors. The specific site where dizziness occurs should be identified. Panic attacks or agoraphobia may be suspected if lightheadedness occurs in crowded areas or public places.

Family History

A positive family history of a balance disorder may contribute to the diagnosis, especially in Meniere syndrome, neurofibromatosis, migraine, and a narrow endolymphatic duct.



▲ **Figure 46–1.** Downbeating nystagmus in a patient with superior canal dehiscence syndrome as proven by coronal temporal bone CT. Upper trace (H) indicates horizontal eye movement and the bottom trace (V) vertical eye movement. There is no nystagmus in the horizontal record. At the beginning, a nystagmus is not observed in the vertical trace. However, from 22nd second on, it shows a downbeating nystagmus with gradually increasing slow-phase velocity (up to 10°/s) as hyperventilation deepened.



▲ **Figure 46–2.** Spontaneous downbeating nystagmus in a patient with diffuse cerebellar atrophy. Diagram shows vertical eye movements (V) only. No nystagmus is noted in the horizontal record (not shown here). Downbeating nystagmus (slow-phase velocity 13°/s) is clearly seen in the trace.

PATIENT EVALUATION

Physical Exam

The physical examination of a patient with a balance disorder should begin with a complete ear, nose, and throat exam. A detailed neurotologic examination should also be performed; it should include an evaluation for nystagmus and oculomotor function, as well as positional tests, postural control tests, and a cranial nerve examination.

Testing & Evaluation

A. Oculomotor Function Tests

Oculomotor function is tested by asking the patient to gaze at the tip of the clinician's index finger. The clinician should first hold her or his finger 25 cm away from the patient's eyes and then move it laterally and vertically, which is the tracking function. The clinician should assess whether the patient's eye movements are conjugate or disconjugate. In testing the horizontal tracking function, anything other than a smooth horizontal eye movement is assumed to be indicative of vestibulocerebellar pathology. During the vertical tracking test, a superimposed horizontal eye movement (ie, a saccadic intrusion) may occur in patients with a central oculomotor lesion. An imbalance in the tonic levels of activity that underlies the otolith-ocular reflexes leads to static ocular torsion, head tilt, and a skew deviation, which is a vertical misalignment of the eyes that is observed upon switching the cover from one eye to the other.

1. Nystagmus testing—In assessing for the presence of nystagmus, the clinician should be aware of possible changes in findings at the time of either the acute or chronic phase of the vertigo or dizziness.

a. Spontaneous nystagmus—Spontaneous nystagmus is identified by having the patient wear Frenzel glasses. If nystagmus is found, the direction of its fast phase, frequency, and amplitude are noted. Determining the characteristics of the nystagmus would give the physician an overall indication, before electronystagmographic testing is performed, if there is an obvious asymmetry in the vestibular system. If primary positional nystagmus is purely vertical or purely torsional, a CNS disorder, usually in the vestibulocerebellum, the vestibular nuclei, and their connections within the interstitial nucleus of Cajal in the midbrain, is likely. Figure 46–2 shows downbeating nystagmus in a patient with diffuse cerebellar atrophy. Spontaneous nystagmus that is peripheral in origin is characteristically diminished by visual fixation and increased only when fixation is canceled.

b. Gaze nystagmus—Gaze nystagmus is identified by holding the index finger at off-center positions. **Central origin nystagmus** may change its direction with different gaze positions. The direction of **peripheral origin nystagmus** is fixed in all gaze positions. A low-velocity, direction-fixed nystagmus (ie, 1–2°/s) or a direction-changing, gaze-evoked nystagmus, both of which present only in darkness, can occur as a nonspecific finding both in nonsymptomatic individuals and patients with organic peripheral or central vestibular lesions. While gazing at a distant object, the passive rotation of a patient's head at the frequency of 1 Hz over 20 seconds causes a patient with oscillopsia to make saccadic corrections and to view the object as no longer being stationary.

c. Head-shaking nystagmus—Head-shaking nystagmus is evaluated in the same way as gaze nystagmus; however, in head-shaking nystagmus, patients either wear Frenzel glasses or close their eyes. The frequency and speed of the patient's head shaking should be maintained at sufficiently high levels (at least 160°/s) to elicit the nonlinearity of the diseased vestibular labyrinth. The direction of head-shaking nystagmus may be toward either the side with the lesion or the side without it, and it may be monophasic, biphasic, or triphasic. If a head-shaking nystagmus beats toward the side

without the lesion in a patient with no spontaneous nystagmus, the presence of a statically compensated peripheral lesion should be considered.

2. Nonlinearity testing—Dynamic nonlinearity in the SCCs can be tested at the bedside by observing the effect of head rotations on eye movements. With this test, the malfunction of individual canals is examined by applying high-acceleration head thrusts, with the eyes beginning about 15° away from the primary position in the orbit and the amplitude of the head movement such that the eyes end near the primary gaze position. The patient is asked to fix his or her gaze on the examiner's nose. Any corrective saccade shortly after the end of the thrusts is a sign of an inappropriate and compensatory slow-phase eye movement. Each canal can be tested in its plane.

3. Fistula testing—The presence of a fistula is suspected if nystagmus occurs or if the patient perceives movement of a visual target that is fixed after applying positive pressure to the outer ear canal. A positive test result (ie, **Hennebert sign**) suggests either a perilymph fistula or Meniere disease. Tullio phenomenon occurs in the same clinical entities when a loud noise is applied. Hyperventilation may induce symptoms in patients with anxiety and phobic disorders, but it seldom produces nystagmus.

B. Positional Tests

Positional tests can be described as either dynamic or static. Static positional tests are discussed in the Electronystagmography section of this chapter.

The dynamic positional test is called the **Dix-Hall-pike maneuver**. This test is performed to elicit typical nystagmus of BPPV of the vertical SCCs. The patient may be asked to wear Frenzel glasses. In the test, the patient sits on the examination table with his head rotated 45° from the sagittal plane to one side. The patient is then moved quickly into a position where his head hangs over the edge of the table. After a 20-second waiting period, if nystagmus is not observed, the patient is returned to his initial sitting position. The patient then rotates his head 45° from the sagittal plane to the alternate side. Then he is again brought quickly into a position where his head hangs over the edge of the table. Nystagmus is again sought. If rotational or torsional nystagmus is observed in any of the head-hanging positions, then typical nystagmus reversal is expected when the patient returns to the initial sitting position. The horizontal variant of BPPV is investigated in a different way; the patient is placed in the supine position with head raised 30° by the clinician. Horizontal geotropic or ageotropic nystagmus is identified when the clinician rotates the patient's head to both sides with nystagmus observation time interval. The side of the lesion is determined based on the intensity of horizontal nystagmus produced by head movement toward each side. It is the side of lesion to which head movement creates more intense nystagmus.

C. Visual Acuity Testing

Visual acuity is the patient's ability to read an eye chart while his or her head is moving. The head is rotated passively at a frequency of 1–2 Hz/s. A drop in acuity of two lines or more from the baseline suggests an abnormal vestibuloocular reflex gain.

D. Postural Control Tests

The examination of postural control includes the following tests: (1) the Romberg test, (2) the pastpointing test, (3) the tandem gait test, and (4) the Fukuda stepping test. Postural control tests are considered to have mild sensitivity and specificity in identifying lesions. Depending on the nature and phase of the pathology, the side of the lesion cannot reliably be identified from these tests. Excessive swaying toward one side in the Romberg test, deviation to one side in the pastpointing test, or rotation to one side in the Fukuda stepping test may all indicate either a paretic lesion of the labyrinth in that side or an irritative lesion in the opposite side. The patient may show sway, rotation, or deviation toward the unaffected side if the peripheral lesion is at the compensated phase.

1. Romberg test—During the Romberg test, which is used to identify vestibular impairment, the patient is asked to stand still with eyes closed and feet together. An increased sway or fall toward either side is considered abnormal. The Romberg test can be made more sensitive by asking the patient to stand with the feet in a heel-to-toe position and with arms folded against the chest.

2. Pastpointing test—The patient and clinician both stand facing each other; they then stretch their arms forward with index fingers extended and in contact with one another. The patient is asked to raise his arms up and bring his index fingers again into contact with the clinician's index fingers, which are fixed. The patient performs this movement 2–3 times with eyes open; later, the patient repeats the same maneuver with eyes closed. Deviation to one side is considered abnormal.

3. Tandem gait test—The patient is asked to take tandem steps with eyes closed. Healthy individuals can take at least 10 steps without deviation. Patients with vestibular disorders fail this test.

4. Fukuda stepping test—The patient is asked to march in place with eyes closed. After 50 steps, a rotation >30° toward one side is considered abnormal.

E. Cranial Nerve Evaluation

An evaluation of cranial nerve function may reveal hypoesthesia of the outer ear canal and an absent corneal reflex, as found in acoustic neuromas. Facial nerve paralysis may be associated with herpes zoster oticus. Eye muscle restrictions may be elicited by evaluating the

functioning of cranial nerves III (oculomotor nerve), IV (trochlear nerve), and VI (abducens nerve) before the electronystagmogram.

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Rosenberg ML, Gizza M. Neuro-otologic history. *Otolaryngol Clin North Am* 2000;33:471 [PMID: 10815031]. (Definitions of the terms vertigo, visual disorientation, lightheadedness, and imbalance, as well as the precipitating factors and symptoms associated with vertigo and dizziness.)
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ELECTRONYSTAGMOGRAPHY

Electronystagmography (ENG) is the fundamental test and the first step in a vestibular testing battery to evaluate the vestibuloocular reflex in patients with a balance disorder. It is based on recording and measuring eye movements or eye positions in response to visual or vestibular stimuli.

A. Equipment

Standard ENG equipment consists of the following components: (1) an amplifier for amplification of the corneal-retinal potential that occurs following eye movement, (2) band-pass and notch filters, (3) a signal recorder, (4) a light array, and (5) water and air caloric stimulators. The techniques available to record eye movements are electrooculography (EOG), infrared recording, magnetic search coil, and video-recording systems.

An ENG analysis consists mainly of three tests: (1) oculomotor tests, (2) positional tests, and (3) caloric tests. Before each test, the system needs to be calibrated to maintain accuracy. The calibration is performed via a saccade test that is discussed in the section on oculomotor tests.

B. Utility of Electronystagmography

ENG is very useful in diagnosing vestibular pathology. No other test provides information on the site of the lesion. The data obtained from an ENG test battery support the diagnoses of horizontal BPPV, vestibular neuronitis, Meniere disease, labyrinthitis, and ototoxicity. With acoustic neuromas, it may be helpful to predict the nerve from which the tumor originates; caloric weakness may be associated with a tumor that originates from the superior vestibular nerve. ENG may also predict whether the patient will experience vertigo after acoustic tumor removal. However, relying on ENG alone to identify lesions in the CNS would not be appropriate.

Abnormal findings in ENG testing do not necessarily indicate a definite CNS lesion. One study investigated the ratio of patients with abnormal results as reported by magnetic resonance imaging (MRI) to patients with abnormal ENG findings in different age groups and found a better correlation between MRI and ENG findings in a group of elderly patients. Overall, MRI confirmed a central lesion in 52% of patients with abnormal ENG findings. In contrast, ENG findings were abnormal in 15 of 21 patients (71%) with an abnormal MRI. In two recent studies, only 30–37% of the patients with abnormal ENG findings had abnormal MRI scans.

1. Oculomotor Tests

Oculomotor tests measure the accuracy, latency, and velocity of eye movements for a given stimulus. The standard oculomotor test battery includes saccade tests, smooth pursuit tests, optokinetic nystagmus testing, gaze tests, and fixation suppression testing. All oculomotor tests are performed with the patient seated upright, with the head stabilized. For oculomotor tests, the ENG device should have a light array on which LED (light-emitting diodes) are given as a stimulus. The light array may be rotated vertically for calibration purposes as well as for testing vertical saccades. The center of the light arrays should be at the same level as the patient's eyes.

▶ Saccade Test

Saccades are rapid eye movements that bring objects in the periphery of the visual field onto the fovea. The latency of saccades is very brief. Because peak velocity can be as high as 700°/s, vision is not clear during saccadic movement. Saccades are controlled by the occipitoparietal cortex, the frontal lobe, the basal ganglia, the superior colliculus, the cerebellum, and the brainstem.

To test saccadic eye movement, the patient is asked to follow the LED with as much accuracy as possible. The LED flashes sequentially in two positions: at the center of the array and then 15–20° to the right or left from the center. The interval between flashes is usually a few seconds. The test is repeated vertically.

Three parameters are of clinical significance in evaluating saccades: latency, peak eye velocity, and accuracy of the saccades.

Latency is the time difference between the presentation of a target and the beginning of a saccade. The mean latency is 192 ± 32 ms in normal subjects. Abnormalities in latency include prolonged latency, shortened latency, and differences in the latency between the right eye and the left eye. These abnormalities are observed in the presence of neurodegenerative disease.

The **peak velocity** is the maximum velocity that eyes reach during a saccadic movement. It ranges from 283°/s to 581°/s for 20° of amplitude in normal subjects. Abnormalities in the saccadic velocity are slow saccades, fast saccades, or a difference in the velocity between the right eye and the left eye. Reasons for saccadic slowing include the use of sedative drugs, drowsiness, cerebellar disorders, basal ganglia disorders, and brainstem lesions. Fast saccades can be observed in calibration errors and eye muscle restrictions. The asymmetry of velocity is observed in internuclear ophthalmoplegia, eye muscle restrictions, ocular muscle palsies, and palsy of cranial nerves III and VI (the oculomotor and abducens nerves, respectively).

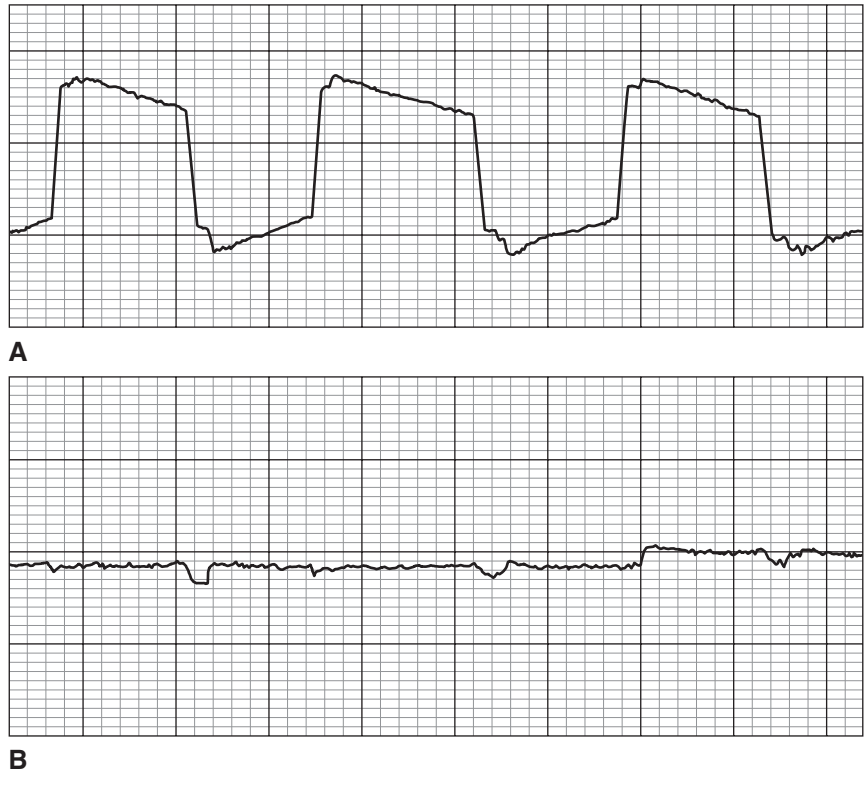
Accuracy is the final parameter in the evaluation of saccades. Saccadic accuracy is determined by saccadic movement by comparing the patient's eye position relative to the target position. Figure 46–3 provides a record of normal saccadic movement with accurate square tracing. If the saccadic eye movement goes farther than the target position, it is referred to as a **hypermetric saccade** (or **overshoot dysmetria**). If the saccadic movement is shorter than the target position, it is referred to as **hypometric saccade** (or **undershoot dysmetria**). Undershooting by 10% of the amplitude of the saccade may be observed in healthy subjects, whereas hypermetric saccades rarely occur in healthy subjects. Inaccurate saccades suggest the presence of a pathologic condition in the cerebellum, brainstem, or basal ganglia.

Smooth Pursuit Test

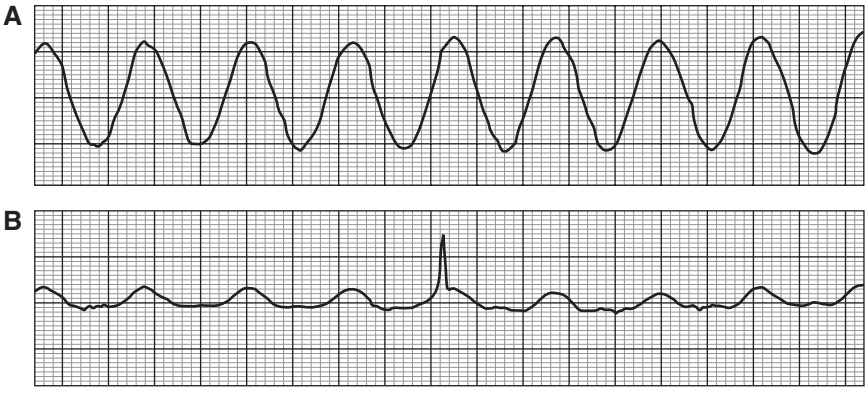
Smooth pursuit is the term used to describe eye movement that is created when the eyes track moving objects. Similar central pathways to those of saccadic movement produce smooth pursuit movement. The neural pathways serving the "pursuit system" are distributed in the cortical and subcortical areas of the brain. Smooth pursuit function also involves the fovea.

In a commonly used stimulus paradigm of the smooth pursuit test, the LED moves back and forth between two points on a light bar at a constant frequency and velocity. The patient is asked to follow this moving target. The frequency of the test stimulus should be between 0.2 and 0.8 Hz/s. A typical pursuit velocity is between 20°/s and 40°/s. Performance declines with higher velocities and increasing patient age.

The primary parameters for evaluation are gain, phase, and trace morphology. **Gain** is the ratio of peak eye velocity to the target velocity. For a stimulus of 0.5 Hz with a sweeping amplitude of 40°, a gain >0.8 is considered normal. A low gain is suggestive of a CNS disorder. **Phase** is the difference in time between eye movement and target movement. Under



▲ **Figure 46–3.** An EOG recording of normal saccadic eye movement. **(A)** Horizontal record. **(B)** Vertical record.



▲ **Figure 46–4.** EOG recording of normal tracking eye movement. **(A)** and **(B)** are horizontal and vertical records of the tracking movement, respectively.

optimal conditions, healthy subjects can track a target with a phase angle of 0°. The level of attention and drugs affecting the CNS can destroy pursuit performance.

A morphologic assessment of the trace is also important. Figure 46–4 shows a record of normal tracking eye movement. A morphologic abnormality is referred to as a staircase of saccades, in which the trace shows staircase-like eye movement while the target is followed. Pursuit traces can be impaired symmetrically or asymmetrically. An asymmetrically impaired pursuit is more suggestive of a CNS lesion than is a symmetrically impaired pursuit. Acute peripheral vestibular lesions can also impair smooth pursuit contralateral to the affected side when the eyes are moving against the slow phase of a spontaneous nystagmus.

Optokinetic Nystagmus & Optokinetic Afternystagmus

Optokinetic nystagmus (OKN) is an involuntary oculomotor response to a moving target that fills at least 90% of the visual field.

A. Equipment

The best optokinetic stimulator is a 360° turning cloth drum with black and white stripes. Because this drum can be unwieldy, it is preferable to use an optokinetic projector.

B. Test Administration

The normal response to an optokinetic stimulator is a smooth eye movement that follows the direction of the visual stimulus both clockwise and counterclockwise. OKN aims to stabilize the visual field onto the retina. OKN is produced by cortical and brainstem structures, which is the same as the pursuit. Optokinetic afternystagmus (OKAN) is a form of nystagmus that is produced by the brainstem after a 10-second, constant-velocity optokinetic stimulus. It lasts about 30 seconds.

OKN can be stimulated with a constant target speed between 20°/s and 60°/s or a sinusoidal target speed of up to 100°/s. Each target speed needs to be repeated in both clockwise and counterclockwise directions. The patient is asked to gaze straight ahead, while the target is moved in front of his or her field of vision. The type of stimulus chosen is presented for 1 minute. When a constant-velocity optokinetic stimulus is used, the patient's eyes reach a constant velocity after 10 seconds of stimulation in one direction. Once this stimulus is discontinued, the room light is turned off and the recording is continued for OKAN until the OKAN is decayed. The same stimulus is then applied in the opposite direction. It should be noted that a sinusoidal stimulus cannot be used to test OKAN.

C. Parameters of Optokinetic Nystagmus

In testing of OKN, the most useful parameters are gain and phase.

1. Gain—The normal value of gain is ≥0.5, as well as symmetry on both sides (ie, in both eyes) for a stimulus of 60°/s. A gain in OKN may be reduced symmetrically or asymmetrically. A symmetrically reduced gain is observed in visual disorders, fast-phase disorders, and congenital nystagmus. Unilateral parietal-occipital lesions cause an asymmetrically reduced gain.

2. Phase—As a testing parameter, phase is applied only for the sinusoidal stimulus of OKN. The testing of OKN is less sensitive than a pursuit test. The sensitivity and specificity of OKN elicited by stimulation of the full visual field are 46% and 92%, respectively, which is superior to the sensitivity and specificity of OKN elicited by stimulation of the partial visual field.

D. Parameters of Optokinetic Afternystagmus

The testing of OKAN is evaluated by three parameters: the initial velocity, the time constant, and the slow-cumulative eye position. The **initial velocity** is calculated from the

OKAN at the 2nd second. This initial velocity is approximately 10°/s for a stimulus of 60°/s. The **time constant** is the length of time required for the slow-phase velocity to decline to 37% of the initial velocity. The **slow cumulative eye position** is a function of both the initial velocity and the time constant. Because it shows less intersubject variability compared with the other two, it is the most useful parameter. The normative value of the slow cumulative eye position varies among the vestibular laboratories. Abnormalities in OKAN present as symmetrically reduced OKAN, which is bilateral; asymmetrically reduced OKAN; and hyperactive OKAN. A complete bilateral loss of OKAN is observed in a bilateral vestibular loss, which may be either peripheral or central. Asymmetry in OKAN is indicative of a unilateral vestibular loss. Hyperactive OKAN may be seen in mal de debarquement syndrome.

Gaze Test

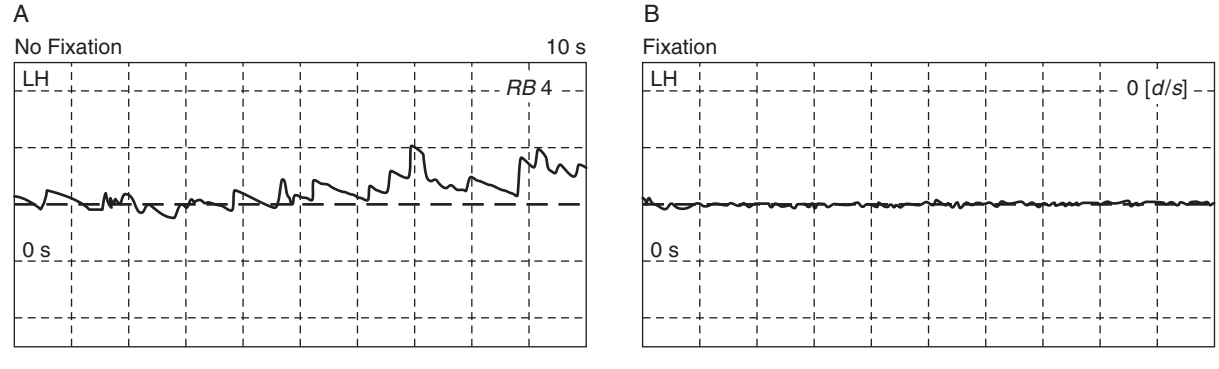
The gaze test is performed by recording eye movements, while the patient fixes his vision on the center of a target; the patient then fixes his gaze 30–40° to the right, to the left, and then above and below the center of the target. The patient's gaze, as well as a recording of that gaze, is sustained for at least 30 seconds. A gaze test may reveal peripheral or CNS lesions that are either vestibular or nonvestibular in origin. It may also reveal either congenital or spontaneous nystagmus. Patients with gaze nystagmus cannot maintain stable conjugate eye deviation away from the primary position; therefore, the focus of the patient's vision is brought back to the center by resetting the corrective saccades. Vestibular spontaneous nystagmus is seen during and after unilateral vestibular dysfunction and beats away from the afflicted side. It is seen as a horizontal nystagmus in an ENG recording, but it is actually both horizontal and torsional in nature. The intensity of vestibular spontaneous nystagmus increases when the patient's gaze is directed toward the direction of the nystagmus.

A typical gaze-evoked nystagmus that is peripheral in origin is unidirectional on a horizontal plane; it is both horizontal and torsional. Its intensity increases when gaze is directed toward the direction of the nystagmus. A gaze-evoked nystagmus with a CNS origin may change direction with the patient's gaze. A nystagmus that results from a vertical gaze is always suggestive of CNS lesions.

Gaze nystagmus may be classified as symmetric, asymmetric, rebound, or disassociated. In **symmetric gaze nystagmus**, the eyes move in equal amplitude in both directions. The ingestion of drugs that affect the CNS, as well as multiple sclerosis, myasthenia gravis, and cerebellar atrophy, may all cause symmetric gaze nystagmus. **Asymmetric gaze nystagmus** is indicative of a lesion within the brainstem or the cerebellum. **Rebound nystagmus** begins in lateral gaze positions and reverses its direction to the primary position, even though there is no evidence of nystagmus in the primary position at the beginning of testing. It is also a strong indicator of cerebellar or brainstem lesions. **Dissociated (disconjugate) nystagmus** is the difference in eye movements during the gaze. It results from lesions of the medial longitudinal fasciculus.

Fixation Suppression Testing

Spontaneous nystagmus is determined by placing the patient, with eyes closed, in a totally darkened room without any visual or positional stimuli. If spontaneous nystagmus is found, its slow-phase velocity is recorded. The patient is then asked to fixate on the center of a visual target (central gaze). The ratio of the slow-phase velocity with fixation to the slow-phase velocity without fixation is then calculated. This calculation provides a **fixation suppression index**. This index should be <50%. Nystagmus that results from a peripheral origin decays to more than 50% with fixation. Figure 46–5 shows the effect of fixation on a spontaneous nystagmus that is peripheral in origin.



▲ **Figure 46–5. (A)** A right-beating spontaneous nystagmus with a slow-phase velocity of 4°/s. **(B)** Note that the nystagmus disappears with fixation. (Reprinted, with permission of Hussam K. El-Kashlan, MD; University of Michigan, Ann Arbor, Department of Otolaryngology–Head & Neck Surgery.)

2. Positional Tests

The purpose of positional testing is to determine the effect of different stationary head positions (and not head movements) on eye movements. The assumption of these tests is that the patient's nystagmus is generated as a result of the orientation of the patient's head to gravity. The patient is asked to wear Frenzel glasses (or the test can be performed while the patient's eyes are closed), and the patient is brought slowly into the following positions: the patient's head (1) is turned right and then left while sitting, (2) is turned right and then left in the supine position, (3) is turned right and then left in a decubitus position, and (4) hangs straight down. Each position is maintained for at least 20 seconds. Positional nystagmus may be intermittent or persistent, and the direction may be fixed or changing.

The identification of positional nystagmus is not a localizing finding since it may be observed in patients with both peripheral and CNS lesions. Two features may help to distinguish the positional nystagmus that results from a peripheral lesion from one that results from a central lesion: (1) positional nystagmus caused by a peripheral lesion is suppressed by fixation; (2) the direction changing nystagmus may be indicative of a CNS lesion. The clinician must be careful about the contamination of spontaneous nystagmus with positional changes. If persistent nystagmus is noted, it should be observed for at least 2 minutes. This observation is especially important with periodic alternating nystagmus, in which the nystagmus reverses direction every 2 minutes. It is found that this type of nystagmus is caused by CNS lesions.

3. Caloric Tests

Caloric tests are based on comparing magnitude of the induced nystagmus on the right and left sides. Since the outer ear canal is close to the horizontal SCC, most of the response origins come from the horizontal SCC. Therefore, the nystagmus is horizontal. The temperature gradient produced by a cold stimulus causes the cupula to move away from the utricle, thereby creating a nystagmus that beats toward the opposite side. A warm stimulus causes the endolymph to rise, resulting in a nystagmus that beats toward the stimulus side.

Caloric testing is an important tool in assessing the vestibular system. It allows for the separate stimulation of each ear. Therefore, it provides data about the site of the lesion. However, there are some disadvantages of this test. Heat transfer from the ear canal to the horizontal SCC may vary among individuals, depending on the differences in the temporal bone pneumatization among patients. Another disadvantage is the fact that a caloric stimulus can provide a means of evaluating the vestibular response, but at only one frequency. The last disadvantage is that the caloric test allows only for the evaluation of the horizontal SCC.

A. Equipment

The caloric test uses a caloric stimulator, either a water or air irrigator, in addition to the EOG recording equipment. Two types of water stimulators are available: open loop and closed loop. The difference between the two stimulators is where the water circulates. **An open-loop stimulator** delivers water directly into the outer ear canal. In closed-loop systems, the water circulates in an expandable rubber medium to preserve its temperature. Open-loop systems are thought to provide more reliable and reproducible results than **closed-loop systems**. Caloric testing with either air or a closed-loop water stimulus should be reserved for patients who have a tympanic membrane perforation.

B. Test Administration

The patient should be in the supine position, with his head tilted 30° upward to bring the horizontal SCC into the earth vertical position—this position makes the horizontal SCC more sensitive. The test can be performed with either a bithermal or a monothermal caloric stimulus. The **bithermal caloric test** provides the most useful data on the vestibular system, which is stimulated by warm and cold water or air. To enhance the nystagmus response, mental tasks are given to the patient during the test. The recording can be performed with the patient's eyes opened in total darkness, with his eyes opened and wearing Frenzel glasses, or with his eyes closed.

In performing caloric testing, temperatures 7 C below and above body temperature (30°C and 44°C) are used as cold- and warm-water stimuli. A total volume of 250 mL of water is given to the outer ear canal over a period of 30–40 seconds. As an alternative to the water stimulus, two air stimuli that are 24°C and 50°C, respectively, are used with a flow rate of 8 L/min for 60 seconds. Four caloric stimuli are given with an interval of no less than 5 minutes to prevent superimposition or conflicting responses. The following order of stimuli is preferred: (1) right–warm, (2) left–warm, (3) right–cold, and (4) left–cold. In response to the caloric stimulus, the nystagmus begins just before the end of the caloric stimulus and reaches a peak at approximately 60 seconds of stimulation; it then slowly decays over the next minute. When it reaches its peak, patients are asked to fixate their eyes on a central point to check the fixation suppression index.

C. Testing Parameters

The most reliable and consistent parameter is the peak slow-phase velocity of the induced nystagmus. The peak slow-phase velocity is averaged over a 10-second period and is calculated for each side.

The values obtained for each caloric stimulus are placed into equations, with each used for specific conditions that define vestibular function. Unilateral weakness (ie, canal

paresis) indicates a significantly weak response on one side relative to the other. It is formulated as follows:

$$(R\ 30°C + R\ 44°C) - (L\ 30°C + L\ 44°C) \times 100\% \div (R\ 30°C + R\ 44°C + L\ 30°C + L\ 44°C)$$

The difference between the sides ≥20–25% indicates the presence of a **unilateral weakness.** However, normative data for this critical percentage should be determined for each laboratory. Unilateral weakness is not a localizing finding and may be caused by lesions from the labyrinth to the root entry zone of the eighth cranial nerve (ie, the vestibulocochlear nerve) in the brainstem, such as Meniere disease, labyrinthitis, vestibular neuronitis, acoustic neuromas (and other tumors pressing on the eighth nerve), and multiple sclerosis.

Directional preponderance (ie, unidirectional weakness) refers to a condition in which the mean-peak, slow-phase velocity of the nystagmus beating toward one side is significantly greater than the mean-peak, slow-phase velocity of the nystagmus beating toward the opposite side. It is determined by the following equation:

$$(R\ 30°C + L\ 44°C) - (R\ 44°C + L\ 30°C) \times 100\% \div (R\ 30°C + R\ 44°C + L\ 30°C + L\ 44°C)$$

A difference >20–30% assumes the existence of a directional preponderance. This critical percentage should be determined by a testing laboratory. The directional preponderance is often associated with a spontaneous nystagmus because a spontaneous nystagmus enhances the nystagmus beating toward its direction and eliminates the nystagmus beating toward the opposite direction. The directional preponderance simply shows the existence of bias in the tonic activity of the vestibular system. However, the directional preponderance is considered to reflect an asymmetry in the dynamic sensitivity between the left and the right medial vestibular neurons, as opposed to the reason behind the spontaneous nystagmus, which is reflected in asymmetry in the resting activity. The directional preponderance is a poor localizing finding. It may be observed in lesions from the labyrinth to the cortex. The directional preponderance is toward the lesion site for labyrinth and eighth nerve lesions, and toward the uninvolved site for lesions of the brainstem and cortex. It is controversial that a directional preponderance without a spontaneous nystagmus is suggestive of a CNS disorder. One retrospective study showed that 5% of patients with an isolated directional preponderance had a CNS lesion. Other patient groups had peripheral lesions or no definite diagnosis. Directional preponderance and unilateral weakness may be observed together, which is suggestive of acute unilateral peripheral lesions.

Caloric weakness may be found in both sides, which is referred to as **bilateral weakness**. The level of response that is considered a bilateral weakness varies based on the normative data. However, several physicians give their own normative measurements. For both sides, the total response to a warm stimulus (<11°/s) and the total response to a cold stimulus (<6°/s) are considered bilateral weakness. Patients with bilateral weakness often present with oscillopsia. A bilateral weakness is often associated with vestibulotoxic antibiotherapy or bilateral Meniere disease. However, it is also observed in patients with lesions of the vestibular nuclei, Lyme disease, Cogan syndrome, pseudotumor cerebri, and neurodegenerative diseases of the brainstem and cerebellum.

Hyperactive caloric responses may also be observed. The numeric criteria for these responses varies among laboratories from 40°/s to 80°/s. Hyperactive caloric responses are associated with a cerebellar lesion or atrophy due to removal of the cerebellar inhibitory effect on the vestibular nuclei.

Failure (ie, an abnormal finding) of the fixation suppression test may be found in the caloric test. The patient is asked to fixate on a central point during the peak caloric response. Vestibular nystagmus is normally suppressed by visual fixation. The fixation index expresses this attenuation quantitatively, which is the difference between the slow-phase velocity in the dark and in the light divided by the slow-phase velocity in the dark. The normal value for the visual suppression of the caloric response is >50%. If it fails—that is, <50%—impaired fixation suppression results. Cerebellar lesions affecting the flocculus cause impaired fixation suppression.

The **inversion of caloric nystagmus** is observed in patients with a tympanic membrane perforation. It occurs because of the cooling effect of the evaporation of moisture in the middle ear mucosa when warm air is used as a caloric stimulus.

Premature caloric reversal is the finding that can be observed in patients with **Friedreich ataxia** and brainstem lesions. The normal caloric response starts to decay at 90 seconds of the stimulation and disappears after 200 seconds, with a nystagmus beating toward the opposite side. In premature caloric reversal, nystagmus reversal occurs earlier than 140–150 seconds. It is worth noting that one should not refer to a preexisting spontaneous nystagmus as a premature caloric response.

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van der Torn M, van Dijk JE. Testing the central vestibular functions: a clinical survey. *Clin Otolaryngol* 2000;25:298 [PMID: 10971537]. (Assesses the reliability of abnormal findings in saccade, smooth pursuit, fixation suppression, and sinusoidal acceleration tests.)

ROTARY CHAIR TEST

The rotary chair test, which is also referred to as **rotational testing**, is used to evaluate the pathway between the horizontal SCC and the eye muscles. This pathway is known as the **horizontal vestibuloocular reflex** because the patient is positioned so that only the horizontal SCC is stimulated. Rotational testing has three main functions: (1) to confirm the bilateral impairment of horizontal functioning of the SCC, (2) to provide evidence of a central vestibular dysfunction, and (3) to quantify the progress of a known vestibulopathy.

A. Equipment

A typical rotary chair test consists of a stimulus device, a response recording and its analysis, a light-proof booth, a video camera, and a two-way communication system. The stimulus device is a chair whose rotational speed is precisely controlled by a computer within certain speed and frequency limits. The response recording is made with electrodes, which are placed to record horizontal eye movements.

B. Stimulus Types

Rotary chair testing includes basically two types of stimuli. Different protocols for each type of stimulus are used in different laboratories. One type of stimulus is called a **sinusoidal harmonic acceleration**; a series of rotational stimuli is used at the octaves of frequencies from 0.01 to 1.28 Hz, to the right and to the left. The velocity of the chair is set at 50–60°/s. The rotational stimulus at a given frequency is used for multiple cycles. The second type of stimulus is a **velocity step test**, which applies a series of velocities. The test is started with an acceleration impulse of 100°/s^2 until a fixed, desirable rotational stimulus of 60–180°/s is achieved. Once the fixed velocity has been reached and applied for 46–60 seconds, the chair is decelerated to 0°/s, with the same magnitude of the acceleration. The test is then repeated in the opposite direction.

After each stimulus protocol, the computer detects slow-component eye velocity, omitting the fast component of the induced nystagmus. During the tests, the eye position, eye velocity, and chair velocity (ie, head velocity) are monitored.

C. Test Administration

The patient sits in the chair with his or her head secured in the head support. The seatbelt should be fastened. Eye movements are recorded with an infrared camera or electrodes placed lateral to both outer canthi. The patient should be informed of the stimulus type to be given and instructed not to move throughout the test unless told to do so. Throughout the test, the patient should be kept mentally alert with arithmetic tasks (eg, counting cities or states in alphabetical order). Before the rotational test, the system should be calibrated. The test is performed in total darkness, with the patient's eyes opened. Throughout the test, the patient's eyes should be monitored with a video camera. A two-way communication system is used to give instructions and arithmetic tasks to the patient.

D. Testing Parameters

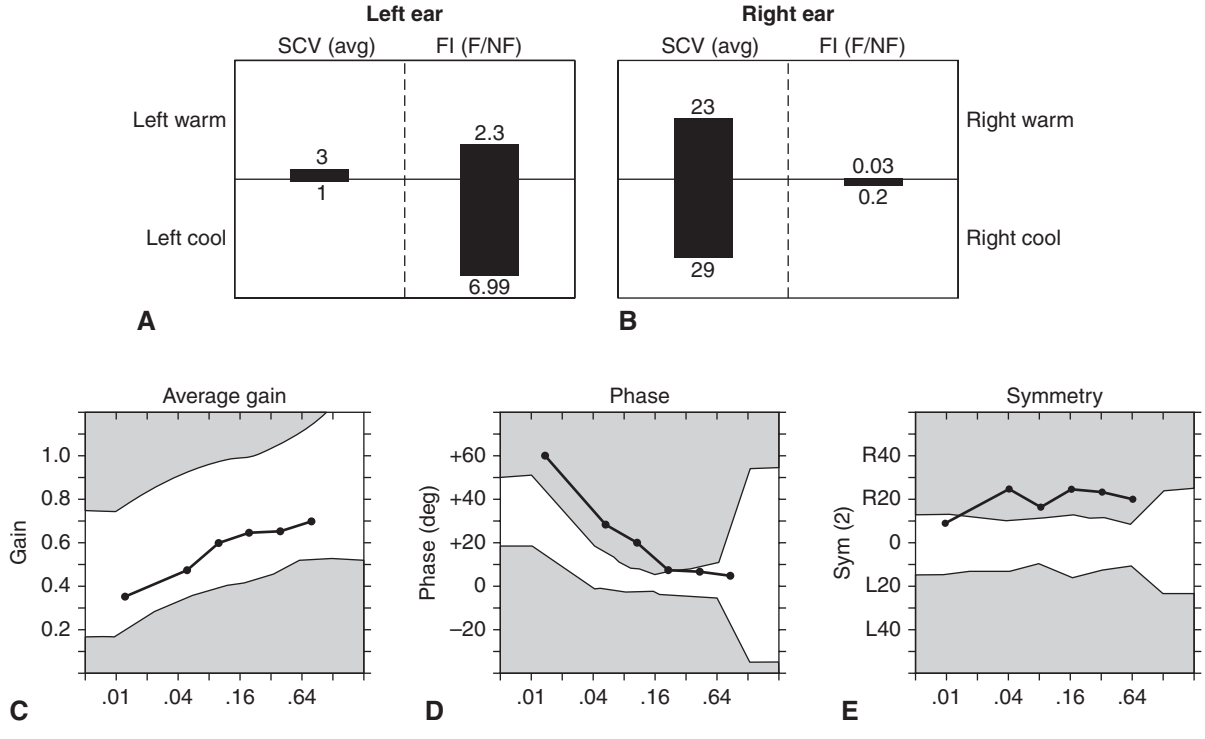
In a sinusoidal harmonic acceleration test, there are three parameters to be evaluated: phase, gain, and symmetry data.

1. Phase—The phase demonstrates a timing relationship between the head velocity and the slow-component eye velocity through the frequencies tested. The difference between the two is defined as the phase angle and is expressed in a measure of degrees. The fact that the eye velocity is greater than the head velocity is known as the **phase lead**. The opposite is known as the **phase lag**. For maintaining the position of objects in the retina, the eye velocity needs to be equal to the head velocity. Under this circumstance, the phase angle would be 180°. An alternative measure of the phase angle is the time constant of the response, which is inversely correlated to it.

2. Gain—The gain is the ratio of slow-component eye velocity to the head velocity, which represents the response capability of the vestibular system through the frequencies tested. The values outside of the normal range, based on normative data, are considered abnormal as long as the system is calibrated and the patient is alert.

3. Symmetry data—Symmetry data demonstrates whether slow-component eye velocities are equal on both sides.

The main testing parameter in the velocity step test is the time constant, which is the time needed for slow-component eye velocity to decline to 37% of the initial value. The second parameter of the velocity step test is the gain, whose definition is the same as its counterpart in the sinusoidal harmonic acceleration test.



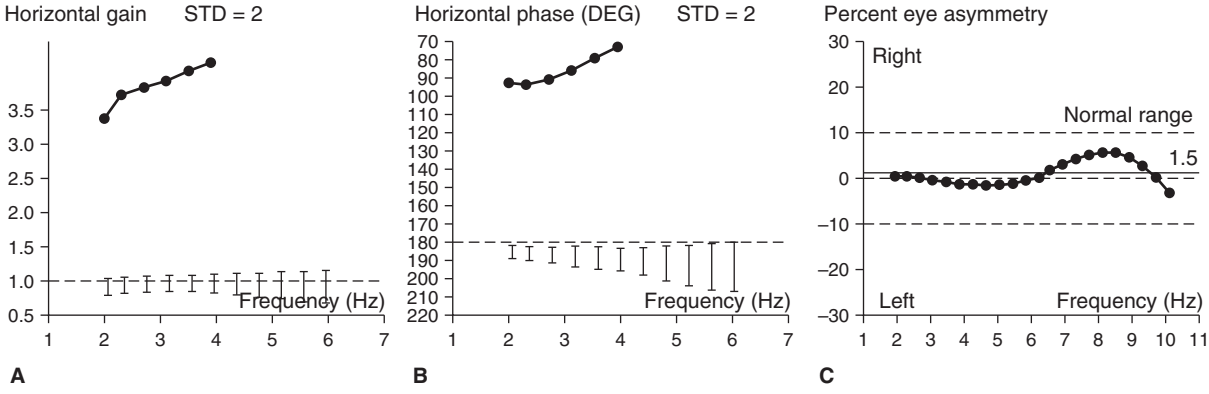
▲ **Figure 46–6. (A)** This panel demonstrates left unilateral weakness (88%) in a patient with an acute peripheral vestibular insult. Left-sided irrigations produce very weak responses (3°/s and 1°/s) compared with **(B)** right-sided irrigations (23°/s and 29°/s). There is no directional preponderance (13%). Fixation indices (FI) in both sides are within the normal range. The patient had right-beating spontaneous nystagmus (6°/s). The sinusoidal harmonic acceleration test in the same patient displays **(C)** normal gain throughout the test frequencies, **(D)** an increased phase angle at lower frequencies, and **(E)** right asymmetry at frequencies higher than 0.01 Hz. Note that there is no asymmetry at 0.01 Hz, which corresponds to an absent directional preponderance on the caloric test. Stippled areas represent the 95th percentile values. (Reprinted, with permission, of Hussam K. El-Kashlan, MD; University of Michigan, Ann Arbor, Department of Otolaryngology–Head & Neck Surgery.)

In a sinusoidal harmonic acceleration test, an increased phase angle may imply a peripheral system insult or, less commonly, vestibular nucleus involvement. A decreased phase angle may imply a lesion in the cerebellum. Low gain is consistent with bilateral peripheral insult; high gain may be seen in cerebellar lesions. Asymmetry can be suggestive of the involvement of a central or decompensated peripheral vestibular system. If the central system is intact, a paretic lesion where either asymmetry or an irritative lesion in the opposite side is present is likely. It is analogous with the directional preponderance in the caloric test. In the velocity step test, an acute peripheral insult results in low gain and a shortened time constant of the response to the rotational stimulus toward the side of the lesion. Figure 46–6 presents a comparative analysis of caloric and rotary chair testing.

The relationship between the horizontal vestibuloocular reflex generated by the rotational stimulus and the caloric stimulus is significant. There is no linear relationship between the gain and canal paresis because as the magnitude of canal paresis increases, the gain decreases somewhat and then remains stable. However, the time constant decreases proportionally with increasing canal paresis.

HIGH-FREQUENCY ROTATIONAL TESTS

High-frequency rotational tests are tools for testing horizontal and vertical vestibuloocular reflexes generated by the patient making active or passive head movements like those encountered in everyday life. High-frequency and high-acceleration rotational stimuli are expected to unmask the inherent asymmetry in the vestibular system. The tests have some advantages over the rotary chair test. For example, the equipment is more affordable. Testing time is very short (almost 20 seconds). The equipment is not heavy machinery



▲ **Figure 46–7.** Horizontal VAT results. He had unilateral weakness more than 30% in caloric test. No spontaneous nystagmus was detected. **(A)** Gain diagram shows abnormally high gains at 2 to 4 kHz. **(B)** Abnormally high phase lead can also be seen at the frequencies tested. **(C)** There is no asymmetry.

in contrast to the rotary chair. The tests investigate vestibuloocular reflex by means of active or passive rotationary head movements in both horizontal and vertical planes.

A. Equipment

The two types of high-frequency rotational tests are the head thrust test and the head (vestibular) autorotation test (VAT). The equipment is almost the same. The equipment mainly consists of skin electrodes or one of the other eye-movement recording systems, a software calculating gain and phase data, and a headband carrying a motion sensor for detecting head movements.

B. Test Administration

There is a target in front of the patient who is sitting upright. The patient keeps his or her eyes on the target during the test. The main difference between the two tests is the way of applying stimulus. Stimuli in the head thrust test are passive (applied by the examiner). Stimuli in the VAT are actively generated by the patient but based on computer-driven tonal stimuli. For the VAT, the patient shakes his or her head like "no" (a movement in horizontal plane) and then "yes" (a movement in vertical plane) while looking at the target. Frequency of the head movement is sinusoidally increased from 2 to 6 kHz in accordance with auditory stimulus. For the head thrust test, rotational stimuli are given manually at an unpredictable onset time and in a randomly varied direction; 20–40 head thrusts are analyzed.

C. Testing Parameters

There are two parameters for each test: (1) gain, phase, and symmetry data for the VAT and (2) gain and response delay for the head thrust test. Description of the gain and the phase is the same as in the sinusoidal harmonic acceleration test (rotary chair test). The response delay is the time between the onsets of head and eye movements.

For healthy subjects, the gain is almost 1 at low frequencies and declines somewhat at the higher frequencies. The phase is almost zero (ie, 180°) at the low frequencies and lags somewhat at the higher frequencies. In case of vestibular lesion, the most common pattern is decreased gain (below 0.7 when especially ipsilesional head movement is performed) and/or increased phase angle. The response delay does tend to be longer. It was shown that sensitivity to identify an abnormality in the vestibuloocular reflex is higher for the head thrust test than for the VAT because of the reflex augmentation in predictable stimulus paradigm used in the latter. A comparative study showed that the VAT provides additional information that could be missed by the caloric testing in diagnosing an abnormality in vestibuloocular reflex caused by a labyrinthine lesion and vestibular schwannoma. Figure 46–7 denotes horizontal VAT results of a patient who had unilateral weakness in caloric test.

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SUBJECTIVE VISUAL VERTICAL & HORIZONTAL TESTS

Subjective visual vertical and horizontal tests are measures of otoliths, and especially of utricular function. The bilateral gravitational input from the otoliths dominates the patients' perception of vertical and horizontal positions. To test for the subjective visual vertical or the subjective visual horizontal, the subject sits with head fixed in an upright position and looks at an illuminated line (either on a computer display or projected with a laser galvanometer system) in complete darkness. The subject is asked to adjust the line several times from starting positions at different angles to his subjective visual vertical or subjective visual horizontal. In acute peripheral vestibular lesions, including the utricles, there is a typical deviation of the subjective visual vertical or subjective visual horizontal of about several degrees to the affected side. With central compensation, gradual improvement occurs in the patient's perception of tilt.

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COMPUTERIZED DYNAMIC POSTUROGRAPHY

Computerized dynamic posturography is an established test of postural stability. It is an important tool to quantitatively assess individual and integral patterns of visual, proprioceptive, and vestibular signal processing, as well as overall balance function, in response to simulated tasks similar to those encountered in daily life.

A. Equipment

The computerized dynamic posturography test described here is the EquiTest platform (Neurocom International, Inc.).

Computerized dynamic posturography measures the force applied by the body to a platform equipped with strain gauges. The device, which is controlled by a computer, measures postural sway in several test conditions and allows for the manipulation of somatosensory and visual feedback. The information obtained with this test includes the vertical and horizontal shear forces generated by the patient during postural sway. Ground reaction forces are used to infer particular types of postural sway.

The test includes some requirements for testing personnel and patients. The patient should be able to stand still, unassisted and with eyes open, for at least 1 minute. The safety harness should be appropriately fastened so that the patient can move freely with no external support. The patient's feet and medial malleolus should be placed at designated points on the force plate.

Testing consists of three main protocols: (1) the sensory organization test, (2) the posture-evoked response, and (3) motor control tests. Of the three tests, the sensory organization test is the most useful in the assessment of patients with vestibular disorders.

Sensory Organization Test

The sensory organization test evaluates whether a patient with a balance disorder appropriately does utilize visual, vestibular, and somatosensory cues, and picks the appropriate cue under conflicting conditions to maintain balance.

A. Sensory Conditions

The sensory organization test includes six sensory conditions of gradually increasing difficulty that disrupt somatosensory cues, visual cues, or both. In **sensory condition 1**, the patient is asked to stand still with eyes open. The support surface and visual surround are fixed. **Sensory condition 2** is like sensory condition 1 except that the patient's eyes are closed. In **sensory condition 3**, the support surface is fixed. The visual surround leans forward, which is called sway referenced. The patient keeps eyes open. **Sensory condition 4** requires the patient to stand on the tilted support surface with eyes open and the visual surround fixed. **Sensory condition 5** is like condition 4 except that the

patient's eyes are closed. In **sensory condition 6**, the support surface is tilted and the visual surround leans forward, which means that the visual and support conditions are sway referenced.

B. Test Administration

This protocol consists of three repetitions of each sensory condition. Before each trial, the patient is asked to stand as still as possible and ignore the visual surround and the support surface motions. During each condition of the sensory organization test, force plates monitor the sway of the patient's center of gravity for periods of 20 seconds. Stability is quantified by an equilibrium score that is the percentage expression of the ratio of anteroposterior peak-to-peak sway amplitude during the trials to the theoretical anteroposterior limits of the stability. Equilibrium scores near 100% show little sway, whereas scores closer to zero are associated with a sway near the limits of the stability. Theoretical limits of stability are calculated on the basis of the maximum backward and forward center of gravity sway angles to which healthy subjects can move without losing balance.

C. Testing Parameters

The primary testing parameters are the composite equilibrium score and the sensory analysis.

1. Composite equilibrium score—The composite equilibrium score, which is a weighted average of all trials, provides an overall idea of the patient's balance performance. Abnormally low scores may be associated with either a malingering circumstance or vestibular, somatosensory, or visual dysfunction.

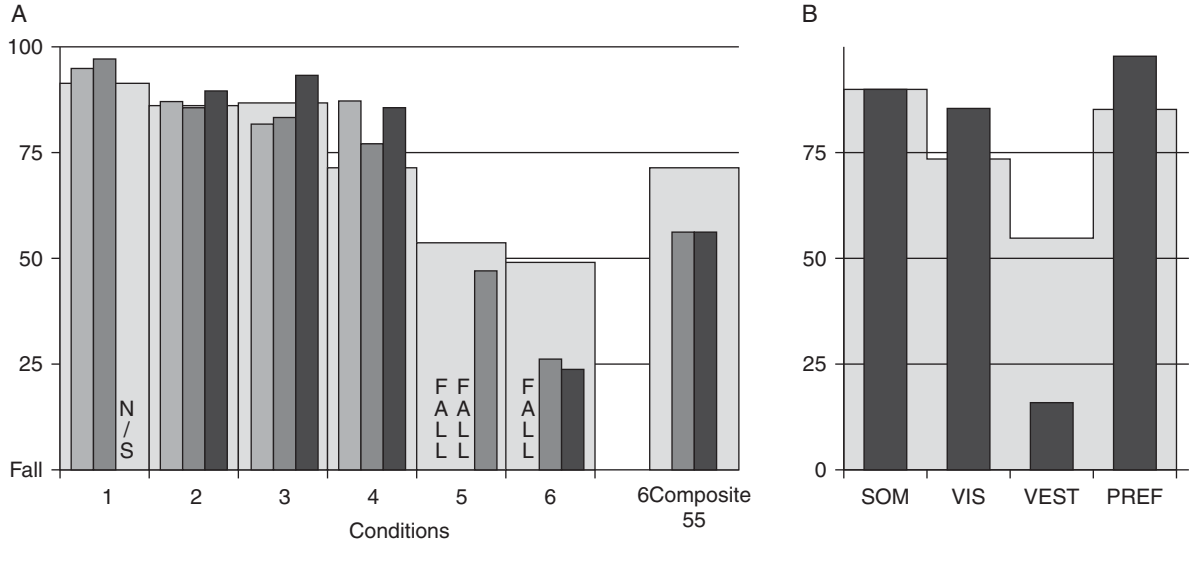
2. Sensory analysis—The sensory analysis quantifies the differences in the equilibrium scores between two conditions. The equilibrium score for sensory analysis is the average of each of the three trials of the conditions 1–6. Differences are sought in four ratios: (1) the somatosensory ratio, (2) the visual ratio, (3) the vestibular ratio, and (4) the vision preference ratio. The vestibular dysfunction pattern should also be considered in the sensory analysis.

A. Somatosensory ratio—In the somatosensory ratio, a comparison is made of the equilibrium scores of conditions 1 and 2. Abnormally low ratios are associated with dysfunction of the somatosensory system.

B. Visual ratio—The visual ratio is the ratio of the equilibrium scores of conditions 1 and 4. Low ratios are associated with a poor processing of visual cues.

C. Vestibular ratio—The vestibular ratio compares the equilibrium scores of conditions 1 and 5. Low scores are considered indicative of a dysfunction of the vestibular system (Figure 46–8B).

D. Vision preference ratio—The vision preference ratio compares the sum of the equilibrium scores of conditions



▲ **Figure 46–8.** A vestibular pattern in the sensory organization test. **(A)** Normal or near-normal equilibrium scores are found in conditions 1 through 4, with falls and low scores demonstrated in conditions 5 and 6. The composite score is also low. **(B)** Sensory analysis reveals a low vestibular ratio. Stippled areas reflect the confidence level of the 95th percentile. SOM, somatosensory ratio; VIS, visual ratio; VEST, vestibular ratio; PREF, vision preference. (Reprinted, with permission of Hussam K. El-Kashlan, MD; University of Michigan, Ann Arbor, Department of Otolaryngology–Head & Neck Surgery.)

3 and 6 with the sum of the equilibrium scores of conditions 2 and 5. It tests whether the patient uses inappropriate and inaccurate visual cues. Low ratios are considered an abnormal preference of visual inputs. Normal subjects suppress inaccurate visual inputs, whereas a patient with a vision preference shows unsteadiness when many stimuli are moving simultaneously. A free-fall is usually enough to rule out an exaggeration or malingering circumstance because it is difficult for a patient to fall freely without a causative disorder.

The vestibular dysfunction pattern in sensory analysis is seen in bilateral vestibular loss or decompensated unilateral vestibular loss. In these cases, the equilibrium scores are expected to be within the normal range for conditions 1 through 4, but below the lower limit of the range for conditions 5 or 6 (or both) (Figure 46–8A). However, the vestibular dysfunction pattern alone is not enough to make a distinction between peripheral and central vestibular lesions. An abnormal vision preference usually occurs in patients following head trauma. It can be associated with a vestibular dysfunction pattern, depending on whether vestibular compensation develops. Multisensory dysfunction patterns, including combinations of vestibular and vision systems or vestibular and somatosensory systems, suggest CNS lesions.

Utility of Computerized Dynamic Posturography

The clinical usefulness of computerized dynamic posturography in neurotologic practice has been assessed in the literature. It is agreed that this test is quite useful in the following conditions and situations: (1) chronic disequilibrium, (2) persistent dizziness or vertigo despite treatment, (3) patients with normal results in other vestibular tests, (4) measuring the baseline postural control prior to treatment, (5) monitoring the results of vestibular ablative treatments, and (6) selecting the most useful rehabilitation strategy. The identification of malingering individuals is possible with this test. Strong indicators of a poor response are (1) a substandard performance on the sensory organization test in conditions 1 or 2 (or both), with great intertrial differences; (2) a relatively better performance in conditions 5 and 6 compared with that in conditions 1 and 2; (3) circular sway without falling; (4) exaggerated motor responses to small platform translations; and (5) inconsistent motor responses to small and large, forward and backward platform translations. However, computerized dynamic posturography alone does not localize and lateralize the site of the lesion and cannot aid in establishing a diagnosis. Moreover, the results of this test may be at odds with the results of the ENG and rotary chair test because computerized dynamic posturography assesses the vestibulospinal and postural control systems, whereas the other two rely on the vestibuloocular reflex.

Black FO, Paloski WH. Computerized dynamic posturography: what have we learned from space? *Otolaryngol Head Neck Surg* 1998;118:S45 [PMID: 9525491]. (Describes the method of sensory organization test, its results in astronauts and usefulness of computerized dynamic posturography.)

Furman JM. Role of the posturography in the management of vestibular patients. *Otolaryngol Head Neck Surg* 1995;112:8 [PMID: 7816461]. (Summarizes computerized dynamic posturography [CDP] protocols, and addresses the evaluation of patients with vestibular disorders, as well as the usefulness of CDP.)

Gianoli G, McWilliams S, Soileau J, Belafsky P. Posturographic performance in patients with the potential for secondary gain. *Otolaryngol Head Neck Surg* 2000;122;11 [PMID: 10629476]. (Describes the Sensory Organization Test analysis of malingering individuals as well as their clinical impression, audiometric and electronystagmographic evaluations.)

Monsell EM, Furman JM, Herdman SJ, Konrad HR, Shepard NT. Computerized dynamic platform posturography. *Otolaryngol Head Neck Surg* 1997;117:394 [PMID: 9339802]. (Addresses the technological aspects of posturography, and reviews the indications and clinical validity of the information.)

VESTIBULAR EVOKED MYOGENIC POTENTIALS

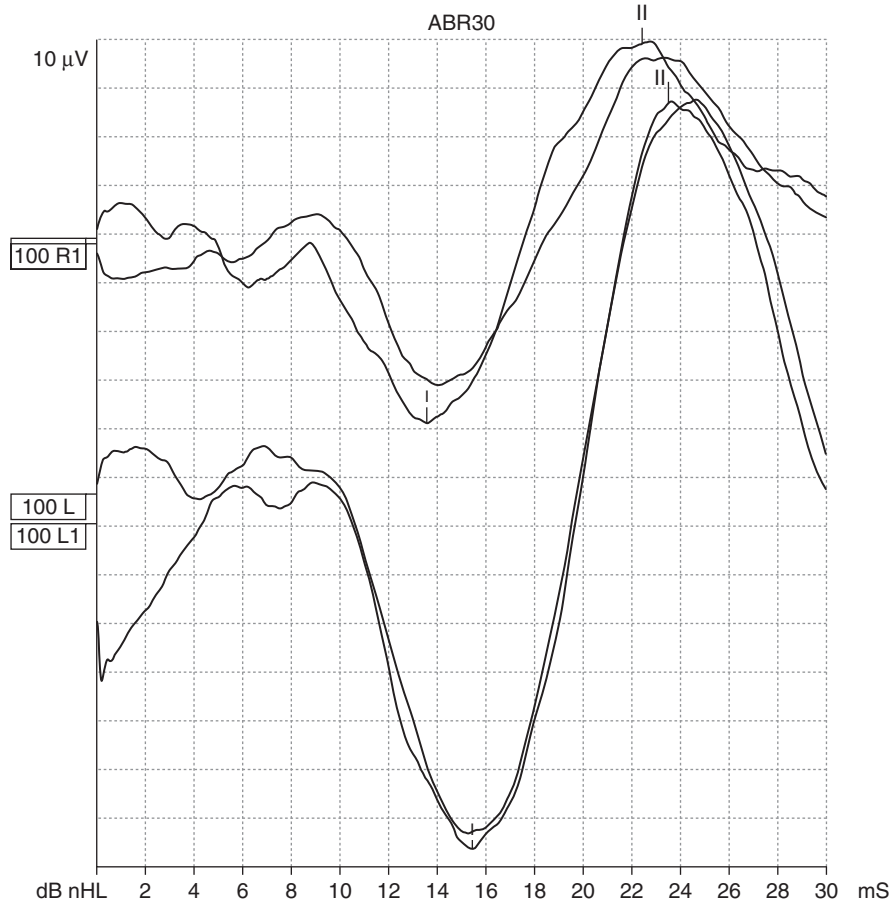
The vestibular evoked myogenic potentials (VEMP) are short latency electromyograms that are evoked by acoustic stimuli in high intensity and recorded from surface electrodes over the tonically contracted sternocleidomastoid muscle. The origin of VEMP has been shown to be the saccule. The response pathway consists of the saccule, inferior vestibular nerve, lateral vestibular nucleus, lateral vestibulospinal tract, and sternocleidomastoid muscle. The test provides diagnostic information about saccular and/or inferior vestibular nerve function. An intact middle ear is required for the response quality.

A. Equipment and Recording

A commercially available evoked potential unit can be used for recording the VEMP. The patient is tested while seated upright with the head turned away from the tested ear to increase tension of the muscle. A noninverting surface electrode is placed at the middle third of the sternocleidomastoid muscle. An inverting electrode is located at the sternoclavicular junction. A ground electrode is placed on the forehead. Rarefaction click (at 100 dB normalized hearing level [nHL]) or tone-burst stimuli (2-0–2 ms at 500 or 750 Hz and 120 dB peak sound pressure level [SPL]) are delivered monoaurally at the rate of 5/s. Electromyogenic activity of the muscle is amplified (×5000) and bandpass filtered from 10 to 2000 Hz. Analysis window is adjusted to 100 ms. Responses are averaged over a series of 128 or more based on the response stability.

B. Waveform of the Response

The VEMP waveform is characterized by a positive peak (P13 or wave I) at 13 (13–15) ms, and a negative peak



▲ **Figure 46–9.** VEMP traces in response to 100 dB nHL tone-bursts at 500 Hz. Note the good agreement between the traces in both sides. Peak-to-peak amplitude difference between the sides is noteworthy. (Reprinted, with permission of Levent Ozluoglu, MD; Baskent University, Ankara, Department of Otolaryngology–Head & Neck Surgery.)

(N23 or wave II) at 23 (21–24) ms. Peak-to-peak amplitude of P13–23 is measured. Exemplary traces are shown in Figure 46–9.

Stimulus intensity, stimulus frequency, and tonic electromyogenic activity may affect response amplitude but not response latency. Click-evoked VEMP threshold ranges from 80 to 100 dB nHL in subjects with normal audiovestibular function. In tone burst-evoked VEMP recordings, robust responses are obtained with 500, 750, and 1000 Hz tone bursts, and thresholds ranges from 100 to 120 dB peak SPL across frequency.

C. Parameters and Evaluation

For clinical purposes, the main interest is amplitude and threshold asymmetries between the right and left sides. However, controlling the tonic state of the sternocleidomastoid muscle is important for the accurate interpretation of interaural amplitude difference. Asymmetry ratio (AR) between the right and left ears is formulated as follows:

$$AR = 100\ (A_L - A_R)/(A_L + A_R)$$

where A_L and A_R indicate peak-to-peak amplitude of P13 and 23, respectively. When the ratio exceeds 36%, it is interpreted as an indicator of saccular hydrops and called "augmented VEMP." The augmented VEMP has been reported in almost 33% of affected ears. This finding was found to correlate with flat and high-frequency hearing loss. VEMP may also be absent in up to 54% of Meniere patients. The absent VEMP correlates with low scores in sensory condition 5 of posturography and also low-frequency hearing loss, which is an indicator of apical hydrops. The test is also useful in detecting vestibular schwannoma originating from the inferior vestibular nerve. In this circumstance, elevated VEMP threshold or absent VEMP is expected.

In vestibular neuronitis, VEMP may be absent. Superior canal dehiscence syndrome causes lowered VEMP thresholds or increased amplitudes. In otosclerosis, absent VEMP is expected. However, despite conductive hearing loss, if there is still normal VEMP, one should suspect the superior canal dehiscence syndrome rather than otosclerosis. Latency of the VEMP peak was focused on less than the parameters aforementioned. However, prolonged P13 latency was reported to correlate with retrolabyrinthine lesions such as large vestibular schwannoma and multiple sclerosis.

Akin FW, Murnane OD, Proffitt TM. The effects of click and toneburst stimulus parameters on the vestibular evoked myogenic potential (VEMP). *J Am Acad Audiol* 2003;14:500 [PMID: 14708838]. (Examines the effects of click and tone-burst level and stimulus frequency on the latency, amplitude, and threshold of vestibular evoked myogenic potentials in healthy subjects.)

de Waele C, Huy PT, Diard JP, Freyss G, Vidal PP. Saccular dysfunction in Meniere's disease. *Am J Otol* 1999;20:223 [PMID: 10100527]. (Investigates VEMP characteristics in Meniere disease and correlation of these findings with degree and type of hearing loss, caloric test, and posturography results.)

Murofushi T, Shimizu K, Takegoshi H, Cheng PW. Diagnostic value of prolonged latencies in the vestibular evoked myogenic potential. *Arch Otolaryngol Head Neck Surg* 2001;127:1069 [PMID: 11556854]. (Describes conditions in p13 latency prolongation.)

Ochi K, Ohashi T, Nishino H. Variance of vestibular-evoked myogenic potentials. *Laryngoscope* 2001;111:522 [PMID: 11224786]. (Investigation of variations in VEMP and its diagnostic parameters and presentation of VEMP characteristics in vestibular schwan-noma and neurolabyrinthitis.)

Ochi K, Ohashi T, Watanabe S. Vestibular-evoked myogenic potential in patients with unilateral vestibular neuritis: abnormal VEMP and its recovery. *J Laryngol Otol* 2003;117:104 [PMID: 12625881]. (Incidence of inferior vestibular nerve disorders in patients suffering from unilateral vestibular neuritis and the recovery of these disorders.)

Streubel SO, Cremer PD, Carey JP, Weg N, Minor LB. Vestibular-evoked myogenic potentials in the diagnosis of superior canal dehiscence syndrome. *Acta Otolaryngol Suppl* 2001;545:41 [PMID: 11677740]. (Presents VEMP characteristics in superior canal dehiscence syndrome.)

Welgampola MS, Colebatch JG. Characteristics and clinical applications of vestibular-evoked myogenic potentials. *Neurology* 2005;64:1682 [PMID: 15911791]. (Reviews VEMP evoked by clicks, tones, and alternative stimuli, and describes its usefulness in diagnosis of peripheral and central vestibular lesions.)

Young YH, Wu CC, Wu CH. Augmentation of vestibular evoked myogenic potentials: an indication for distended saccular hydrops. *Laryngoscope* 2002;112:509 [PMID: 12148863]. (Describes differentiating features of VEMP in Meniere disease and sudden deafness.)

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47 Diseases of the External Ear

Kevin D. Brown, MD, PhD,
Victoria Banuchi, MD, &
Samuel H. Selesnick, MD, FACS

ANATOMY

Morphology

The pinnae of the external ear are cartilaginous frames that aid in focusing and localizing sound. Each pinna is anchored to the cranium by skin, cartilage, auricular muscles, and extrinsic ligaments. The anatomy of the pinna is illustrated in Figure 47–1.

The external auditory canal (EAC) is typically 24 mm in length with a volume of 1–2 mL. The lateral third of the canal is made of fibrocartilage, whereas the medial two thirds are osseous. During early childhood, the canal is straight, but takes on an "S" shape by the age of 9. The EAC has an important relationship with the mastoid segment of the facial nerve, which lies posterior to the EAC as it descends toward the stylomastoid foramen. The temporomandibular joint is anterior to the EAC, and disease processes affecting this joint may lead to otalgia.

Skin

The EAC is lined by stratified squamous epithelium that is continuous with the skin of the pinna and the epithelial covering of the tympanic membrane. The subcutaneous layer of the cartilaginous portion of the canal contains hair follicles, sebaceous glands, and ceruminous glands, and is up to 1 mm thick. The skin of the osseous canal does not have subcutaneous elements and is only 0.2 mm thick (Figure 47–2). The epithelium of the EAC migrates laterally, allowing the canal to remain unobstructed by debris. The rate of epithelial migration is 0.07 mm/d and is thought to occur at the basal cell layer.

The ceruminous glands are modified apocrine sweat glands surrounded by myoepithelial cells; they are organized into apopilosebaceous units (Figure 47–3). Cerumen prevents canal maceration, has antibacterial properties, and has a normally acidic pH, all of which contribute to an antibacterial effect of cerumen.

Innervation

The pinna is innervated laterally, inferiorly, and posteriorly by the great auricular nerve (cervical plexus). Arnold's nerve (a branch of the vagus nerve) innervates the inferior bony canal, the posterosuperior cartilaginous canal, and corresponding segments of the tympanic membrane and the cymba concha. The posterosuperior bony EAC is innervated by branches of the facial nerve. The auriculotemporal branch of V3 supplies the anterior portion of the pinna. The glossopharyngeal nerve contribution to the external ear is not well delineated.

Lymphatic Drainage

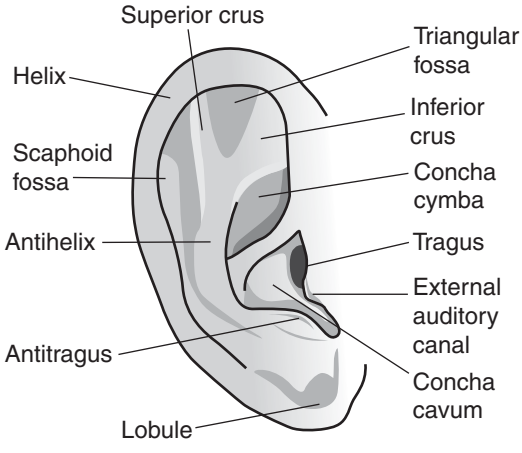
The anterior and superior wall of the EAC and tragus are drained by preauricular lymph nodes. The infraauricular lymph nodes drain the helix and the inferior wall of the EAC, whereas the concha and antihelix are drained by the mastoid nodes.

Vascular Supply

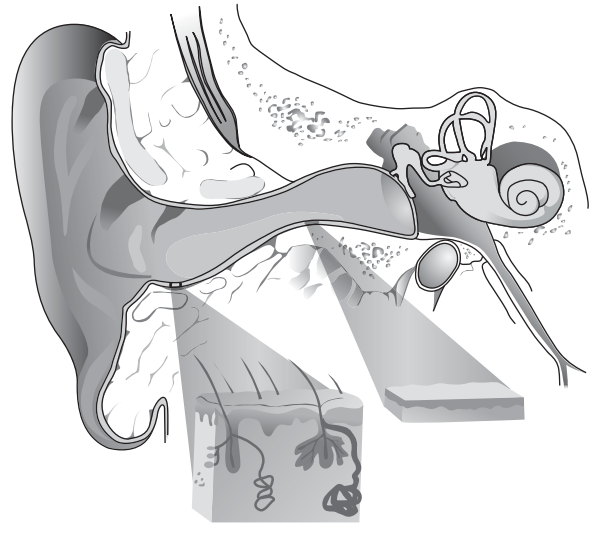
The posterior auricular artery and the superficial temporal artery arise from the external carotid artery and supply the auricle and lateral EAC. The deep auricular branch of the maxillary artery supplies more medial aspects of the canal and the external surface of the tympanic membrane. The posterior auricular and superficial temporal veins drain the external ear.

PHYSIOLOGY

The external ear aids in the efficient transmission of sound to the tympanic membrane by serving as a functional resonator and, in particular, boosts transmission in the speech frequencies.



▲ **Figure 47–1.** Anatomy of the pinna.



▲ **Figure 47–2.** Coronal section of the ear canal. The skin of the cartilaginous and osseous canals are magnified. (Reproduced, with permission, from Lucente F, ed. *The External Ear.* Copyright Elsevier, 1995.)

The hairs in the lateral canal, as well as the depth and tortuosity of the EAC, protect the tympanic membrane and structures of the middle ear.

EMBRYOLOGY

The mammalian ear is divided into external, middle, and inner ear components, which differ in their embryologic origin (Figure 47–4). The external ear consists of the pinna, the EAC, and the tympanic membrane, and is embryologically derived from the first and second branchial arches, and includes both ectodermal and mesodermal components. The mesenchymal tissue of the arches is composed of paraxial mesoderm and neural crest cells. The pinna is formed by gradual change in shape and fusion of components of the six auricular hillocks, which are derived from the first and second branchial arches (Figure 47–5). The formation of the external auditory meatus results from an ingrowth of a solid epithelial plate of ectodermal cells, the meatal plug, which eventually resorbs with only the lining of the canal remaining. The canal is lined by epithelial cells of ectodermal origin. The tympanic membrane begins to develop during the 28th week of gestation and arises from the most medial aspect of the meatal plug, which eventually becomes the external layer of the tympanic membrane.

CONGENITAL ANOMALIES OF THE EXTERNAL EAR

General Considerations

Congenital anomalies of the external ear include a spectrum of malformations of the pinna as well as varying degrees of atresia and stenosis of the EAC. The causes of these disorders may be genetic or secondary to environmental exposures. These disorders include variants of microtia, lop ear, cup ear, Stahl's ear, cryptotia, and prominent ear. Patient evaluation requires a thorough head and neck examination to exclude additional congenital anomalies. The list of associated syndromes is extensive and includes Goldenhar (hemifacial microsomia), branchio-oto-renal, Treacher Collins, and Robinow syndromes.

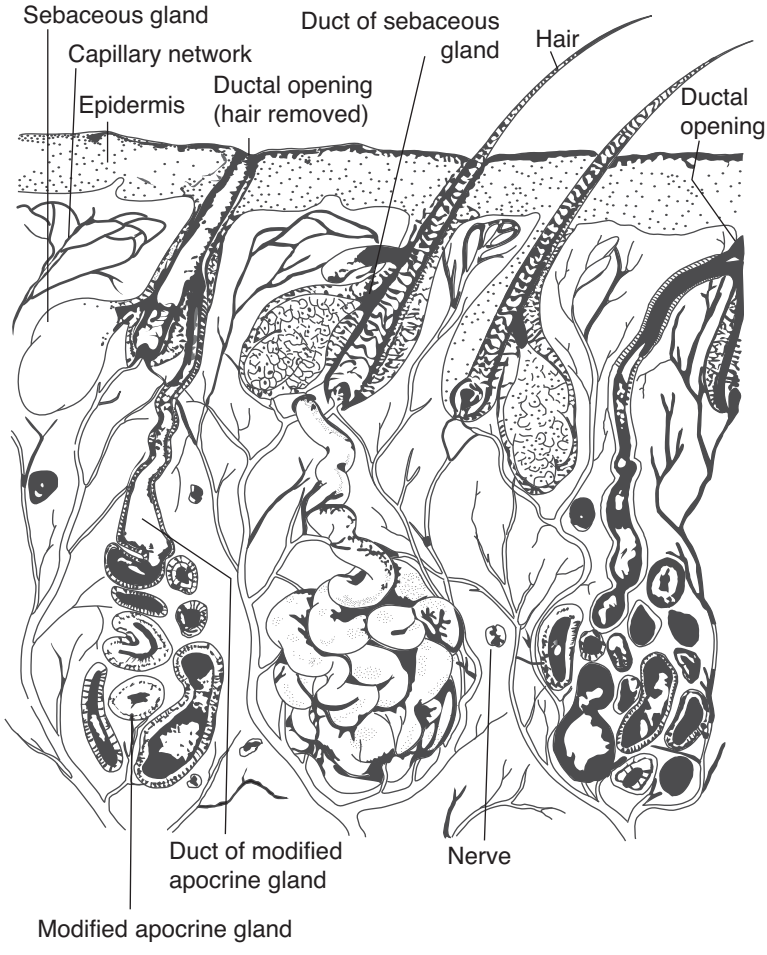
Pathogenesis

Multiple genes may have redundant roles in outer ear formation, which can account for phenotypically similar malformations. The sequence of such dysregulation is only beginning to be understood with the help of murine knockout and knock-in models. The auricular hillocks that give rise to the pinna arise during the sixth week of embryogenesis, whereas the inner two thirds of the EAC are not formed until the 26th week. Untoward events throughout this period could give rise to structural anomalies of the external ear.

MICROTIA

Clinical Findings

Patients typically present at birth with obvious auricular malformations. Several classification systems are used to further subcategorize this entity, one of which is detailed below.



▲ **Figure 47–3.** Skin of the cartilaginous portion of the external auditory canal depicting apopilosebaceous units. (Reproduced, with permission, from Main T, Lim D. The human external auditory canal: An ultrastructural study. *Laryngoscope.* 1976;86:1164. Copyright LWW.)

A. Grade I

The ear exhibits mild deformity, typically with a slightly dysmorphic helix and antihelix. This group includes low-set ears, lop ears, cupped ears, and mildly constricted ears. All major structures of the external ear are present to some degree. The lop ear is characterized by inferiorly angled positioning of the auricular cartilage and poor development of the antihelical fold, whereas the cup ear protrudes with a deep conchal bowl.

B. Grade II

All pinna structures are present, but tissue deficiency and significant deformity exist.

C. Grade III

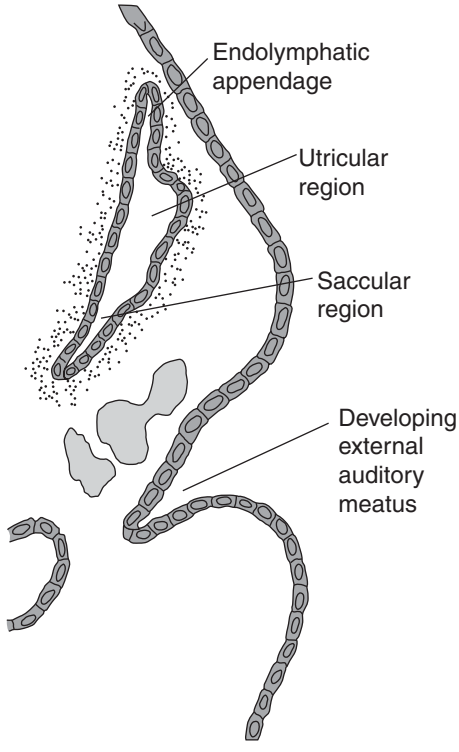
Also known as, classic microtia or peanut ear, type III microtia has few or no recognizable landmarks of the auricle. The ear lobule is usually present and anteriorly positioned. This subgroup includes anotia, which is complete absence of the external ear.

Treatment

Classically, microtia has been treated by a multistage auricular reconstruction. Patients undergo observation until the age of five to allow for growth of rib cartilage, which is harvested for reconstruction, and the development of the contralateral ear. This approach offers the benefit of reconstruction with autogenous material, which ultimately requires little or no maintenance. However, it is difficult to achieve a perfect cosmetic result. Typically, reconstruction occurs in four stages.

A. Stage I: Cartilage Implantation

Rib graft is typically harvested from the chondrosis of ribs 6, 7, and 8. The goals of this stage include symmetry in the position



▲ **Figure 47–4.** Development of the ear at 29 days' gestation. (Reproduced, with permission, from Larsen WJ, ed. *Human Embryology,* 3rd ed. Churchill Livingstone, 2001. Copyright Elsevier.)

of the reconstructed cartilaginous ear framework with the normal ear. Postoperatively, the patient must be assessed for pneumothorax, which may arise with rib harvest.

B. Stage II: Lobule Transfer

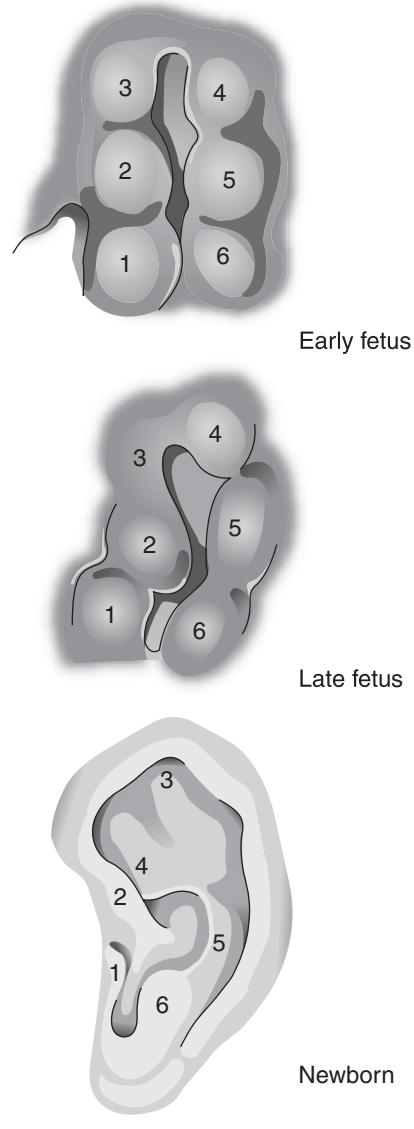
This procedure should be performed 2–3 months after Stage-I reconstruction and aligns the lobule with the reconstructed cartilage framework.

C. Stage III: Postauricular Skin Grafting

A postauricular sulcus is created to allow the ear to project away from the mastoid. This step should be performed 3 months after Stage-II reconstruction. Skin for the creation of the sulcus may be harvested from the groin, lower abdomen, buttocks, contralateral postauricular sulcus, or back.

D. Stage IV: Tragal Reconstructtion and Soft Tissue Debulking

This should be performed several months after Stage-III reconstruction.



▲ **Figure 47–5.** Differentiation of the six auricular hillocks. (Reproduced, with permission, from Larsen WJ, ed. *Human Embryology,* 3rd ed. Churchill Livingstone, 2001. Copyright Elsevier.)

E. Other Treatment Options

Another option for reconstruction includes the placement of a prosthesis. This can be either glued on or anchored to bone. If the patient selects a bone-anchored prosthesis rather than auricular reconstruction, he/she must be aware that daily maintenance is required and that the anchor may compromise the vascularity of the surgical site, complicating future reconstructive surgery if the patient becomes dissatis-

fied with the prosthesis. A prosthesis does offer the advantage of a minor surgical procedure and allows for auricular replacement at an earlier age than surgical reconstruction. Complications of all types of auricular reconstructions include infection, hematoma formation, skin-flap necrosis, scar contracture, and poor contouring.

PROTRUDING EARS

Clinical Findings

An increase in the distance from the helical rim to the mastoid is thought to be due to a lack of the antihelical fold and prominence of the conchal bowl. Ideal distance has been described as 15–20 mm with an ideal angle of 30°. Greater than 45° angulation is considered abnormal. This entity is most frequently bilateral.

Treatment

Otoplasty is the mainstay of treatment for protruding ears. Often used techniques include recreating the antihelical fold utilizing 2–4 horizontal mattress sutures through the cartilage and anterior perichondrium (Mustarde technique). Stiff cartilage may require additional contouring. Conchal excess may be treated by removal of soft tissue and skin from the postauricular sulcus followed by concha-to-mastoid sutures at the fossa triangularis, cavum concha, and cymba concha.

Complications

Excessive overcorrection of the middle third of the ear should be avoided to prevent development of the "telephone ear" deformity. Hematoma is the most common complication following otoplasty occurring in approximately 3% of cases. Lack of patient satisfaction, although not a true complication, is not an uncommon occurrence as loss of up to 40% of correction has been reported.

ATRESIA & STENOSIS OF THE EXTERNAL AUDITORY CANAL

Clinical Findings

Congenital anomalies of the EAC range from mild stenosis to complete atresia. These are often seen in association with malformations of the pinna and the structures of the middle ear. A canal cholesteatoma can develop in the face of severe EAC stenosis, and may also occur with epithelial rests left behind the atresia plate.

Audiologic evaluation via behavioral or electrophysiologic measures should be performed to confirm normal hearing in the contralateral ear in unilateral disease, and to assess for ipsilateral sensorineural hearing loss. The typical pattern of hearing loss in affected ears is a conductive hearing loss of 50–70 dB. Axial and coronal computed tomography (CT) scans are essential in the evaluation of patients with canal atresia or stenosis. CT scanning assesses for ossicular, facial nerve, and otic capsule abnormalities as well as for the degree of temporal bone pneumatization. In addition, CT scanning can be used to identify a cholesteatoma that would necessitate earlier surgical intervention.

Treatment

A discussion on reconstruction for aural atresia can be found in Chapter 48, Congenital Disorders of the Middle Ear.

EXTERNAL EAR TRAUMA

The external ear is subject to a wide variety of injuries. All trauma patients require appropriate stabilization and triage of associated injuries based on their severity. Adherence to basic surgical principles and wound care prevents complications and improves the likelihood of a successful outcome.

AURICULAR HEMATOMA

ESSENTIALS OF DIAGNOSIS

- History of auricular trauma
- Edematous, fluctuant, and ecchymotic pinna with loss of normal cartilaginous landmarks
- Early diagnosis and treatment necessary to minimize cosmetic deformity.

General Considerations

Auricular hematoma refers to the accumulation of blood in the subperichondrial space, usually secondary to blunt trauma.

Pathogenesis

Cartilage lacks its own blood supply and instead relies on the vascularity of the perichondrium via diffusion. Shearing forces secondary to blunt trauma to the pinna lead to an accumulation of blood in the subperichondrial space. This creates a barrier for diffusion between the cartilage and the perichondrial vascularity, leading to necrosis of the cartilage and predisposing it to infection and further injury.

Clinical Findings

A patient with an auricular hematoma usually presents with an edematous, fluctuant, and ecchymotic pinna, with loss of the normal cartilaginous landmarks. Failure to evacuate the

hematoma may lead to infection and/or cartilage necrosis and permanent disfigurement known as "cauliflower ear."

Treatment

The evacuation of hematomas can be performed using a skin incision parallel with the natural auricular skin folds. The irrigation of evacuated hematomas with topical antibiotics reduces the likelihood of infection. Splinting after drainage prevents the reaccumulation of hematomas, and options include cotton bolsters, plaster molds, silicon putty, and water-resistant thermoplastic splints. Through-and-through whip-type absorbable mattress sutures without a bolster have also been described.

AURICULAR LACERATIONS

Sharp or severe blunt trauma may lead to laceration or avulsion of the auricle. The expeditious repair and prevention of infection are essential. Auricular lacerations should be cleansed and débrided prior to repair. Simple lacerations can be closed primarily, whereas extensive injuries with tissue loss may require undermining, flap reconstruction, or tissue grafts. In the case of a near-total ear avulsion still attached to the helical root, the ear can be successfully reattached as the supply of the upper auricular-helical artery seems to be sufficient for the entire ear. Leech therapy may be required to support venous outflow until neovascularization occurs. Repairs should be covered with pressure dressings to prevent edema and hematoma formation, and cartilage-penetrating antibiotics such as quinolones should be prescribed. Excellent cosmetic results can be achieved, even with extensive lacerations.

Pham TV, Early SV, Park SS. Surgery of the auricle. *Facial Plast Surg.* 2003;19(1):53. [PMID: 12739182] (A thorough review of external ear anatomy and embryology, as well as the surgical management of auricular deformities and trauma.)

OTITIS EXTERNA

ESSENTIALS OF DIAGNOSIS

- Otalgia, otorrhea, pruritus, hearing loss, history of water exposure
- In severe cases in which edema occludes ear canal, wick is critical to maintain EAC and permit antibiotic drops to reach infected tissues
- Cases in which erythema and tenderness extend outside of EAC require oral antibiotics with antipseudomonal activity.

General Considerations

Otitis externa is an inflammatory and infectious process of the EAC. *Pseudomonas aeruginosa* and *Staphylococcus aureus* are the most commonly isolated organisms. Less commonly isolated organisms include *Proteus* species, *Staphylococcus epidermidis,* diphtheroids, and *Escherichia coli.* Fungal otitis externa is discussed in the next section.

Pathogenesis

In the preinflammatory stage, the ear is exposed to predisposing factors, including heat, humidity, maceration, the absence of cerumen, and an alkaline pH. Loss of acidity has been shown to be proportionate to the degree of infection. This can cause edema of the stratum corneum and occlusion of the apopilosebaceous units. In the inflammatory stage, bacterial overgrowth ensues, with progressive edema and intensified pain. Incomplete resolution or persistent inflammation for more than 3 months refers to the chronic inflammatory stage.

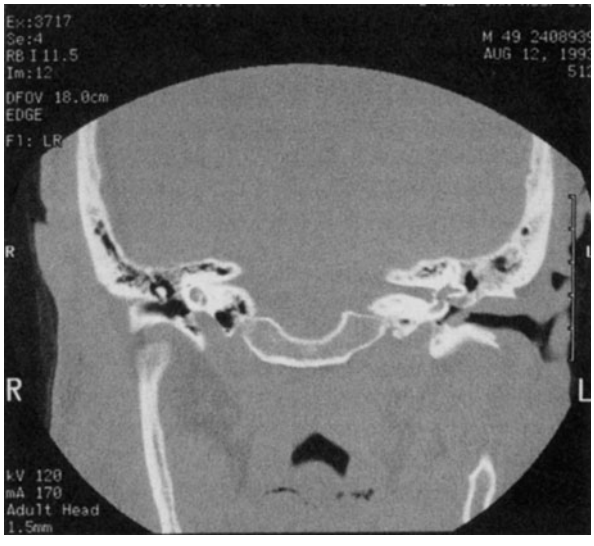
Clinical Findings

Symptoms of otitis externa may vary, depending on the stage and extent of disease. The clinical diagnosis is suggested by the presence of otalgia, otorrhea, aural fullness, pruritus, tenderness to palpation, and varying degrees of occlusion of the EAC. The patient may also present with hearing loss, which results from occlusion of the EAC by edema and debris. Signs of otitis externa include pain on distraction of the pinna, EAC erythema, edema, otorrhea, crusting, and, in more advanced disease, lymphadenopathy of the periauricular and anterior cervical lymph nodes. Skin changes of cellulitis may be present as well. In the chronic stage, the skin of the EAC may be thickened. A culture may be helpful for infections that are refractory to treatment.

Treatment

Treatment for otitis externa involves meticulous atraumatic debridement of the EAC with the help of a microscope. Analgesia can be achieved with nonsteroidal antiinflammatory drugs (NSAIDs), opioids, or topical steroid preparations. After cleansing is complete, otic drop preparations that are antiseptic, acidifying, or antibiotic (or any combination of these) should be used. These have been shown to be equally effective in the management of uncomplicated otitis externa in a recent Cochrane review. If the degree of stenosis of the canal is severe, a wick must be placed in an effort to stent open the EAC and permit delivery of drops to the medial portion of the canal.

Available antiseptic preparations include acetic and boric acids, ichthammol, phenol, aluminum acetate, gentian violet, thymol, thimerosal (eg, Merthiolate), cresylate, and alcohol. Available antibiotic preparations include ofloxacin, ciprofloxacin, colistin, polymyxin B, neomycin, chloramphenicol, gentamicin, and tobramycin. Polymyxin B and neomycin



▲ **Figure 47–6.** High-resolution coronal CT scan demonstrating soft tissue edema of the left external auditory canal consistent with otitis externa.

preparations are often used in combination for the treatment of *S aureus* and *P aeruginosa* infections. Ofloxacin and ciprofloxacin are single-agent antibiotics with an excellent spectrum of coverage for pathogens encountered in otitis externa. Preparations with steroids help to reduce edema and otalgia. Systemic antibiotics are indicated for infections that spread beyond the EAC. For chronic otitis externa, a canalplasty may be indicated for thickened skin that has caused canal obstruction. Patients must be instructed to avoid EAC manipulation and water exposure if they have a history of recurrent otitis externa (Figure 47–6).

OTOMYCOSIS

ESSENTIALS OF DIAGNOSIS

- Pruritus, otalgia, otorrhea, fullness, hearing loss, no response to topical antibiotics
- Fungal elements on physical examination
- Positive KOH preparation or fungal culture.

General Considerations

Otomycosis is an inflammatory process of the external ear canal due to infection with fungi and is responsible for more than 9% of the diagnoses of otitis externa. In 80% of cases, the etiologic agent is *Aspergillus*, whereas *Candida* is the next most frequently isolated fungus. Other more rare fungal pathogens include *Phycomycetes, Rhizopus, Actinomyces,* and *Penicillium*.

Pathogenesis

Otomycosis has similar predisposing factors to bacterial otitis externa. Patients with diabetes mellitus or an immunocompromised state are particularly susceptible to otomycosis. Patients with a mastoid bowl after a canal wall down procedure are predisposed to development of otomycosis as well.

Clinical Findings

Patients with otomycosis most frequently present with pruritus, aural fullness, and otorrhea, and may also complain of otalgia and hearing loss. The hearing loss associated with otomycosis usually results from the accumulation of mycotic debris.

Otoscopy often reveals mycelia, establishing the diagnosis. The EAC may be erythematous and fungal debris may appear white, gray, or black. Patients have typically been tried on topical antibacterial agents with no significant response. The diagnosis can be confirmed by identifying fungal elements on a KOH preparation or by a positive fungal culture.

Treatment

The treatment of otomycosis includes cleansing and debriding the EAC, acidifying the canal, and administering antifungal agents. Nonspecific antifungal agents include thimerosal (eg, Merthiolate) and gentian violet. Commonly used specific antifungals include clotrimazole, Nystatin (otic drops or powder), and ketoconazole. Topical ketoconazole, cresylate otic drops, and aluminum acetate otic drops were all relatively effective with >80% resolution rate on initial application. CSF powder (chloramphenicol, sulfamethoximazole, and fungizone) is also an excellent option.

SKULL BASE OSTEOMYELITIS

ESSENTIALS OF DIAGNOSIS

- Immunosuppressed patients with intense otalgia, otorrhea, hearing loss, fullness, and pruritus
- Edema and erythema of the EAC, granulation tissue at the bony–cartilaginous junction, cranial neuropathies in advanced stages
- Elevated erythrocyte sedimentation rate (ESR) or C-reactive protein (CRP). Culture of EAC. CT and/or technetium scan diagnostic; gallium scan to follow resolution of disease
- Biopsy is necessary to rule out carcinoma.

General Considerations

Skull base osteomyelitis, also known as malignant otitis externa or necrotizing otitis externa (NOE), is a bacterial infection of the EAC and skull base. This disease process is most frequently seen in elderly diabetics and immunocompromised patients. It most commonly begins as an external otitis that progresses to involve the temporal bone, and may progress to fatal meningitis, sepsis, and death if unrecognized or untreated.

Pathogenesis

Skull base osteomyelitis commonly begins as an external otitis that progresses to cellulitis, chondritis, osteitis, and, ultimately, osteomyelitis. Unlike otitis media, which spreads through the pneumatized portion of the temporal bone, NOE disseminates through the haversian canals and vascularized spaces of the skull base. As this progresses along the base of the skull, the facial nerve (stylomastoid foramen), hypoglossal nerve (hypoglossal canal), the abducens and trigeminal nerves (petrous apex), the glossopharyngeal, vagus, and spinal accessory nerves (jugular foramen) may be involved. Cranial neuropathy has classically been considered to portend a poor prognosis, although recent data has not supported a difference in mortality.

The most frequently isolated causative organism is *P aeruginosa*, which may exhibit high levels of antibiotic resistance. *Aspergillus* may also be an etiologic organism and is thought to originate from the middle ear or mastoid. Elderly diabetics are thought to be particularly susceptible because of the microangiopathic changes that blunt an already attenuated immune response. The cerumen of diabetic patients has also been described to be more acidic in nature, further contributing to their susceptibility.

Clinical Findings

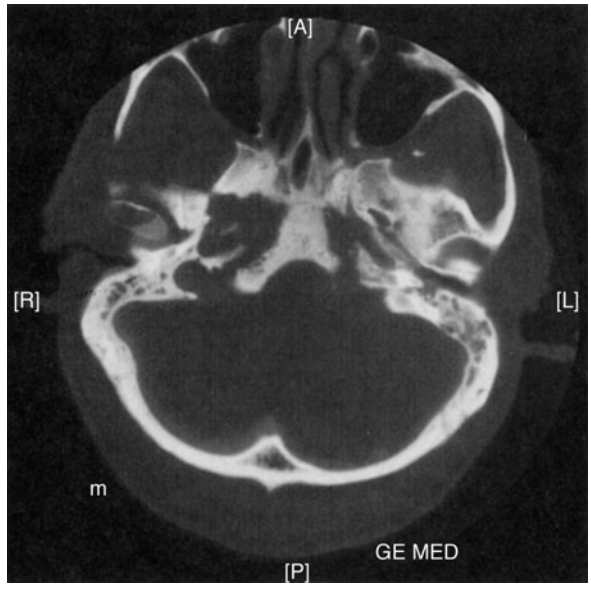
A. Symptoms and Signs

Patients may present with intense otalgia, otorrhea, aural fullness, pruritus, and hearing loss. As the disease advances to involve the temporal bone, granulation tissue is seen on the floor of the EAC at the osteocartilaginous junction. Bony sequestra can also be found in the EAC. Edema, periaural lymphadenopathy, and trismus may be present. Cranial neuropathies occur in more advanced presentations of disease, and the facial nerve is the most frequently affected cranial nerve. Further progression may lead to sigmoid sinus thrombosis, meningitis, sepsis, and death.

B. Diagnostic Tests

Inflammatory markers such as ESR and CRP may be elevated. Cultures and sensitivity should be obtained to help in selecting appropriate antibiotics.

CT and MRI are useful in the initial evaluation to determine the extent of disease. Bone scans are sensitive for assessing bony involvement but are not specific (Figures 47–7, 47–8, and 47–9). Gallium scans are used to track the resolution of the infection, since bone scans often remain positive long after the infection has resolved (Figure 47–10).



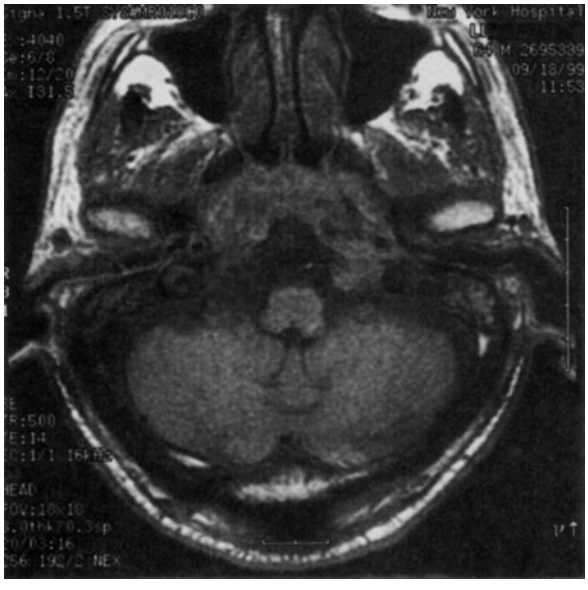
▲ **Figure 47–7.** Axial high-resolution CT scan demonstrating skull base osteomyelitis with evidence of petroclival bone erosion.

Differential Diagnosis

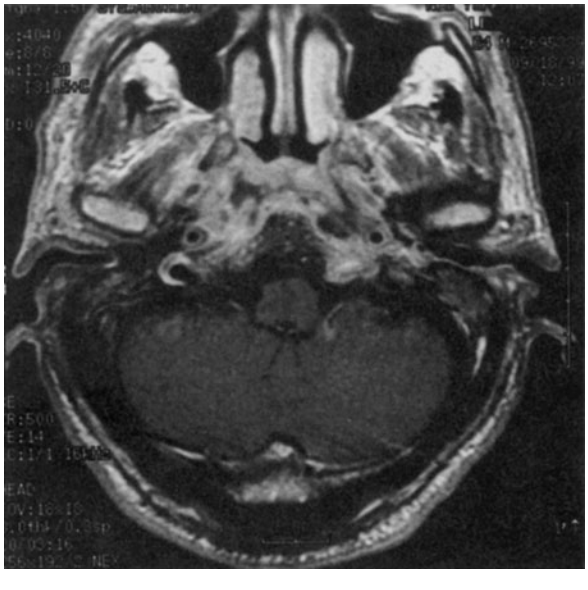
Carcinomas of the EAC, chronic granulomatous disease, Paget disease, fibrous dysplasia, and nasopharyngeal carcinomas must be considered in the differential diagnosis. As carinoma of the EAC mimics many features of NOE, a biopsy is requisite to rule out carcinoma.

Treatment

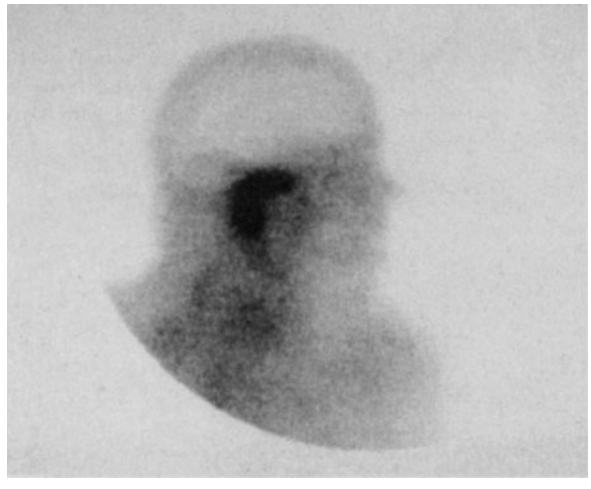
Long-term parenteral antibiotics are the treatment of choice. Aminoglycosides (eg, tobramycin) and antipseudomonal β-lactam antibiotics, including piperacillin, ticarcillin, or ceftazidime, may be used. Some physicians recommend the use of outpatient fluoroquinolones such as ciprofloxacin or ofloxacin; however, this is appropriate only for patients with early presentations who can be followed up closely. Control of hyperglycemia and immunosuppression is necessary to maximize treatment. Surgical debridement may be necessary to remove necrotic tissue. Circumferential petrosectomy has been described as a method for surgical debridement with hearing and facial nerve function preservation. The use of hyperbaric oxygen has been described in cases refractory to antibiotics, with variable results. In an effort to prevent skull



▲ **Figure 47–8.** Axial T1-weighted MRI depicting the replacement of bone marrow in the clivus with inflammatory tissue.



▲ **Figure 47–9.** Axial T1-weighted MRI, with gadolinium enhancement, with evidence of petroclival bone erosion and enhancement of inflammatory tissue secondary to skull base osteomyelitis.



▲ **Figure 47–10.** Sagittal image of a bone scan in a patient with skull base osteomyelitis revealing focal enhancement of the skull base.

base osteomyelitis, all diabetic and immunocompromised patients must be followed up closely and treated aggressively if they present with symptoms suggestive of external otitis.

Rubin Grandis J, Branstetter BF IV, Yu VL. The changing face of malignant (necrotizing) external otitis: Clinical, radiological, and anatomic correlations. *Lancet Infect Dis.* 2004;4(1):34. [PMID: 14720566] (An overview of the diagnosis and management of skull base osteomyelitis.)

DERMATOLOGIC DISEASES OF THE EXTERNAL EAR

ESSENTIALS OF DIAGNOSIS

- Atopic dermatitis—pruritic erythematous patches or weeping plaques
- Psoriasis—oval salmon-pink plaques with silvery scales on elbows, knees, scalp, and buttocks
- Contact dermatitis—pruritic, indurated, and erythematous lesions after exposure to allergen or irritant.

ATOPIC DERMATITIS

General Considerations

Atopic dermatitis is a chronic skin disease of immune-mediated origin. It may remit spontaneously or endure as

a chronic condition. Lesions presenting on the ear may be pruritic and erythematous. Patients often have a personal or family history of atopy and allergy.

Atopic dermatitis often manifests in infancy on extensor surfaces and the face. Children may present with skin lesions on flexural areas and on the hands.

Pathogenesis

Though not completely understood, the clinical presentation of atopic dermatitis is thought to be secondary to immune dysfunction. Atopic skin lesions have been shown to have higher levels of Th2 T-lymphocytes, which produce inflammatory mediators such as interleukin 4, 5, and 10.

Clinical Findings

The diagnosis of atopic dermatitis is a clinical one. There is variability in skin lesions ranging from erythematous patches to weeping plaques. Lesions presenting on the ear are often pruritic and erythematous. Lesions typically persist for more than 1 month. Secondary infections with *S aureus,* herpes simplex virus, vaccinia, and molluscum contagiosum may occur.

Atopic dermatitis is characterized by the absence of specific laboratory and histologic markers. Elevated IgE and eosinophilia may be present yet are not specific for the diagnosis.

Differential Diagnosis

The differential diagnosis includes seborrheic dermatitis and psoriatic dermatitis.

Treatment

Topical corticosteroids are the mainstay of treatment. Antihistamines and lubricants may be used for the treatment of accompanying pruritus. Moisturizers and mild soaps are preferred to minimize exposure to potential allergens found in many cosmetic products. Food elimination and desensitization are not recommended. Though often self-limited, the disease may recur spontaneously and can become chronic. Bacterial superinfection may require topical and systemic antibiotics.

PSORIASIS

General Considerations

Psoriasis is a chronic inflammatory disorder of the skin. Eighteen percent of patients with psoriasis have some involvement of the external ear, which may be secondary to extension from the scalp. Plaques may present on the concha and meatus of the EAC and are variably pruritic.

The incidence of psoriasis in the United States ranges from 2% to 5%. Males and females are equally affected, with the onset of disease typically occurring in adolescence.

Pathogenesis

The cause of psoriasis is unknown, yet there is a strong genetic component. Attacks of psoriasis may be triggered by certain drugs such as NSAIDs, beta-blockers, lithium carbonate, and antimalarial agents, as well as by infection, trauma, and stress.

Clinical Findings

Psoriasis is characterized by erythematous papules that coalesce to form round or oval salmon-pink plaques with silvery white scales found on the elbows, knees, scalp, and buttocks. These lesions bleed in pinpoint areas when scratched (Auspitz sign). Opacification or "oil spots" of the nails, as well as pitting and subungual hyperkeratosis, are also suggestive of this disease. Psoriatic lesions may present over areas of trauma, an entity known as Koebner phenomenon. Psoriatic arthritis occurs in 5–10% of all psoriatic patients.

Treatment

Patients should avoid excessive drying of the skin. For ears and face, treatment includes low-dose topical nonfluorinated corticosteroids such as alclometasone, mometasone, desonide, clocortolone, hydrocortisone valerate, and butyrate creams and topical calcipotriene. Warm-water soaks, 1–5% coal tar treatment, and topical anthralin C may also be helpful. Oral psoralens and UVA phototherapy for patients with widespread disease may be necessary. Antihistamines are used to treat the associated pruritus. Methotrexate may be required for severe cases and for psoriatic arthritis. The response to treatment is variable, and the condition may become chronic.

CONTACT DERMATITIS

General Considerations

Contact dermatitis can be an acute or chronic inflammatory disorder of the skin caused by contact with an allergen or irritant. This process may occur anywhere along the pinna or the EAC. Eruption may occur secondary to instrumentation, foreign objects—including jewelry, earplugs, and hearing aids—and other objects used to scratch pruritic lesions. In addition, cosmetics and hair products are frequent culprits.

Pathogenesis

Allergic contact dermatitis is a Type IV hypersensitivity reaction, and cutaneous manifestations are often delayed

by 1–3 days. This is in contrast to irritant-mediated contact dermatitis, which usually manifests earlier.

Clinical Findings

Allergic contact dermatitis is characterized by an indurated, erythematous, pruritic, and poorly demarcated process. This is in contrast to irritant dermatitis, which often presents with well-defined areas of exposure.

Skin testing to identify contact allergens may be of use.

Treatment

The avoidance of exposure to irritants and allergens and high-dose topical glucocorticoids are the mainstays of therapy.

FIRST BRANCHIAL CLEFT ANOMALIES

ESSENTIALS OF DIAGNOSIS

- Cyst or tract along anterior border of sternocleidomastoid muscle usually near angle of mandible
- Recurrent neck or ear drainage and infection
- CT scan may be helpful to identify tract
- Work classification system describes anomaly and relationship to facial nerve.

Pathogenesis

First branchial cleft anomalies occur as a result of anomalous fusion of the first and second branchial arches, with incomplete obliteration of the first branchial cleft.

Clinical Findings

Patients may present with a cyst or tract along the anterior border of the sternocleidomastoid muscle near the angle of the mandible. A membranous band between the medial aspect of the floor of the ear canal and the tympanic membrane at the manubrium of the malleus is also highly associated with first branchial cleft anomalies. The patient may have a history of recurrent infection and drainage from the ear or neck.

The Work classification system has been used to describe first branchial cleft cysts. A Work type 1 anomaly duplicates the membranous EAC only. It is lined with squamous epithelium and opens to the external skin. It is located superficial to the facial nerve. A Work type 2 anomaly duplicates both the membranous and cartilaginous EAC. It has a variable relationship with the facial nerve.

Treatment

The treatment for first branchial cleft anomalies is complete excision. Incomplete excision predisposes the patient to recurrence and reinfection. The tract may be intimately involved with the facial nerve, which is at risk during excision. This necessitates early identification of the facial nerve as it exits the stylomastoid foramen and tracing distally through the lesion. A superficial parotidectomy type approach may be required for complete excision.

AURICULAR FROSTBITE

ESSENTIALS OF DIAGNOSIS

- Cold exposure
- Auricle initially numb, then subsequently painful
- Auricle initially pale, cyanotic, and hypesthetic, then subsequently erythematous with bullae.

Pathogenesis

Freezing temperatures lead to both direct cellular injury as well as vascular compromise. Prolonged exposure to cold temperatures can lead to vasoconstriction, cold-mediated dehydration, endothelial injury, thrombosis, and ischemia of auricular tissue. In the early stage, this process may be reversible, but over time, it leads to tissue necrosis.

Clinical Findings

Temperatures below 10°C may lead to hypesthesia, and the person is frequently unaware of impending frostbite. The ear is initially pale and then cyanotic. Ultimately, as the ear thaws, pain, erythema, and subcutaneous bullae secondary to extravasated extracellular fluid or blood may develop.

Treatment

The initial treatment for auricular frostbite consists of rapid rewarming of the ear to 40–42°C. Nonhemorrhagic blisters may be débrided, and patients should be given pain medicine and antibiotics. Aloe vera has antithromboxane properties and, together with ibuprofen, may help in re-establishing circulation. More aggressive débridement should be delayed for several weeks until demarcation is complete.

Petrone P, Kuncir EJ, Asensio JA. Surgical management and strategies in the treatment of hypothermia and cold injury. *Emerg Med Clin North Am.* 2003;21(4):1165. [PMID: 14708823] (An overview of the current recommendations for the management of frostbite, including frostbite of the external ear.)

AURICULAR BURNS

ESSENTIALS OF DIAGNOSIS

- Superficial burn—erythema and pain
- Partial-thickness burn—painful blisters
- Full-thickness and subdermal burns—painless, gray/black eschar.

General Considerations

Thermal injury can be classified by the degree of the burn. Superficial burns involve the superficial layer of the epidermis. Partial-thickness burns extend into, but not through, the dermis. Full-thickness burns extend through the full thickness of the dermis. Subdermal burns extend into the subcutaneous tissue, including fat, muscle, tendon, cartilage, and bone.

Clinical Findings

Superficial auricular burns present with erythema secondary to dermal capillary dilation and vessel congestion. These burns are red and moderately painful. Patients with partial-thickness burns usually present with blisters that blanch on direct pressure and are very painful. Deep partial-thickness burns are associated with less pain, and there may be an eschar. Full-thickness and subdermal burns are painless because dermal nerve endings have been destroyed. The wound surface is of varying color, but may be gray or black and charred.

Treatment

Superficial burns do not scar and may be treated with moisturizing creams. The blisters of partial-thickness burns should be débrided, and antibiotic ointment applied. When not deep, these burns heal without scarring as well. Full-thickness, subdermal, and deep partial-thickness burns of the auricle heal with scarring and contracture and may be complicated by suppurative chondritis. These burns should be treated with both topical (usually silver based) and systemic cartilage penetrating antibiotics. Early débridement and closure with skin grafts should be considered. Secondary reconstruction is usually performed at approximately 1 year after injury.

DeSanti L. Pathophysiology and current management of burn injury. *Adv Skin Wound Care.* 2005;18(6):323. [PMID: 16096398] (An overview of the current recommendations for the management of burns, including those of the external ear.)

FOREIGN BODIES OF THE EXTERNAL EAR

General Considerations

Foreign bodies within the external ear may present in both children and adults. Common objects include erasers, pills, batteries, and insects.

Clinical Findings

Patients may present with pain, pruritus, conductive hearing loss, and bleeding. A persistent foreign body may lead to infection and the formation of granulation tissue. Batteries lodged within the EAC, when in contact with moisture, may cause liquefaction necrosis, low-voltage injury, or pressure necrosis of the EAC skin or tympanic membrane.

Treatment

The removal of foreign objects should be done in an atraumatic manner. Injury to the EAC is minimized with direct visualization using the operating microscope and proper instrumentation (eg, right angle pick, curet, forceps, and suction) as well as minimizing patient movement. In children, general anesthesia is often required. Irrigation may help dislodge cerumen or smaller objects. Cerumen impaction may require prior softening with an otic preparation. Two percent lidocaine may be used for the removal of insects both to achieve topical anesthesia and also to kill the insect. Complete occlusion of the EAC with cyanoacrylate adhesives (ie, "superglue") may require surgical removal with a postauricular approach

NEOPLASMS OF THE EXTERNAL EAR AND EAR CANAL

ESSENTIALS OF DIAGNOSIS

- The majority of external ear carcinomas can be reconstructed primarily
- The AJCC system may be used to classify external ear carcinoma, while the Pittsburgh staging system should be used for carcinoma of the ear canal
- Lateral temporal bone resection is indicated for T2 or greater ear canal carcinoma
- Parotidectomy and neck dissection should be reserved for advanced lesions and/or palpable disease
- Survival with ear canal carcinoma is highly correlated with T stage at presentation.

BASAL CELL CARCINOMA OF THE AURICLE

General Considerations

Basal cell carcinomas are the most common malignant neoplasm of the auricle, representing 45% of auricular carcinomas.

Pathogenesis

Chronic long-term sun exposure is the predominant cause of basal cell carcinoma. Specifically, UVB radiation has been identified as a major carcinogen. The incidence of cancer increases with age. Other risk factors include fair skin, outdoor occupations, and a history of skin carcinoma.

Clinical Findings

Patients may initially present with a skin lesion that is nodular, ulcerated, and/or bleeding. Basal cell carcinomas of the auricle typically occur on the posterior surface of the pinna and in the preauricular area. The diagnosis of any suspicious lesion should be confirmed with biopsy. CT scans and MRI may be used to evaluate advanced disease with tumor extension to the adjacent temporal bone and soft tissue structures of the head and neck. The overall rate of metastasis is 0.003–0.1%.

Staging

Basal cell carcinomas of the EAC can be staged using the American Joint Committee on Cancer (AJCC) general staging system for nonmelanoma cancer of the skin. This staging system is limited by the fact that it does not account for histologic subtypes or the anatomic variability of the skin of the external ear compared with other skin sites.

Differential Diagnosis

Given the variability of subtypes, the differential diagnosis includes benign nevi, amelanotic melanomas, cutaneous squamous cell carcinomas, eczema, and scleroderma.

Treatment

A. Nonsurgical Measures

1. Topical 5-fluorouracil.

2. Radiation therapy—Indicated for poor surgical candidates or unresectable lesions.

B. Surgical Measures

1. Curettage with electrodissection—Operator dependent and typically used to excise nodular lesions and desiccate the base.

2. Cryosurgery—Indicated for small basal cell carcinomas (<1 cm) with well-defined borders.

3. Local excision—Ninety-five percent of basal cell carcinomas <2 cm in size can be successfully treated with local excision with a surgical margin of at least 4 mm. Auricular reconstruction may be required for large defects.

4. Mohs surgical technique—Refers to complete micrographic excision of the tumor using intraoperative histopathology to assess for positive margins. This technique is particularly useful for recurrent basal cell carcinomas, those larger than 2 cm, or those with an aggressive histology. Five-year cure rates using Mohs technique should approach 97.1%.

CUTANEOUS SQUAMOUS CELL CARCINOMA

General Considerations

Squamous cell carcinomas account for 20% of all cutaneous malignant neoplasms and commonly occur in elderly males.

Pathogenesis

Risk factors for squamous cell carcinoma include immunosuppression, advanced age, a nonhealing ulcer, and exposure to chemicals such as arsenic, soot, coal, tar, paraffin, and petroleum oil. The most important risk factor is exposure to UV radiation.

Clinical Findings

The appearance of these tumors is variable and includes plaques, nodules, and ulcerations. They may be friable and prone to bleeding. Auricular lesions frequently occur on the helix or preauricular region, but may occur on any sun-exposed areas.

CT scanning and MRI may be used to evaluate advanced disease with tumor metastasis to the adjacent temporal bone and soft tissue structures of the head and neck. The proper diagnosis should be made with biopsy. The overall risk of metastasis for cutaneous squamous cell carcinoma of the external ear is approximately 6–18%.

Staging

The AJCC system may be utilized for carcinoma of the external ear. AJCC staging systems for nonmelanoma cancer of the ear canal may also be utilized, but the University of Pittsburgh system (Figure 47–11) is more frequently used for staging squamous cell carcinoma of the temporal bone, as the AJCC does not account for the unique nature of tumors arising in the ear canal.

Differential Diagnosis

The differential diagnosis includes basal cell carcinoma, actinic keratosis, seborrheic keratosis, keratoacanthomas, scars, psoriatic lesions, melanomas, and sarcomas.

T1	Tumor limited to EAC without bony erosion or soft tissue extension
T2	Tumor with limited EAC bony erosion (not full thickness) or limited (<0.5 cm) soft tissue involvement
T3	Tumor eroding the osseous EAC (full thickness) with limited (<0.5 cm) soft tissue involvement, or tumor involving middle ear and/or mastoid, or patients presenting with facial paralysis
T4	Tumor eroding the cochlea, petrous apex, medial wall of the middle ear, carotid canal, jugular foramen, dura, or with extensive soft tissue involvement

▲ **Figure 47–11.** University of Pittsburgh Staging System for Squamous Cell Carcinoma.

Treatment

A. Nonsurgical Measures

Radiation therapy may be indicated for unresectable lesions or those that may lead to significant cosmetic disfigurement with surgery.

B. Surgical Measures

1. Local excision—Ninety-five percent of squamous cell carcinomas <2 cm limited to external ear can be successfully treated with local excision with a surgical margin of at least 6 mm. Auricular reconstruction may be required for large defects. T1 lesions of the EAC may be treated with sleeve excision with careful attention to deep margins. T2 lesions or greater necessitate lateral temporal bone resection. Subtotal temporal bone resection involves the piecemeal removal of structures medial to the tympanic membrane and may be necessary for T3 and T4 lesions. Facial nerve involvement may necessitate its resection and grafting with a nerve graft remote to the site of the tumor (ie, sural nerve).

2. Mohs surgical technique—This technique is particularly useful for recurrent lesions, those >2 cm, or those with an aggressive histology.

3. Neck dissection and parotidectomy—In all cases of palpable disease in the parotid and neck, and in the case of T3 and T4 squamous cell carcinomas, parotidectomy, neck dissection, and adjuvant radiation should be strongly considered.

Prognosis

In addition to the patient's age and overall immune status, the prognosis for squamous cell carcinoma is dependent on the histologic subtype, size, and location of the tumor. A better prognosis is associated with a well-differentiated histology. The 5-year cure rate for squamous cell carcinomas of the external ear range from 75% to 92%.

Squamous cell carcinoma of the EAC carries a much more dire prognosis with recent studies suggesting a range of 5-year survival of T1 tumors of 83% and T4 tumors of 25%. Facial nerve involvement and nodal disease are poor prognostic findings.

MELANOMA OF THE EXTERNAL EAR

General Considerations

The incidence of melanoma in the United States is 11.1 cases per 100,000 individuals. Auricular melanoma accounts for 1% of all melanomas. Melanomas of the ear have a 10-year survival rate of 70%.

Clinical Findings

Most melanomas involving the ear present on the helix. Though initially painless, these lesions may change in size, ulcerate, and bleed. A thorough head and neck examination requires attention to enlarged lymph nodes that may occur with regional spread of disease.

The diagnosis of melanoma is dependent on the histologic evaluation of a biopsy. At a minimum, metastatic evaluation should include a chest x-ray to rule out lung metastases and liver function tests to rule out liver metastases. CT scanning and MRI have added sensitivity in detecting metastatic disease. Radio-nuclide bone scans can be used to diagnose bony metastases.

Staging

Melanomas may be staged using the staging system of the AJCC. This system incorporates the depth of invasion, measured in millimeters. Deeper lesions and lesions with ulceration are associated with higher stages and higher mortality rates.

Differential Diagnosis

The differential diagnosis is diverse and includes benign lesions as well as basal cell and squamous cell carcinomas.

Treatment

A. Nonsurgical Measures

Adjunctive radiation therapy may have a role in palliation.

B. Surgical Measures

The extent of excision, including surgical margins, is dependent on the histologic type and stage of disease. Management

of the regional lymphatics is controversial and may include elective regional lymph node dissection and parotidectomy. Recently, sentinel lymph node biopsy has become a well-accepted approach in the management of the N0 neck for lesions more than 1 mm deep.

Prevention

The avoidance of and protection from sun exposure are important in preventing disease, as is early detection. Early detection is also extremely important in improving prognosis.

GLANDULAR TUMORS OF THE EXTERNAL AUDITORY CANAL

ESSENTIALS OF DIAGNOSIS

- Otorrhea, fullness, otalgia, and conductive hearing loss.
- Sensorineural hearing loss indicates inner ear extension.
- CT and MRI to define tumor and surrounding anatomy.
- Biopsy essential.

Classification

Glandular tumors of the EAC are rare and include four types: (1) adenoid cystic carcinomas, (2) ceruminous adenomas, (3) ceruminous adenocarcinomas, and (4) pleomorphic adenomas.

A. Adenoid Cystic Carcinoma

These are capsular tumors most often found in salivary gland tissue. They have a predilection for perineural, perivascular, and fatty infiltration. Patients with perineural invasion often present with otalgia. Histologically, these tumors may show cribriform, tubular, or solid patterns of cellular arrangement. Lymph node metastases are rare, but late distant metastasis in particular to the lung are not an uncommon feature of these tumors.

B. Ceruminous Adenoma

Ceruminous adenoma consists of benign painless masses that may grow undetected for prolonged periods of time. Patients may present with a conductive hearing loss or otitis externa. They are histologically characterized by double-layered cuboidal or columnar cells, and the epithelium may show apical "snouts" of apocrine secretion.

C. Ceruminous Adenocarcinoma

These tumors share histologic features with ceruminous adenomas, but they have higher rates of mitoses and cellular atypia. Invasion into adjacent structures may be present, and lymph node metastases are rare.

D. Pleomorphic Adenoma

These tumors vary histologically but are characterized by epithelial and mesenchymal elements. These benign tumors do not display features of invasion.

Clinical Findings

Patients with glandular tumors of the EAC may present with otorrhea, aural fullness, otalgia, and conductive hearing loss. Sensorineural hearing loss signifies tumor extension into the inner ear. CT imaging is helpful in determining the amount of bony erosion and the size of the tumor. Generous tissue samples are important for histologic diagnosis.

Treatment

Benign glandular tumors are treated with wide local excision. Malignant tumors are treated with a variant of temporal bone resection, and consideration should also be given to adjuvant radiation. In the case of adenoid cystic carcinoma, parotidectomy should be considered as it has been associated with increased survival.

Devaney KO, Boschman CR, Willard SC, Ferlito A, Rinaldo A. Tumours of the external ear and temporal bone. *Lancet Oncol.* 2005;6(6):411. [PMID: 15925819] (Overview of the diagnosis and management of malignancies that affect the external and middle ear.)

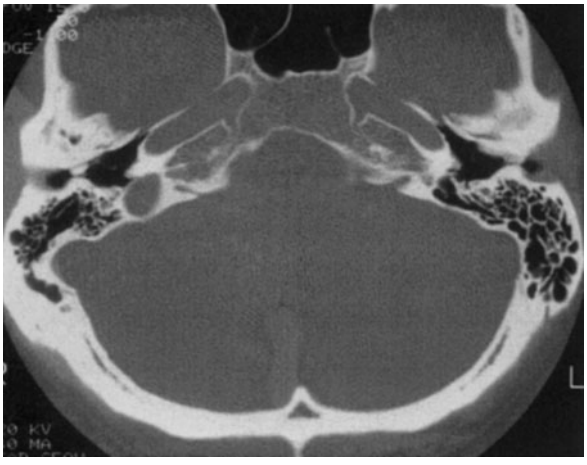
OSTEOMAS & EXOSTOSES OF THE EXTERNAL AUDITORY CANAL

ESSENTIALS OF DIAGNOSIS

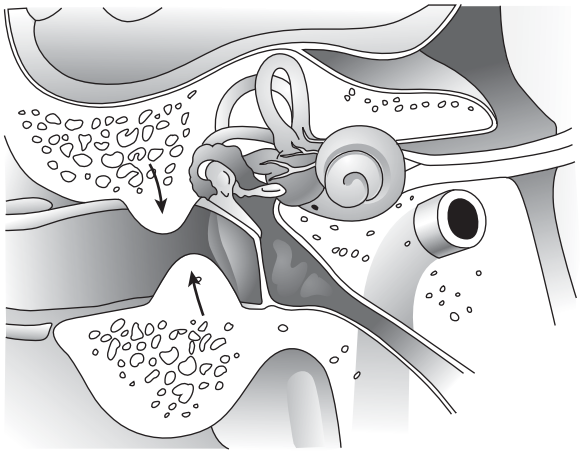
- Usually asymptomatic; may present with cerumen impaction, otitis externa, or conductive hearing loss
- Osteoma—pedunculated bony EAC lesion
- Exostoses—multiple EAC lesions.

General Considerations

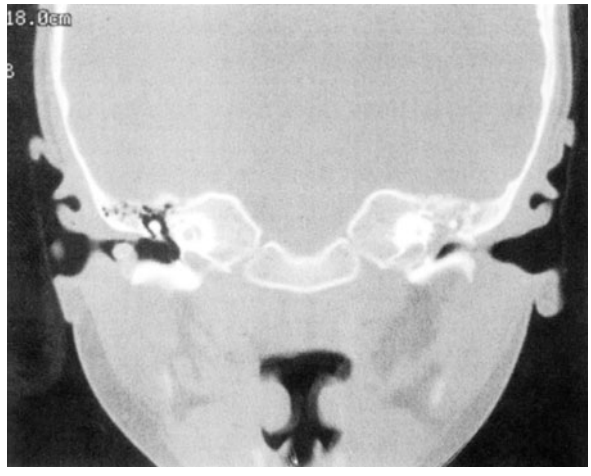
Osteomas are benign osseous neoplasms. Exostoses are firm, bony, broad-based lesions composed of a lamellar bone (Figure 47–12). Exostoses are formed by reactive bone formation and have been associated with cold-water



▲ **Figure 47–12.** High-resolution axial CT scan revealing right anterior and posterior external auditory canal exostoses.



▲ **Figure 47–13.** Coronal view of superior and inferior exostoses of the external auditory canal. (Reprinted with permission of Jackler RK.)



▲ **Figure 47–14.** High-resolution coronal CT scan demonstrating an inferiorly based osteoma of the right external auditory canal.

exposure. Both osteomas and exostoses arise from the bony portion of the EAC (Figure 47–13).

Clinical Findings

Osteomas are usually pedunculated and often have a vascular core (Figure 47–14). Exostoses commonly present as multiple lesions. Although most osteomas and exostoses are asymptomatic, occlusion of the EAC with an enlarged lesion may lead to cerumen impaction, external otitis, and a conductive hearing loss on audiogram.

Treatment

Most exostoses and osteomas require no intervention. If surgery is necessary, a transcanal or postauricular approach can be used, depending on the size of the lesions. The preservation of skin flaps speeds healing.

When used for long, earplugs have been shown to be protective against exostoses in patients with frequent cold water exposure.

We would like to acknowledge Eli Grunstein, MD, and Felipe Santos, MD, for their contribution to this chapter in the previous editions of CDT.

48 Congenital Disorders of the Middle Ear

Kevin D. Brown, MD, PhD &
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EMBRYOLOGY & DEVELOPMENT

INITIAL STAGES OF DEVELOPMENT

Beginning at week 4, the tubotympanic sulcus develops as an extension of the endodermal epithelium of the first pharyngeal (branchial) pouch and eventually forms the middle ear canal and the eustachian tube. The tubotympanic recess has elongated and constricted to form the primordial tympanic cavity and eustachian tube by week 8. Simultaneously, the expanding end of the tubotympanic sulcus comes into proximity with the medial aspect of the ectodermal first pharyngeal cleft, the primordial external auditory canal. Although intimately related, the two linings remain separated by a layer of mesenchyme known as the pharyngeal membrane. This trilaminar relationship develops into the adult tympanic membrane, which comprises the outer cutaneous, middle fibrous, and inner mucosal layers. As the middle ear cavity expands, the tympanic sinus is created by the pneumatization of already ossified temporal bone. By 9 months, pneumatization of the tympanum and epitympanum is virtually complete. At the same time, the mastoid antrum is formed by the growth of the tympanic cavity into the mastoid portion of the temporal bone. The attachment of the sternocleidomastoid on the temporal bone promotes the formation of the mastoid process. Although the development of the mastoid air cells begins in fetal life, full maturation does not occur until age 2.

Early in development, the middle ear cavity is filled with loose mesenchyme that spans the gap between the primordial tympanic membrane and oval window. However, during the last 2 months of pregnancy, this mesenchyme is systematically reabsorbed, leaving the nearly mature ossicles suspended in the middle ear cavity. Beginning sometime between weeks 4 and 7, a condensation of neural crest ectoderm embedded within the mesenchyme begins to form the ossicles. Meckel cartilage, which is derived from the first pharyngeal (branchial) arch, gives rise to the head of the malleus and the body of the incus (ossicle portions above the tympanic membrane). The remainder of Meckel cartilage develops into the mandible and sphenomandibular ligament (Meckel ligament). The first pharyngeal arch is also associated with the mandibular division of the trigeminal nerve, the muscles of mastication, the tensor tympani muscle, and the tensor veli palatini muscle. The second pharyngeal arch gives rise to Reichert cartilage, which eventually forms the manubrium of the malleus, the long process of the incus, stapes suprastructure, and the tympanic portion of the stapes footplate (ossicle portions below upper limit tympanic membrane). The vestibular portion of the stapes footplate derives from the otic capsule. The facial nerve, the muscles of facial expression, the stapedius muscle, the upper portion of the hyoid bone, and the stylohyoid ligament are also derived from the second pharyngeal arch mesoderm. It is important to note that although the pharyngeal arches are mesenchymal, the ossicles are derived from neuroectoderm that is embedded within the mesenchyme. This partly explains the association between ossicular malformations and disorders of neuroectoderm.

STAPES

The stapes requires the longest period of development and is therefore the most frequently malformed. The earliest stages of development begin at 4 weeks, and ossification does not occur until week 26. Development of the stapes footplate is induced by a depression on the otic capsule, the lamina stapedialis. This occurs between weeks 6 and 9. Ultimately, the lamina stapedialis becomes the annular ligament and the vestibular portion of the footplate. Failure of this precise association between the stapes footplate and the lamina stapedialis may result in a malformed or atretic oval window.

The primordial stapes is characterized as a chondral ring. Resorption, periosteal erosion, and ossification shape

this cartilaginous precursor into an adult-like ossified stirrup. As a result of this developmental process, the adult stapes is fragile; a "plate" of endosteal bone overlying the original layer of cartilage forms the head and base, and thin periosteal bone makes up the crura. This contrasts with the relatively dense incus and malleus, which form from the repeated layering of endosteal bone on a cartilaginous framework. Furthermore, in contrast to the stapes, the malleus and the incus do not undergo morphologic changes, which minimizes the complexity of the shaping process and the potential for error.

MALLEUS & INCUS

The developmental process of the malleus and incus is rapid. The chondral elements reach adult size by week 15 and are fully ossified skeletal structures by week 25. Before the full development of the ossicular ligaments, projections from the endodermal lining of the middle ear cavity help to support the position of the ossicles. Invaginations of the endodermal lining between the ossicles also serve to separate the developing ossicles from each other and from the walls of the tympanic cavity. Failure of this results in ossicular fusion. The articulations between the ossicles develop early, with the incudomalleolar joint forming at 7 weeks. Adult size and relationships are fully established by the 9th month. Full ossicular mobility, however, does not occur until 2 months after birth, when the mesenchyme of the middle ear cavity is fully reabsorbed.

STAPEDIAL ARTERY

The developing intracranial vasculature originates from six paired aortic arches and their associated arteries. During the 4th week of development, the stapedial artery arises from the hyoid artery (second aortic arch) near the origin of the proximal internal carotid artery (ICA) (third aortic arch). It enters the anteroinferior quadrant of the middle ear and courses over the promontory and through the primordial stapes to form the obturator foramen. It then proceeds anteriorly to pierce the horizontal facial canal and enter the cranial cavity. The artery subsequently divides into an upper (supraorbital) division and a lower (maxillomandibular) division. The supraorbital division provides the vasculature to the orbit and to the supraorbital areas early in fetal development. However, as the ophthalmic artery matures to assume these distributions, the supraorbital division largely involutes and persists as the middle meningeal artery. The maxillomandibular division exits the cranial cavity through the foramen spinosum and contributes to the fetal vasculature of the lower face, as well as to the inferior alveolar and infraorbital areas. By the third month, this division is largely replaced by branches of the external carotid artery. The proximal trunk of the stapedial artery normally atrophies, whereas the distal portion, the middle meningeal artery, persists and is supplied by the external carotid artery.

VASCULAR ANOMALIES

JUGULAR VEIN ANOMALIES

ESSENTIALS OF DIAGNOSIS

- Dehiscence of the jugular bulb may lead to aberrant position within the middle ear.
- This may be asymptomatic or may lead to tinnitus or conductive hearing loss.
- Visible on CT and MRI/MRA.
- Avoidance is most prudent management.

Between the third and fourth weeks of development, paired cardinal veins first appear in the primordial neck. The cranial portion of the anterior cardinal vein ultimately gives rise to the internal jugular vein, whereas the cephalad portion forms the jugular bulb. The sigmoid sinus and the inferior petrosal sinus converge at the jugular bulb, which drains into the jugular vein in the neck. Normally surrounded by a layer of bone within the jugular fossa, the bulb is subject to congenital dehiscence and an aberrant position within the middle ear. A "high-riding" bulb may be defined anatomically as a bulb that rises above the inferior aspect of the bony annulus or the basal turn of the cochlea. It is present in 5% of temporal bone specimens and may be related to the poor pneumatization of the mastoid air cells and middle ear. The bony covering of the bulb may be thin or absent, resulting in dehiscence and protrusion into the middle ear cavity. Tinnitus, vestibular symptoms, and conductive hearing loss due to ossicular, tympanic membrane, or round window compression have been described. However, dehiscent jugular bulbs are often discovered incidentally on otoscopic examination. Typically, a blue mass is seen in the posteroinferior quadrant of the tympanic membrane.

Contrast-enhanced computed tomography (CT) scanning, magnetic resonance imaging (MRI), and magnetic resonance angiography (MRA) help delineate a vascular mass in the middle ear, whereas a high-definition temporal bone CT scan will reveal a bony defect in the floor of the hypotympanum. Venography may differentiate this lesion from other vascular masses in difficult cases. The lack of a fascial covering over the jugular bulb predisposes it to inadvertent laceration during myringotomy. Therefore, avoidance during middle ear surgery represents the most judicious management of these lesions.

INTERNAL CAROTID ARTERY ANOMALIES

ESSENTIALS OF DIAGNOSIS

- Agenesis, aneurysm, and aberrancy of the intratemporal carotid artery have been described.
- Symptoms include hearing loss, pulsatile tinnitus, aural fullness, otalgia, and vertigo.
- Pulsatile red mass is seen in the middle ear.
- Imaging studies differentiate this from other vascular lesions.

General Considerations

Anomalies of the intratemporal ICA are extremely rare. Typically, there is a female preponderance, and these anomalies first present in the third decade of life with conductive hearing loss, bloody otorrhea, headache, pulsatile tinnitus, or cranial nerve palsies. Conductive hearing loss is due to impingement by the aneurysm on the ossicles or tympanic membrane. Otoscopic exam may reveal a red and pulsatile mass in the middle ear or blood in the external auditory canal. However, it is presumed that most intratemporal aneurysms of the ICA are asymptomatic and go unrecognized.

Pathogenesis

The ICA normally enters the carotid canal in the petrous portion of the temporal bone medial to the styloid process. The initial vertical segment is anterior to the cochlea, separated from the internal jugular vein by the carotid ridge and from the tympanic cavity by a thin bony wall, 0.5 mm thick. When laterally displaced, this portion of the ICA is found in the hypotympanum with possible extension over the oval window. Displacement of the tympanic membrane and ossicles, as well as erosion of the cochlear promontory, may also be present. Although temporal bone studies have revealed an incidence of <1% of an aberrant carotid artery, gross and micro-dehiscences of the carotid canal have a reported incidence of 7% and 15%, respectively.

Multiple etiologies for an aberrant ICA have been proposed, including (1) agenesis of the bony carotid canal; (2) lateral traction of the ICA by persistent embryonic vessels (eg, stapedial artery); and (3) agenesis of the vertical ICA with compensatory vascular communication from branches of the developing external carotid artery (ECA) system. The latter theory also explains the association of aberrant ICAs with other vascular anomalies, such as persistent stapedial artery (PSA).

Clinical Findings

A. Symptoms and Signs

The presenting signs and symptoms of an aberrant ICA include pulsatile tinnitus, otalgia, aural fullness, vertigo, hearing loss (61% conductive, 6% sensorineural, and 33% normal) and a pulsating, red mass in the anteroinferior quadrant of the middle ear. There may be a right-sided predominance of this anomaly, and bilateral involvement has been described.

Although hypoplasia, agenesis, aneurysm, and aberrancy of the ICA have all been reported, the low incidence of these lesions demands a high clinical suspicion if disastrous complications are to be avoided. Agenesis and hypoplasia are most often found incidentally on radiographic imaging and may be unilateral or bilateral. These lesions may remain clinically silent since they may be well compensated by the vertebrobasilar, external carotid, or contralateral internal carotid systems. Alternatively, they may present with neurologic symptoms secondary to cerebral insufficiency or aneurysm formation. The latter occurs in 24–34% of cases.

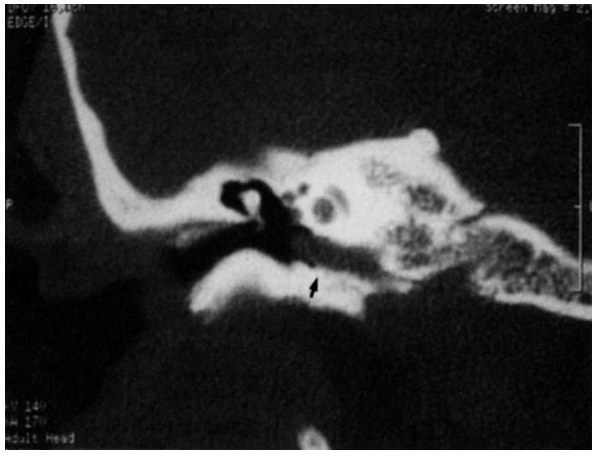
B. Imaging Studies

Radiographic imaging is essential and should include high-resolution CT scanning of the temporal bones (Figure 48–1), MRA, and angiography. CT and MRA are noninvasive and may delineate the vasculature and bony anatomy. A temporal bone CT scan in patients with carotid agenesis shows the complete absence of the petrous carotid canal. Angiographic findings include persistent fetal branches of the ECA, such as the hyoid, caroticotympanic, inferior tympanic, and stapedial arteries, as well as other intracranial vascular anomalies. Findings suggestive of an aberrant ICA include the following: (1) a vascular mass in the hypotympanum, (2) an enlargement of the inferior tympanic canaliculus, and (3) a lack of bony canal wall over the vertical ICA. This last feature helps distinguish aberrancy from a glomus tumor.

Several clinicians advocate angiography as the gold standard in the diagnosis of vascular lesions of the middle ear. The classic angiographic finding of an aberrant ICA is identification lateral to a vertical line drawn through the lateral border of the vestibule. Angiography also allows for occlusion testing to define the adequacy of the contralateral carotid circulation if ligation is to be considered.

Differential Diagnosis

The rarity of ICA anomalies dictates that a broad differential diagnosis for vascular masses of the middle ear be considered. Also included in this list are glomus tympanicum, glomus jugulare, vascular tumors of the temporal bone, dehiscent jugular bulbs, arteriovenous malformations, and arterial fistulas.



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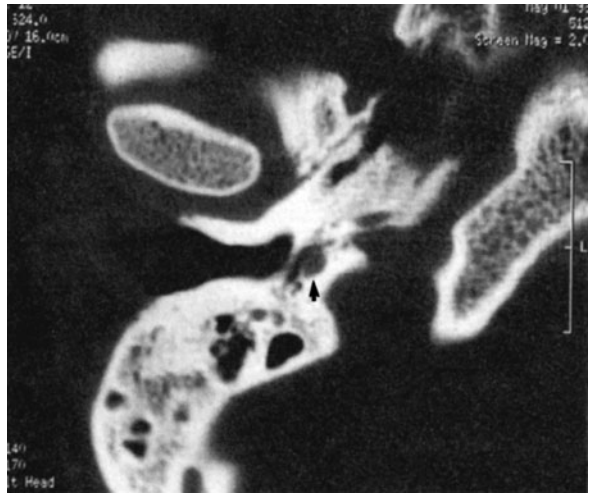


B

▲ **Figure 48–1. (A)** Aberrant position of the internal carotid artery. **(B)** Coronal CT scanning demonstrates extension of the internal carotid artery into the hypotympanum (arrow).

Treatment

The treatment of aneurysms and aberrancy of the ICA should be determined on a case-specific basis. Most authors agree that if the patient's only symptom is pulsatile tinnitus or if the patient is asymptomatic, the lesions may be followed expectantly. Indications for definitive therapy include debilitating or progressive symptoms, the prevention of aneurysm formation, embolic phenomenon from an aneurysm, and the destruction of middle ear structures. Aneurysms may be embolized during angiography. Covering an aberrant vessel with fascia, a bone graft, or a Silastic (ie, polymeric silicone) sheet has been described but carries a significant risk of distal ischemia from compression. Inadvertent injury to an aberrant or aneurysmal ICA during myringotomy or middle ear surgery may result in severe hemorrhage. In these situations, the middle ear should be tightly packed. If this fails, surgical ligation of the internal or common carotid artery may be necessary to prevent exsanguination.

Botma M, Kell RA, Bhattacharya J, Crowther JA. Aberrant internal carotid artery in the middle ear space. *J Laryngol Otol* 2000;114:784 [PMID: 11127152]. (Highlights radiographic findings and clinical presentation of aberrant internal carotid artery.)

Windfuhr JP. Aberrant internal carotid artery in the middle ear. *Ann Otol Rhinol Laryngol Suppl* 2004;192:1 [PMID: 15053213]. (Case series and literature review evaluating the incidence, signs, and management of patients with an aberrant internal carotid artery.)

PERSISTENT STAPEDIAL ARTERY

ESSENTIALS OF DIAGNOSIS

- Usually asymptomatic, but may cause pulsatile tinnitus and hearing loss.
- May be associated with other anomalies and may complicate middle ear surgery.
- Retraction or avoidance may be the most prudent management.

A persistent stapedial artery (PSA) is a rare vascular anomaly of the middle ear. The reported prevalence of 0.48% in cadaveric studies of temporal bones is significantly less than the 0.02–0.05% found in surgical series.

Normally atrophied by 3 months of fetal development, the stapedial artery may persist as a 1.5- to 2.0-mm branch of the petrous ICA. As a result of this anomaly, the middle meningeal artery arises from the stapedial artery, and the foramen spinosum is absent. Although pulsatile tinnitus, conductive hearing loss, and sensorineural hearing loss have been described, most cases are clinically asymptomatic and found incidentally at the time of middle ear surgery. Case series have also noted multiple congenital anomalies associated with PSA, including aberrant ICA, Paget disease, anencephaly, anomalous stapes, anomalous facial nerve, thalidomide deformities, and trisomies 13 and 15.

Although the pathophysiology of these associations is poorly understood, an awareness of its possible existence at the time of surgery remains the most important aspect of treating PSA. Inadvertent transection during exploration of the middle ear may result in profuse hemorrhage. This has been described as a complicating factor for cholesteatoma surgery, stapes surgery, and cochlear implants. Some clinicians have described surgical ligation at the time of exploration, but this poses a theoretical risk of ischemic stroke. Generally, avoidance or retraction of a PSA is advocated.

Silbergleit R, Quint DJ, Mehta BA et al. The persistent stapedial artery. *Am J Neuroradiol* 2000;21:572 [PMID: 10730654]. (Case series and review of persistent stapedial artery, with a detailed discussion of embryology and developmental anatomy.)

CHOLESTEATOMAS

CONGENITAL CHOLESTEATOMA

ESSENTIALS OF DIAGNOSIS

- Commonly present as small pearl in the anterosuperior quadrant of the mesotympanum.
- May result from persistence of fetal epidermoid rests.
- Often asymptomatic and not associated with a history of otitis media, tympanic membrane perforation, or eustachian tube dysfunction (white mass behind normal drum).
- Timely surgical removal is indicated to avoid complications.

General Considerations

Historically, congenital cholesteatoma has been defined as a middle ear cholesteatoma in the presence of an intact tympanic membrane without a history of perforation, otitis media, otorrhea, or otologic surgery. However, subsequent physicians have argued that these findings should not represent exclusionary criteria for congenital cholesteatoma, given the high incidence of middle ear infections or effusions in the general population.

Several features help distinguish acquired from congenital cholesteatoma. Patients with acquired lesions present in the setting of frequent episodes of otitis media, structural pathology of the tympanic membrane, eustachian tube dysfunction, and diseased mastoid cavities. The developing mass is frequently symptomatic, causing otorrhea, otalgia, and hearing loss, and on examination it is found to expand in direct continuity with a tympanic membrane perforation or retraction pocket.

In contrast, congenital cholesteatomas are not associated with a history of recurrent otitis media and develop in the setting of a normal tympanic membrane, a functional eustachian tube, and a well-aerated mastoid cavity. Furthermore, they are often clinically silent and discovered on routine examination.

Pathogenesis

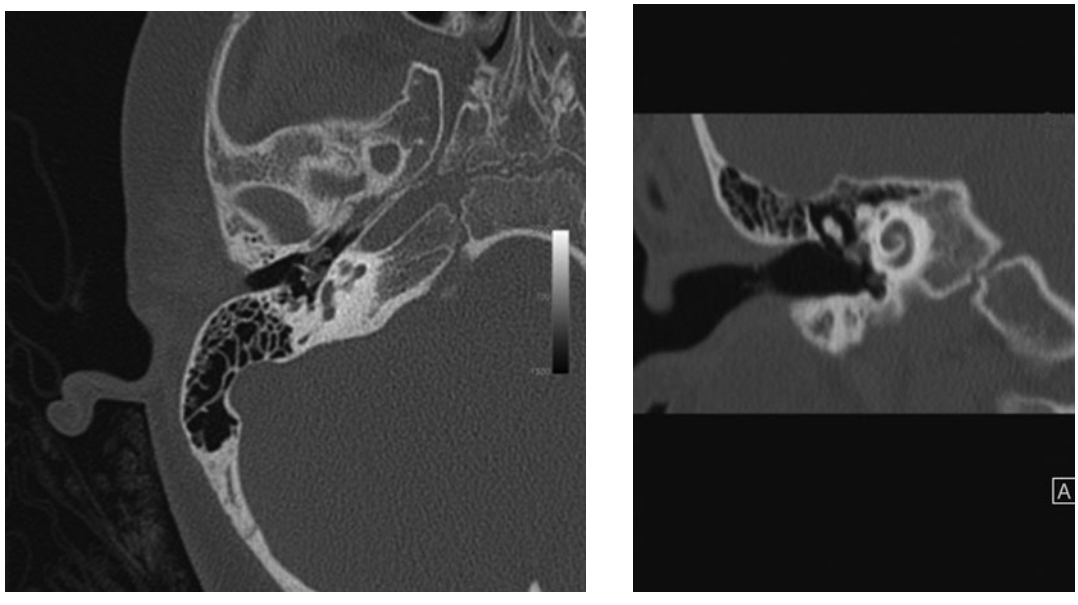
Multiple theories have been put forth to describe the pathophysiology of congenital cholesteatoma. The presence of the epidermoid formation in the anterior epitympanum of the developing fetal temporal bone between weeks 10 and 33 of gestation has been described. This implies that congenital cholesteatoma of the anterosuperior quadrant may result from a failure of normal involution of this epidermoid tissue. This theory, however, does not account for posterior lesions. Proposed etiologies of posterior congenital cholesteatoma include the posterior migration of anterior epidermoid tissue, presence of amniotic cellular material in the middle ear, or ingrowth of external canal epithelium through a defect in the tympanic ring. To date, no single theory has been able to adequately account for the clinical spectrum of congenital cholesteatoma.

Clinical Findings

A. Symptoms and Signs

Lesions occurring "classically" in the anterosuperior quadrant of the mesotympanum account for anywhere from 27% to 67% of all cases. These typically present as small pearls adjacent to the long process of the malleus, with minimal ossicular involvement or hearing loss. Lesions in the posterosuperior mesotympanum, considered a minor variant in older series, develop near the incudostapedial joint and have recently been reported to account for 33–78% of all congenital cholesteatomas. These tend to be larger, with more frequent ossicular involvement and hearing loss. Bilateral congenital cholesteatoma (3% of cases), as well as extension into the epitympanum, sinus tympani, and facial recess, has been described.

Congenital cholesteatoma in any location is often clinically silent for years but may eventually present with a combination of tinnitus, vertigo, 30–40 dB conductive hearing loss, or sensorineural hearing loss. Although classically described as occurring in an ear free of structural pathology, a congenital cholesteatoma presenting at an advanced stage may perforate through the tympanic membrane or obstruct the eustachian tube and predispose to otitis media, making the distinction between a congenital and an acquired lesion difficult. No single symptom complex is diagnostic for congenital cholesteatoma, although the presence of a discrete, round white lesion seen in the anterosuperior quadrant of an otherwise normal tympanic membrane is suggestive. There is a male predilection, with a male-to-female ratio of approximately



A B

▲ **Figure 48–2. (A)** Axial CT Scan of patient with congenital cholesteatoma. Note anterior position relative to malleus. **(B)** Coronal CT scan of same lesion. Note scutum intact, relatively anterior position.

2–3:1. The average age at presentation is 2–4 years for anterior lesions and 12 years for posterior lesions.

B. Special Tests

The diagnosis of a congenital cholesteatoma is clinical and based initially on the history and otoscopic examination. Audiometry is performed to evaluate and document preoperative hearing, and temporal bone CT scans help determine the extent of disease (Figure 48–2). A common finding in these studies is a well-aerated mastoid cavity, in contradistinction to patients with acquired cholesteatoma.

Treatment

The management of congenital cholesteatoma is timely surgical removal. Nonoperative intervention or observation may result in progressive growth of the lesion with progressive erosion of the ossicles. Although multiple surgical approaches have been advocated, the goal of complete extirpation remains universal. Most lesions located in the anterior mesotympanum may be successfully removed via a postauricular transcanal approach. Posterior or extensive lesions may also require an atticotomy or mastoidectomy to enhance exposure. In contrast to acquired cholesteatoma, congenital lesions result in minimal inflammatory reactions or adhesions between the matrix and the middle ear mucosa. A clear plane can be easily developed between the cholesteatoma and the surrounding mucosa of the middle ear or ossicles, especially if prior surgeries have not been performed. Cases in which a clear plane cannot be developed between the tympanic membrane and the cholesteatoma mass may necessitate removing the tympanic membrane and performing a lateral graft tympanoplasty.

The mastoid air cells in patients with congenital cholesteatoma tend to be well pneumatized, and bony resection to the limits of the lesion in cases involving the mastoid cavity often spares the majority of the air cells. Most clinicians, therefore, recommend intact canal wall procedures in patients with congenital cholesteatoma in an effort to prevent creating a large open cavity with its associated lifelong burden of care. Congenital cholesteatoma may be associated with ossicular erosion (most commonly the incus). Ossicular reconstruction can be staged with a "second look" procedure and ossicular reconstruction 6 months later.

Prognosis

Congenital cholesteatomas recur in approximately 30–55% of cases after surgical removal. The incidence of recurrence is notably higher in patients with involvement of the posterosuperior quadrant, attic, or mastoid. The mean time to recurrence ranges from 8 to 14 months in patients with disease limited to the middle ear, and 30 months for patients with more extensive disease. The high rate of recurrence in patients with a history of surgery for congenital

cholesteatoma requires that these patients be followed clinically for a significant period of time.

Nelson M, Roger G, Koltai PJ et al. Congenital cholesteatoma. *Arch Otolaryngol Head Neck Surg* 2002;128:810 [PMID: 12117341]. (Retrospective review to derive a classification system for congenital cholesteatoma and assess whether it is a reliable guide for surgical intervention, reexploration, and hearing outcome.)

Potsic WP, Korman SB, Samadi DS et al. Congenital cholesteatoma: 20 years' experience at the Children's Hospital of Philadelphia. *Otolaryngol Head Neck Surg* 2002;126:409 [PMID: 11997782].

Yeo SW, Sung-Won K, Ki-Hong C, Byung-Do S. The clinical evaluations of pathophysiology for congenital middle ear cholesteatoma. *Am J Otolaryngol* 2001;22:184 [PMID: 11351288]. (Case series with review of the literature and thorough discussion of congenital cholesteatoma.)

OSSICULAR ANOMALIES

ESSENTIALS OF DIAGNOSIS

- May occur in isolation or as part of a syndrome.
- Varying degrees of stable, conductive hearing loss may be present.
- Treatment is individualized based on the ossicular lesion, the patient's overall health, and the degree of hearing loss.

General Considerations

Ossicular anomalies may be unilateral or bilateral and may be associated with anomalies of the external ear (atresia) or the middle ear (facial nerve, stapedial muscle, tendon, or pyramidal eminence), or with a multiorgan syndrome (Treacher Collins or Goldenhar syndrome) (Table 48–1).

Classification

Historically, congenital malformations of the ear have been divided into major and minor types with the latter limited to the middle ear alone. Teunissen's classification system is based on the site of involvement and aids in determining the appropriateness for surgery (Table 48–2).

Surgical experience in patients with stapes ankylosis (Class I) and stapes ankylosis combined with ossicular anomaly (Class II) has been favorable, with a 73% rate of postoperative air–bone gap <20 dB. In contrast, patients with mobile footplates, ossicular discontinuity, epitympanic fixation (Class III), or dysplasia of either the round or oval windows (Class IV) are poor surgical candidates. Finally, multiple ossicular anomalies with subtle but significant variations have been described (Figure 48–3 and Table 48–3).

Clinical Findings

A. Symptoms and Signs

Isolated ossicular anomalies are rare, as is evident from large retrospective reviews of otologic practices documenting only dozens of cases. Approximately 1–2% of patients with congenital conductive hearing loss have isolated middle ear anomalies. In addition to this low incidence, other factors make accurate preoperative diagnosis difficult. With the exception of malleus–incus fusion, hypoplasia of the malleus, and middle ear aplasia, the otoscopic examination is unremarkable. Furthermore, audiometric evaluation demonstrates a similarly moderate-to-severe conductive hearing loss that is fixed over time with most anomalies. These factors mandate a high index of suspicion to ensure both an accurate diagnosis and an appropriate management.

A general examination of the patient is performed to evaluate the overall health and to search for any findings suggestive of a syndrome. Otoscopic examination of patients with anomalies of the malleus or combined ossicular anomalies may demonstrate loss of the tympanic membrane landmarks. Furthermore, the noninvolved ear should be evaluated for possible bilateral disease (25–40%).

B. Specials Tests and Imaging Studies

Audiometry demonstrates a stable moderate-to-severe conductive hearing loss, determines the severity of the air–bone gap, excludes bilateral or sensorineural disease, and can differentiate between ossicular discontinuity and fixation. A speech reception threshold worse than 30 dB has been defined as an indication for surgery. A high-resolution CT scan of the temporal bones may define the ossicular anomaly as well as the anatomy of the facial nerve and inner ear structures.

Treatment

Multiple factors are important in determining a patient's candidacy for operative intervention. Children with multisystem syndromes may be at a considerably higher anesthetic risk if there is involvement of the upper airway, heart, lungs, or kidneys. For children in overall good health, the indications, timing, and ideal method of surgical correction remain a source of controversy. The patient should be assessed for a delay in speech acquisition and the presence of cognitive and learning delays. Deferring surgery until at least the age of 5 is associated with a decreased incidence of otitis media, improved patient cooperation, and more sophisticated audiometric testing.

Surgery for unilateral disease in the setting of a normal contralateral ear can be either performed at the age of 5 or delayed until the patient is able to participate fully in the decision-making progress. Delaying surgery remains a source of controversy since the beneficial effects of binaural hearing on speech and development are continually being discovered. Finally, amplification with hearing aids, as a transition or an alternative to surgery, should be offered to the patient and family.

Table 48–1. Syndromes with Known Middle Ear Anomalies.

Syndrome	Cardinal Features	Middle Ear Anomalies
Apert	Patent cochlear aqueduct, enlarged internal auditory canal, craniofacial dystosis, brachiocephaly, spina bifida, hypertelorism, syndactyly, cleft palate	Fixed stapes
Beckwith–Wiedemann	Exophthalmos, macroglossia, gigantism, auricular deformities, facial nevus flammeus, midface hypoplasia, organomegaly of viscera, genitourinary anomalies, advanced bone age, neonatal hypoglycemia	Fixed stapes
Branchio-oto-renal (BOR) syndrome	Branchial clefts, preauricular pits or cysts, canal atresia, abnormal middle ear, dilated vestibular aqueduct, Mondini dysplasia/cochlear hypoplasia, renal abnormalities including cysts or agenesis	Hypoplastic or fused ossicles, stapes fixation, absent oval window, incus malformation
CHARGE	Coloboma, heart anomalies, choanal atresia, mental retardation, genital anomalies, external and internal ear anomalies	Aplasia or malformation of stapes and incus, aplasia of oval and round windows
Congenital rubella	Inner ear anomalies, mental retardation, microcephaly, ocular abnormalities, thrombocytopenia, cardiovascular deformities, deformities of lower extremities	Fixed malleus head, hypoplasia of incudal ligament, malformation of stapes, fixed stapes, persistent mesenchyme
Congenital syphilis	Malformation of the temporal bone, inner ear anomalies, perforated nasal septum, interstitial keratitis, Hutchinson teeth	Fixed and hyperplastic malleus, spongy long process of incus, malformation of stapes
Crouzon	Premature craniosynostoses, midfacial hypoplasia, ocular and auricular deformities, underdevelopment of periosteal portion of labyrinth, reduced periosteal layer of petrous bone, hard cleft palate, cleft palate	Fixed malleus, malformed or fixed stapes, hypoplasia of middle ear
DiGeorge	Auricular deformities, hypoplastic thymus, aortic arch anomalies, patent ductus arteriosus, thyroid agenesis, acrania, microcephaly, micrognathia, short philtrum, cleft palate or bifid uvula	Atresia of EAC, aplasia of ossicles, aplasia of oval window, hypoplastic facial nerve, absent stapedius muscle, hypoplasia of tympanic cavity
Goldenhar	Unilateral facial hypoplasia, dermoids, lipodermoids, lipomas of eyes, vertebral anomalies, malformation of pinna, micrognathia, cleft lip and palate, laryngeal anomalies	EAC atresia, malformation or aplasia of ossicles, hypoplasia of oval window, chorda tympani, facial nerve
Hurler	Dwarfism, auricular deformities, hepatosplenomegaly, mental retardation, hypertelorism, facial deformities, skeletal deformities, broad stubby fingers, increased body hair, cardiac anomalies	Aplasia of incudomalleal joint, malformation of stapes, fibrous tissue replacement of otic capsule, persistent mesenchyme overlying oval and round window, underdevelopment of mastoid air cells, hypertrophied mucosa
Klippel–Feil	Fused cervical vertebrae, pectoral girdle deformities, auricular deformities, inner ear anomalies, spina bifida, cleft palate	Atresia of EAC, aplasia of ossicles, malformation of malleoincudal joint, fused short process of incus, aplasia of lenticular process, fused long process of incus, fixed stapes, fistula of stapes footplate, aberrant course of facial nerve
Osteogenesis imperfecta	Blue sclerae, multiple bone fractures, skeletal deformities, abnormal tooth dentin, weak joints, cardiovascular and platelet anomalies, macrocephaly	Malformation of stapes head and crura, fragile stapes, otosclerosis
Otopalatodigital	Frontal and occipital bossing, inner ear anomalies, hypertelorism, broad nasal root, small mandible, cleft palate, dwarfism, skeletal abnormalities, mental retardation	Fetal-shaped ossicles, fixed stapes, aplasia of round window

(continued)

Table 48–1. Syndromes with Known Middle Ear Anomalies. *(continued)*

Syndrome	Cardinal Features	Middle Ear Anomalies
Treacher–Collins	Antimongoloid palpebral fissure, coloboma, micrognathia, hypoplasia of malar bones and infraorbital rim, short palate, cleft lip and palate, auricular deformities, clinodactyly and sternal deformities, mild mental retardation	Atresia or stenosis of EAC, aplasia of tensor tympani muscle, stapedial muscle and tendon, malformation of ossicles, aberrant course of facial nerve, hypoplasia of epitympanum and mesotympanum
Trisomy 21 (Down syndrome)	Auricular deformities, hypertelorism, epicanthal fold, protruding tongue, high arched palate, inner ear anomalies, cardiovascular defects, mental retardation	Stenosis of EAC, persistent mesenchyme, wide angle of facial genu, malformation of ossicles, high jugular bulb, poor mastoid pneumatization, eustachian tube stenosis
Turner	XO chromosome, auricular deformities, short stature, sexual gonadal dysplasia, short and thick neck, antimongoloid palpebral fissure, cardiovascular anomalies, renal malformations, mandibular hypoplasia	Underdevelopment of mastoid air cells, malformation of ossicles
VATER	Vertebral defects, anal atresia, tracheoesophageal fistula with esophageal atresia, renal defects, skeletal deformities, cardiac defects	Hypoplasia of facial nerve, chorda tympani, malformation of stapes

EAC, external auditory canal.

MALLEUS ANOMALIES

Although multiple anomalies of the malleus have been described, the incidence is lower than anomalies of the incus or stapes. Hypoplasia or aplasia of the malleus results from a failure of embryogenesis between weeks 7 and 25. Given the common pharyngeal arch origin, hypoplasia of the malleus is often associated with hypoplasia of the incus. An ossicular replacement prosthesis can be placed at the time of middle ear exploration in these cases. Fixation of the head of the malleus represents 80% of all isolated congenital anomalies of the malleus (Figure 48–4). Exploration of the temporal bone in these patients reveals bony bridges between the head of the malleus and the lateral epitympanum in 75–80% of cases. The term "malleus bar" has been used when this bridge connects to the posterior tympanic wall. Malleus fixation, in general, is presumed to result from failure of mesenchymal absorption and is correctable by either laser division of the connecting bridge or resection of the head and placement of a stapes to a manubrium ossiculoplasty prosthesis.

Table 48–2. Teunissen's Classification of Ossicular Anomalies.

Class	Anomaly
I	Congenital stapes ankylosis
II	Stapes ankylosis with ossicular anomaly
III	Ossicular anomaly with mobile footplate
	Ossicular discontinuity
	Epitympanic fixation
IV	Aplasia or dysplasia of round or oval window
	Aplasia or dysplasia with crossing facial nerve
	Aplasia or dysplasia with persistent stapedial artery

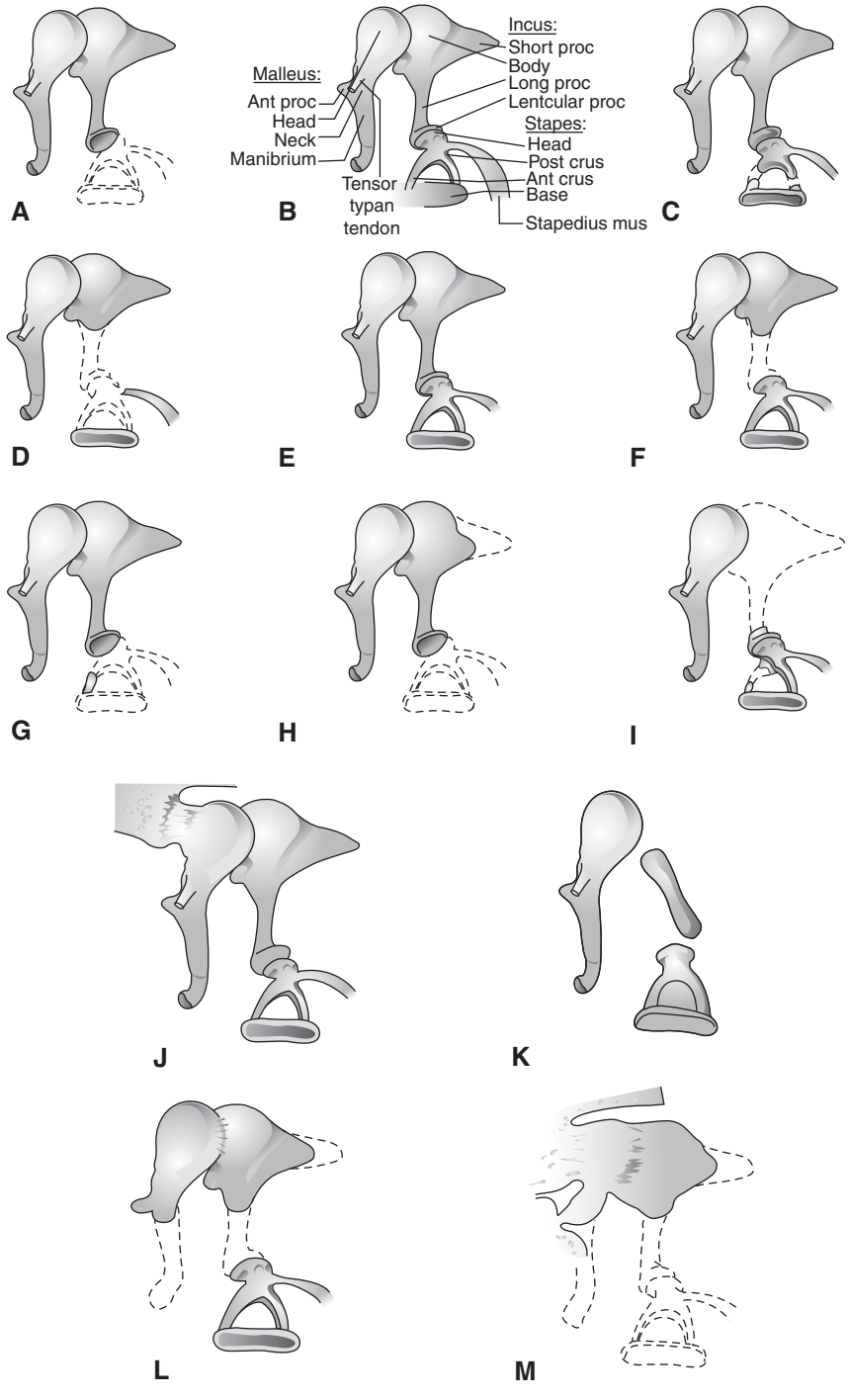
INCUS ANOMALIES

Hypoplasia or aplasia of the incus typically occurs in conjunction with hypoplasia of the malleus but may occur in isolation. Ossicular replacement techniques used for patients with acquired erosion of the incus secondary to chronic otitis media are, similarly, effective for patients with these congenital lesions. The incus is also susceptible to fixation to the epitympanum. Treatment involves sectioning of the bony bridge with a laser.

STAPES ANOMALIES

Isolated congenital anomalies of the stapes represent approximately 40% of all congenital ossicular lesions. The stapes requires the longest period of embryologic development and, therefore, has the greatest potential for malformation. In addition, the stapes is derived from both branchial arch and otic capsule precursors, adding to the complexity of the development of this ossicle.

Numerous anomalies with variable morphologies exist. Congenital stapes footplate fixation is the most common isolated ossicular anomaly and is thought to result from ossification of a portion of cartilage in the annulus of the oval window. Footplate fixation also frequently occurs in BOR syndrome and Apert syndrome. Surgical therapy involves either stapedotomy or total stapedectomy. Stapes surgeons should be cautioned, however, due to a rare syndrome known as X-linked stapes gusher. Surgery in these patients



▲ **Figure 48–3.** Congenital ossicular anomalies. **(A)** Absent stapes and stapedius muscle. **(B)** Anterior stapes fixation and hypoplasia of the oval window. **(C)** Stapes with incomplete anterior and posterior crus. **(D)** Absence of long crus of incus and crural arch of stapes. **(E)** Connective tissue strand replacing long crus of incus. **(F)** Absence of long crus of incus. **(G)** Absence of stapes and stapedius muscle except for small remnant of anterior crus. **(H)** Absence of stapes, stapedius muscle, and short process of incus. **(I)** Absence of anterior crus of stapes and absence of incus except for lenticular process. **(J)** Bony fixation of the lateral attic wall and head of malleus. **(K)** Solid stapes and hypoplasia of incus with only long crus present. **(L)** Conglomerate mass of incus and malleus. **(M)** Absent stapes and conglomerate mass of malleus and incus with fusion to the lateral attic wall. (Reproduced, with permission, from Paparella MM, Shumrick DA, Gluckman JL, Moeyerhoff WL. *Otolaryngology,* 3rd ed. Philadelphia: WB Saunders, 1991.)

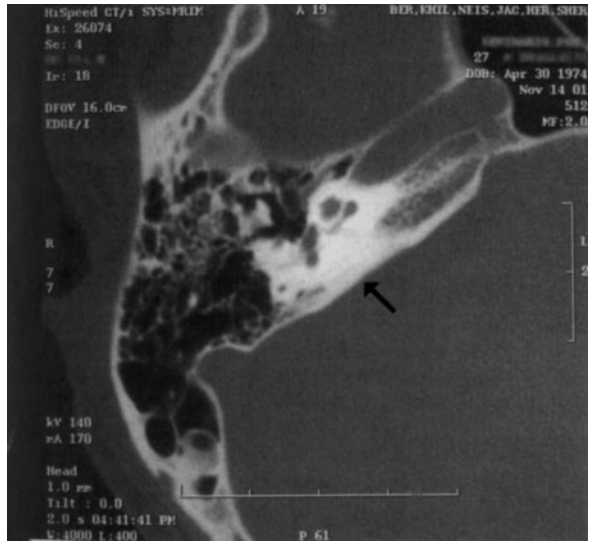
Table 48–3. Congenital Ossicular Anomalies.

Location	Anomaly
Malleus	Hypoplasia or aplasia Head fixation Manubrium fixation Manubrium aplasia Manubrium separation from head Spindle handle
Incus	Hypoplasia or aplasia Long process hypoplasia Lenticular process hypoplasia Fixation
Stapes	Hypoplasia or aplasia Aplasia of the head or crus Hyperplasia Columellar stapes Superstructure fixation Head fixation Obturator foramen obliteration Stapedius tendon ossification Footplate fixation, absence, or doubling Juvenile otosclerosis
Combined	Ossicular agenesis Malleus-incus fusion Incudostapedial joint disarticulation, absence, or fixation Ossicular mass

may lead to a CSF leak as well as a total hearing loss, and as such it should be avoided. Patients are identified by a bulbous internal auditory canal on CT scan as well as an incomplete separation of the basal turn of the cochlea from the fundus of the internal auditory canal.

Although aplasia of the stapes is rare, multiple forms of hypoplasia that include small or absent crura and small, blob-like stapes have been described. The surgical options include total stapedectomy or stapedotomy. In contrast, isolated hyperplasia of the stapes is often an incidental finding that does not require therapy. This anomaly is thought to result from a failure of the resorption and remodeling that occurs during the final stages of stapes development and accounts for up to 20% of all ossicular anomalies.

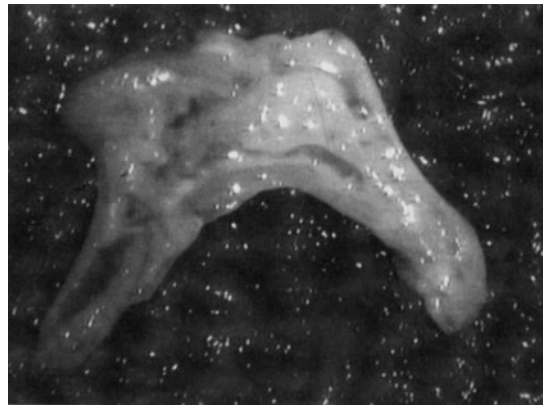
Several crural anomalies have been described, including thin, absent, fused, and angled crura. The crura may also be replaced with a columella-like structure. Laser resection followed by stapes prosthesis replacement is effective in symptomatic crural lesions and columella stapes. The incomplete absorption of mesenchyme may result in bony bridges between the facial canal and either the head or the crus of the stapes that result in a symptomatic conductive hearing loss. Laser division of these bony attachments is effective. Equally effective is laser removal of a bony bar that spans the pyramidal eminence and stapes neck in cases of ossified stapedius tendon.



▲ **Figure 48–4.** Coronal CT scan of a patient with external canal atresia and lateral fixation of the head of the malleus (arrow).

MULTIPLE OSSICULAR ANOMALIES

Ossicular anomalies involving more than one ossicle occur as frequently as isolated anomalies. Complete agenesis of the ossicles occurs in conjunction with multisystem syndromes (eg, DiGeorge syndrome) and is not amenable to reconstruction. Fusion of the heads of the malleus and incus results from a failure of formation of the incudomalleolar joint at 7 weeks and is a common finding in aural atresia (Figure 48–5). Furthermore, the handle of the malleus is typically fixed to the atretic plate and posterior canal wall.



▲ **Figure 48–5.** Fusion of the incus with the head of the malleus.

This placement, in combination with the atresia of the external auditory canal, results in a maximal conductive loss.

Many management strategies have been proposed for appropriate surgical candidates. The incus–malleus complex may be removed and replaced with a partial ossicular replacement prosthesis. Alternatively, a combination of laser and a drill may be used to enlarge the canal and free the ossicular mass from the atretic plate and canal wall. Finally, the ossicular mass may be disarticulated from the stapes, remodeled, and used for reconstruction. All three ossicles may be fused either as a single mass or at specific articulation points (the malleus handle, the incus long process, or the stapes head). Although the treatment of complete ossicular fusion is limited secondary to fusion to the oval window, lesions involving fusion at single articulation points are amenable to reconstruction with a prosthesis.

One-third of all anomalies of the stapes are associated with anomalies of the long process of the incus. The incudostapedial joint forms during week 8 of fetal development as the incus precursor migrates to articulate with the future stapedial ring. The fibrous union of this joint results in a conductive hearing loss of approximately 30 dB and may be transmitted in an autosomal dominant fashion. Treatment options include incus removal and prosthesis replacement, stapedectomy, or cartilage interposition. Other congenital lesions of the incus and stapes include bony fusion and aplasia of the articular joint. Both lesions are amenable to laser remodeling followed by interposition grafts.

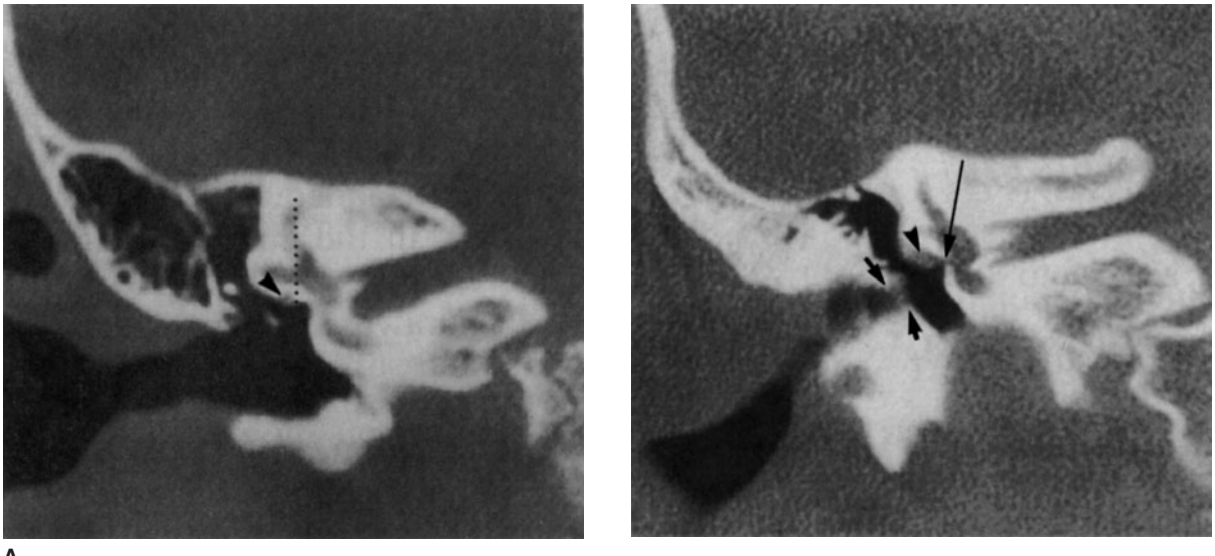
Raveh E, Hu W, Papsin BC et al. Congenital conductive hearing loss. *J Laryngol Otol* 2002;116:92 [PMID: 11827579]. (Results of 67 patients undergoing exploratory tympanotomy for nonserous congenital conductive hearing loss suggest exploring the ear, but in a more realistic, informed way.)

Teunissen EB, Cremers CWRJ. Classification of congenital middle ear anomalies. Report on 144 ears. *Ann Otol Rhinol Laryngol* 1993;102:606 [PMID: 8352484]. (Classic description of congenital ossicular anomalies, including their classification scheme and surgical interventions.)

ANOMALIES OF THE OVAL & ROUND WINDOWS

ESSENTIALS OF DIAGNOSIS

- Abnormal development of the oval window may be associated with failure of stapes insertion, a maximal conductive hearing loss, and abnormal position of the facial nerve.
- Round window aplasia is commonly associated with stapes ankylosis and results in unsuccessful stapedectomy.



A **B**

▲ **Figure 48–6.** Congenital oval window aplasia. **(A)** Coronal CT scan demonstrating obliteration of the oval window by a bony plate and a normal facial nerve canal (arrow) lying lateral to the anterior junction of the anterior and superior semicircular canals (vertical line). **(B)** Partial absence of the oval window (long arrow) in a patient with external canal stenosis (short arrows) and a large horizontal facial nerve (arrowhead). (Reproduced, with permission, from Zeifer B, Sabini P, Sonne J. Congenital absence of the oval window: radiologic diagnosis and associated anomalies. *Am J Neuroradiol* 2000;21:322.)

OVAL WINDOW ANOMALIES

Hypoplasia or aplasia of the oval window is a rare anomaly and may occur in isolation or in conjunction with other anomalies. Failure of the normal association between the primordial oval window niche (the otic capsule) and the developing stapes footplate between the 5th and 6th weeks of development results in aplasia of the oval window and is most commonly associated with anterior displacement of the tympanic segment of the facial nerve. Additional anomalies of the stapes, round window, and inner ear may be present. A maximal conductive hearing loss (60 dB) is usually detected in early childhood, and an absent oval window may be visualized on high-resolution CT scanning (Figure 48–6). Radiographic imaging may also be used to confirm the presence of normal inner ear structures, determine the anatomy of the facial nerve, and detect any associated ossicular anomalies.

The management of oval window aplasia remains controversial. Options include hearing aids, vestibulotomy with prosthesis insertion, fenestration and piston insertion above the aberrant facial nerve, or fenestration of the horizontal semicircular canal. The success of all these different surgical approaches has been mixed. Furthermore, the facial nerve and the inner ear are at considerable risk for injury during these surgical approaches.

ROUND WINDOW ANOMALIES

Aplasia or hypoplasia of the round window may be associated with endemic cretinism and mandibulofacial dysostosis. Non-syndromic cases of round window anomalies are rare, with fewer than 10 reports described in the literature. More commonly, the round window position and size may vary without functional consequence. The significance and management of round window aplasia remain unclear. During week 11 of fetal development, a condensation of connective tissue forms at the future site of the round window. This develops into a cartilage ring that prevents ossification of the round window niche. Failure of the development of this ring results in bony obliteration of the primordial niche.

Round window aplasia is often associated with stapes ankylosis and a 40-dB conductive hearing loss. When stapedectomy is unsuccessful in reversing this hearing loss, the absence of the round window may be diagnosed in retrospect. Although high-resolution CT scans may detect aplasia of the round window, most cases are diagnosed after unsuccessful stapedectomy. Attempts at surgical fenestration have met with poor results and carry a significant risk of sensorineural hearing loss. Therefore, amplification represents the most practical therapy.

Martin C, Tringali S, Bertholon P et al. Isolated congenital round window absence. *Ann Otol Rhinol Laryngol* 2002;111:799 [PMID: 12296334]. (Case report describing the diagnosis of congenital absence of the round window using a high-resolution computed tomography scan.)

Zeifer B, Sabini P, Sonne J. Congenital absence of the oval window: radiologic diagnosis and associated anomalies. *Am J Neuroradiol* 2000;21:322 [PMID: 10696017]. (Radiographic diagnosis and clinical evaluation of oval window aplasia.)

We would like to acknowledge Abtin Tabaee, MD, Michelle Roach, BA, and Vicki Owczarzak, MD for their contribution to this chapter in the previous editions of CDT.

49 Otitis Media

Seema Pai, MD, MPH & Sanjay R. Parikh, MD, FACS

Introduction

Otitis media (OM) is a global health care problem most commonly seen in the pediatric population. Aside from upper respiratory infections, OM is the most commonly rendered diagnosis in the pediatric primary care setting. The majority of children will be diagnosed with at least one episode of acute otitis media (AOM) with rates of incidence peaking at age 2. Various retrospective studies demonstrate a wide berth of incidence, suggesting that 19–62% of children will experience at least one episode of AOM by age 1, and 50–84% of children by age 3.

While mainly considered a pediatric medical problem, OM does present in the adolescent and adult population, albeit at a lower rate. Approximately 3% to 15% of all-comers with OM presenting to otolaryngologists are adults.

Over the past decade, in particular, health care discussions have intently focused on cost and consequences of medical conditions and interventions. While the economic implications of OM are largely abstruse, estimates of a single episode of AOM range from $233 to $1330 USD. When considering these figures, OM (including medical and surgical interventions) in the United States costs $3 to 18 billion dollars annually.

Alsarraf R et al. Measuring the indirect and direct costs of acute otitis media. *Arch Otolaryngol Head Neck Surg.* 1999;125(1). (Description of an economic model using the Otitis Media Diary (OMD) to calculate the indirect and direct costs of a single, medically treated episode of AOM.)

Casselbrant ML, Mandel EM. Epidemiology. In: *Evidence-Based Otitis Media*. BC Decker, 1999. pp. 117–136. (Book chapter summarizing the overall epidemiology and risk factors of otitis media in the United States.)

Gates GA. Cost-effectiveness considerations in otitis media treatment. *Otolaryngol Head Neck Surg.* 1996;114(4):525–530. (A cost-effectiveness analysis of medial and surgical therapies used in the treatment of young children with otitis media.)

Definitions

ESSENTIALS OF DIAGNOSIS

- OM is stratified into two distinct categories: AOM and otitis media with effusion (OME).
- The most common bacterial pathogens that cause AOM are Streptococcus pneumoniae, Haemophilus influenzae, and Branhamella (moraxella) catarrhalis.
- OME is defined as the presence of a middle ear effusion for 3 months or more.

Classification of a disease process is paramount to optimal diagnosis and management. Historically, extensive efforts have been put forth to define OM and its manifestations. Generally, OM refers to an inflammatory process localized to the middle ear cleft. The term "otitis media" can be separated into two distinct categories: AOM and OME.

AOM is characterized by a rapid onset of signs and symptoms, such as pyrexia and otalgia, leading to inflammation of the middle ear. Traditionally, terms such as acute suppurative or purulent OM have been used interchangeably with AOM. Current recommendations state, however, that AOM is the most accurate term used to describe middle ear inflammation in absence of effusion. Recurrent AOM is defined as: three or more episodes in a 6 month period, or four or more episodes in a 12 month period with complete resolution of symptoms between episodes.

OME, as the name suggests, is characterized by an inflammation of the middle ear space with the presence of effusion. As in the case with AOM, myriad terms such as secretory, nonsuppurative, and serous OM have been used synonymously with OME. Because effusions localized to the middle

ear space may be asymptomatic or sterile and/or contain bacteria or even purulence, it is a misnomer to describe all effusions as "secretory" or "serous" or "transudative."

Pathogenesis

The middle ear cleft is a continuous space that begins at the Eustachian tube orifice in the nasopharynx and extends to include the mastoid air cells. The cleft comprises three different contiguous components: the Eustachian tube, the middle ear, and the mastoid air cells (including the petrosa). The middle ear cleft is lined with variable epithelium—ranging from thick, ciliated respiratory epithelium found in the Eustachian tube to the thin, nonglandular cuboidal epithelium in the mastoid cells.

The underlying pathogenesis of all forms of OM (with the exception of cholesteatoma-related OM) is Eustachian tube dysfunction. The main function of the Eustachian tube is to aerate the middle ear space, providing pressure equivalent to atmospheric pressure. Additionally, the Eustachian tube plays a role in mucociliary clearance of the middle ear space and furthermore, prevents nasopharyngeal contents from entering the middle ear. Obstruction of the Eustachian tube, whether it is functional (eg, failure of contraction of tensor veli palatini during swallowing) or anatomic (eg, adenoid hypertrophy), results in the development of OM. Also of note, in patients with OM, there is an increase in the number of goblet cells found in the respiratory epithelium lining the Eustachian tube. While most episodes of AOM are preceded by viral infections, the majority of AOM have a bacterial component. Table 49–1 provides a comparative evaluation of middle ear cultures from children worldwide.

Despite the environmental differences, the results are universal—the most common bacterial pathogens found in AOM are *Streptococcus pneumoniae, Haemophilus influenzae*, and *Moraxella catarrhalis*.

OME has a similar pathogenesis to AOM in that Eustachian tube dysfunction is nearly universal in children with OME as well. OME develops following untreated or unresolved episodes of AOM. Teele et al. found persistent effusion (>30 days) in 40% of children after their first episode of AOM, and continued effusion (up to 3 months) in 10%. Risk factors for AOM and subsequent OME include parental smoking, absence of breast feeding, day care attendance, craniofacial anomalies, adenoid hypertrophy, and allergic rhinitis. All predisposing factors appear to have a deleterious impact on Eustachian tube function.

Bluestone CD et al. Percentage of bacteria from middle-ear aspirates from children with acute otitis media from the United States, Finland, Denmark and Japan. *Ann Otol Rhinol Laryngol Suppl.* 1990;99:43. (A landmark, retrospective, international study examining the bacterial components of middle ear effusions in children with acute otitis media from the United States, Finland, Denmark, and Japan.)

Teele DW et al. Greater Boston Otitis Media Study Group. Epidemiology of otitis media during the first seven years of life in children in greater Boston: A prospective, cohort study. *J Infect Dis.* 1989;160(1):83–94. (A prospective, cohort study examining the epidemiology of acute otitis media and the duration of middle ear effusion in 877 children in the greater Boston area.)

Table 49–1. Percentage of Bacteria from Middle-Ear Aspirates from Children with AOM from the United States, Finland, Denmark, and Japan.

	United States[a] (*n* = 1431 ears) 1980–1985	Finland[b] (*n* = 707 ears) 1977–1978	Japan[c] (*n* = 1277 ears) 1984–1986	Denmark (*n* = 147 ears) 1973
Streptococcus pneumoniae	29.8	33.8	45.9	19.1
Haemophilus influenzae	20.9	8.5	33.4	27.6
Branhamella catarrhalis	11.7	7.2	2.3	—
Streptococcus pyogenes	3.1	2.1	6.3	8.2
Staphylococcus aureus	1.6	5.0	5.0	17.1
Staphylococcus epidermidis	—	11.5	—	—
Other	19.1	3.0	3.9	—
No growth	19.6	39.3	7.2	—

Data from Bluestone CD et al. *Ann Otol Rhinol Laryngol Suppl 1990;99:43.*

[a]From Rohnd D, Wald ER, unpublished data, 1980–1985.

[b]From Karma P and others, unpublished data, 1986.

[c]From Takahara T and others, unpublished data, 1986.

Clinical Presentation

ESSENTIALS OF DIAGNOSIS

- Manifestations of AOM include: otalgia, pyrexia, thickened or bulging tympanic membrane, hearing loss, and otorrhea.
- Manifestations of OME include: persistent hearing loss, dull or immobile tympanic membrane, and flat tympanogram.

Accurate diagnosis of AOM versus OME is becoming increasingly important, especially in the present day challenge of antibiotic-resistant organisms. Diagnosis of AOM and OME can be made by direct visualization of the TM using an otoscope or pneumatic otoscope. The symptoms most often associated with AOM are otalgia, fevers, decreased appetite, upper respiratory infection, and fatigue. In children less than 2 years old, otalgia is evidenced by fussiness, insomnia, and generalized irritability. Since these symptoms are vague and may be attributable to a variety of conditions, symptomatology alone should not be used as sole criteria to render a diagnosis of AOM or OME.

Examination of the TM can be challenging and heavily clinician dependent. Description of otoscopic findings is variable and subjective. It is helpful to consider physical examination of the TM systematically—the use of a mnemonic, "COMPLETES" has been published as a teaching and clinical tool to ensure thorough and methodical examination (Table 49–2).

Otoscopy in AOM classically demonstrates a thickened, hyperemic, immobile TM. As diagnosis can often be made on history and physical exam alone, further studies are not indicated for AOM. OME, in contrast, is often asymptomatic. The most common complaint associated with OME is decreased hearing. Otoscopy classically demonstrates a dull gray- or yellow-tinged, immobile TM. If the TM is clear, bubbles or air fluid levels can be elucidated. Tympanometry and audiometry are complimentary diagnostic tools used in evaluating patients with OME.

Tympanometry is an objective and quantitative way to evaluate TM mobility and middle ear function. It is defined as "the measurement of the acoustic immittance of the ear as a function of ear canal air pressure". The procedure involves placing a probe into the external auditory canal and measuring the amount of sound energy returned. Patients with OME demonstrate flattened tracings on tympanometry indicating fluid in the middle ear space. Table 49–3 depicts examples of different tympanometry tracings.

As mentioned, OME often presents with varying degrees of hearing loss. Therefore, serial audiometry is helpful in establishing a diagnosis of OME. Audiologic testing may include pure tone threshold, speech reception threshold, speech awareness testing, behavioral observation, and auditory brain-stem response (ABR). Conductive hearing loss is most often documented in children with OME.

Table 49–2. COMPLETES: Mnemonic for Otoscopic Examinations.

Color	Gray, white, yellow, amber, pink, red, blue
Other conditions	Fluid level, bubbles, perforation, retraction pocket, atrophic area, otorrhea, bullae, tympanosclerosis, cholesteatoma
Mobility	4+, 3+, 2+, 1+
Position	Neutral, bulging, retracted
Lighting	Battery charged, halogen or xenon bulb
Entire surface	Visualize all quadrants
Translucency	Translucent or opaque
External auditory canal and auricle	Inflammation, foreign body, displacement, deformed
Seal	Appropriate sized speculum Airtight pneumatic system

Kaleida PH. The COMPLETES exam for otitis. *Contemp Pediatr.* 1997;4:93–101. (Describes a detailed and systematic method of observing and documenting otoscopic findings.)

Margolis RH, Henter LL, Giebink GS. Tympanometric evaluation of middle-ear function in children with otitis media. *Ann Otol Rhinol Laryngol* 1994;103:34–38. (Review describing the different types of tympanometry used to evaluate middle ear function. Established that multifrequency tympanograms are more sensitive in identifying sequelae of otitis media than conventional audiometry.)

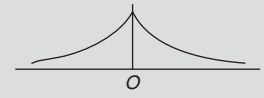
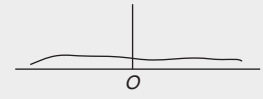
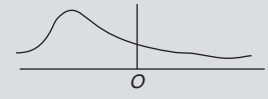
Lalwani AK, Yates PD. Otitis Media. *Current Diagnosis and Treatment in Otolaryngology—Head and Neck Surgery*. McGraw-Hill, 2004, p. 700. (Comprehensive and accessible review of the sciences and clinical practice of otolaryngology-head & neck surgery.)

Management

ESSENTIALS OF DIAGNOSIS

- The basis for medical treatment of AOM is antibiotic therapy
- Amoxicillin remains the first line antibiotic treatment for AOM
- Observation for 48 hours for fever or progressive symptoms is an acceptable alternative to initiating antibiotics

Table 49–3. Types of Tympanograms. (*Current Diagnosis and Treatment in Otolaryngology—Head & Neck Surgery,* 2004; p. 700)

Tympanogram Type	Middle Ear Presure	Typical Appearance of Trace
A	–99 daPa to +200 daPa	
B	No compliance peak	
C	–400 daPa to –100 daPa	

daPa = deca Pascal.

Tympanostomy tubes and adenoidectomy are the surgical treatments of choice for OME.

A. Medical Management

Although most episodes of AOM will resolve spontaneously, the basis of medical treatment in clinical practice in the United States is antibiotic therapy. Several randomized control trials (RCTs) have been conducted comparing antimicrobial therapy versus placebo or no drug as initial therapy for AOM. Antibiotics used in these studies were penicillin or aminopenicillin alone or in combination with sulfisoxazole or clavulanate given for 7 to 14 days. Although various meta-analyses demonstrate only marginal benefit with antibiotic use and earlier resolution of symptoms in some instances, amoxicillin remains as first-line antibiotic treatment for AOM. Specifically, studies found no benefit within the first 24 hours and small benefit at 2 to 7 days. Observation for 48 hours for fever or progressive symptoms prior to initiating antibiotic coverage has also been shown as a safe alternative.

As an adjunctive therapy, using decongestants, vasoconstrictors, or other forms of topical therapy to diminish nasal symptoms did not have an effect on shortening the course of AOM.

The treatment of OME varies from observation with close follow-up in asymptomatic patients to extended courses of antibiotics for symptomatic patients. Review of various RCTs demonstrates that antimicrobial therapy (including but not limited to ampicillin, amoxicillin, trimethoprim/ sulfisoxazole, erythromycin) is indicated in OME. The Agency for Health Care Policy and Research in 1994 recommended a course of antibiotics in children with symptomatic OME followed by a 1-month period observation. If symptoms fail to improve or effusions persist, surgical intervention is indicated. While steroids, decongestants, and antihistamines are all used as adjunctive treatment for OME in the general otolaryngology practice, RCTs do not demonstrate statistically significant benefit. Another topic of discussion in the management of OME is the use of antibiotic prophylaxis. Prophylactic doses typically administered are generally half of the therapeutic dose. Review of the literature showed only one study that demonstrated benefit using sulfisoxazole as antibiotic prophylaxis in a small sample size).

Del Mar C et al. Are antibiotics indicated as initial treatment for children with acute otitis media? A meta-analysis. *Br Med J.* 1997;314:1526–1529. (Meta-analysis demonstrating that early administration of antibiotics provides only modest benefit for acute otitis media. According to the review, to prevent one child from experiencing pain by 2–7 days after presentation, 17 children must be treated with antibiotics early.)

Rosenfeld RM et al. Clinical efficacy of antimicrobial drugs for acute otitis media: Meta-analysis of 5400 children from 33 randomized trials. *J Pediatrics* 1994; 124:355–357. (Meta-analysis review of 33 randomized trials examining the clinical application and efficacy of antibiotics for acute otitis media.)

Spiro DM, Tay K, Arnold DH et al. Wait-and-see prescription for the treatment of acute otitis media: A randomized controlled trial. *JAMA* 2006;296:1235–1241. (A randomized controlled trial conducted in 283 children using the wait-and-see prescription (WASP) method. Using the WASP method substantially reduced unnecessary use of antibiotics in children with acute otitis media in an emergency department setting.)

Stool SE. Otitis media with effusion in young children. *Clinical Practice Guideline Technical Report No. 12 AHCPR Pub No 94-0622.* Rockville, Maryland: Agency for Health Care Policy and Research, Public Health Services, U.S. Department of Health and Human Services; 1994:192–208 (Clinical practice guidelines recommended by the Agency for Health Care Policy and Research in 1994.)

B. Surgical Management

Surgical management of AOM and OME is largely dependent on the impending development of complications as a result of the disease process. AOM is largely a medically managed disease, as discussed above, with antibiotic therapy and often times, spontaneous resolution. However, tympanocentesis and placement of tympanostomy tubes can play a role for refractory cases. Selection of appropriate antibiotic therapy can be enhanced by tympanocentesis (direct transtympanic membrane needle aspiration of middle ear fluid) in immunocompromised patients and patients who fail initial appropriate antibiotic therapy. Typically, tympanostomy tube placement is reserved in the acute setting for those patients who develop complications of AOM (discussed later in this chapter).

The mainstay of treatment for chronic OME is surgical intervention although a wide array of debate focuses on indications. The purpose of surgical intervention is to provide ventilation of the middle ear space and prevent onset of serious OME sequelae, including conductive hearing loss and speech development in the pediatric population. Surgery for OME is recommended for patients with hearing loss and persistent middle ear effusion for 4–6 months. Historically, myringotomy, insertion of tympanostomy tubes, adenoidectomy, and tonsillectomy have been offered as possible surgical treatments for OME. Once commonly practiced, tonsillectomy has been shown to demonstrate little to no benefit on resolution of middle ear effusions. Myringotomy alone, although commonly practiced, does not play a significant role in the modern treatment of OME when considering the cost-benefit ratio of myringotomy alone versus myringotomy with tube placement and risks of anesthesia.

Tympanostomy tubes were first introduced in 1954 by Armstrong and have been the therapeutic treatment of choice for OME. The goal of placement of tympanostomy tubes is to aerate the middle ear space and prevent accumulation of middle ear inflammation and effusion. In effect, ventilation of the middle ear enhances hearing thresholds. Once tympanostomy tubes extrude from the TM, there is no residual clinical benefit.

Adenoidectomy serves an increasingly important role in the effective surgical treatment of OME. Hypertrophic adenoid tissue causes nasal obstruction, mouth-breathing, and similarly, obstruction of the Eustachian tube orifices. Removing large adenoids enhances the patency of the nasopharyngeal airway, relieving the overall pressure in the nasopharynx, in turn allowing improved aeration of the middle ear cleft. Adenoidectomy also reduces distortion of the mucosal lining of the nasopharynx, making it a less hospitable environment for bacterial colonization or nidus of inflammation.

Gates GA et al. Effectiveness of adenoidectomy and tympanostomy tubes in the treatment of chronic otitis media with effusion. *N Engl J Med.* 1987;31:1444–1451. (A randomized, controlled study looking at the effectiveness of surgical intervention in 578 children with otitis media with effusion. The authors concluded that adenoidectomy should be considered when surgical therapy is indicated in children 4–8 years old who are severely affected by otitis media with effusion.)

Inglis AF and Gates GA. Acute otitis media and otitis media with effusion. *Cummings: Otolaryngology: Head & Neck Surgery*, 4th ed. Elsevier, 2005. (Comprehensive, reference textbook in otolaryngology-head & neck surgery.)

Maw AR. Chronic otitis media with effusion (glue ear) and adenotonsillectomy: A prospective randomized controlled study. *Br Med J.* 1983;127:1586–1588. (A prospective, randomized controlled study exploring the effects of adenoidectomy and adenotonsillectomy in 103 children with otitis media with effusion unresponsive to medical treatment. The study demonstrated a resolution of 36–46% of chronic effusions as a result of adenoidectomy.)

Complications

The sequelae and complications of OM are vast, boasting a significant impact on both the pediatric and adult populations. Different types of complications result from AOM and OME as seen in Table 49–4.

1. Complications of AOM—The spectrum of complications resultant from AOM ranges from the more common persistent TM perforation to the infrequent, but more severe intracranial complications. Critical complications of AOM arise in the modern antibiotic era generally due to poor access to medical care, poor compliance, or inappropriate diagnosis and management.

Table 49–4. Complications of Otitis Media.

Acute Otitis Media (AOM)
1. Perforation
2. Mastoiditis
   a. Coalescent
   b. Masked
   c. Chronic
3. Petrositis
4. Facial nerve paresis
5. Labyrinthitis
6. Intracranial complications
   a. Meningitis
   b. Otitic hydrocephalus
   c. Abscess
      i. Epidural
      ii. Subdural
      iii. Brain
   d. Sigmoid sinus thrombophlebitis

Otitis media with effusion (OME)
1. Conductive hearing loss
2. Speech delay
3. Atelectasis
4. Cholesteatoma

2. Tympanic membrane perforation—TM perforation can occur in the setting of AOM from accumulating inflammation and corresponding ischemia of the TM. The vast majority of perforations from AOM heal spontaneously within 48 to 72 hours. Non-healing perforations can lead to long-term sequelae such as conductive hearing loss or otorrhea.

3. Mastoiditis—Acute mastoiditis, the most common intratemporal complication of AOM, occurs due to direct extension of disease from the middle ear cleft to the mastoid air cells. Classically, acute mastoiditis refers to the coalescent type with mastoid bone destruction and possible subperiosteal abscess formation lateral to the mastoid cortex. The patient typically presents with fevers, post-auricular erythema, and tenderness, ear proptosis, and AOM on otoscopy. Computerized tomography (CT) imaging demonstrates loss of mastoid air cell trabeculations, local bone destruction, and presence of soft tissue within the mastoid cavity and middle ear cleft.

If infection escapes through the mastoid tip and tracks down the upper neck along the sheath of the sternocleidomastoid muscle (SCM), an abscess, known as Bezold's abscess, forms just deep to the SCM. Bezold's abscess occurs in older children with fully pneumatized mastoid tips, and in adults with mastoiditis or cholesteatoma. Similarly, when infection extends beyond the mastoid to penetrate the plane adjacent to the posterior belly of the digastric muscle, it is referred to as a Citelli's abscess.

The term "masked mastoiditis" is used to describe granulation tissue and bony erosion of the mastoid in the absence of otorrhea. On otoscopy, the TM appears normal however a focus of infection (not responsive to antibiotics) continues to persist in the mastoid cavity. Patients may experience chronic postauricular pain with only slight tenderness on palpation of the mastoid. Furthermore, CT scan demonstrates localized opacification with an otherwise normal appearing mastoid.

Patients with chronic mastoiditis classically present with purulent otorrhea, dull otalgia, often associated with multiple episodes of AOM, TM perforation, or cholesteatoma.

4. Petrositis—Although exceptionally rare, petrositis is a known complication of AOM. Petrositis occurs when infection spreads within the temporal bone into the petrous apex. The classic triad, or Gradenigo's syndrome, is rare and characterized by retroorbital pain, AOM, and ipsilateral abducens nerve paresis. In conjunction with the clinical triad, diagnosis is confirmed with radiographic findings of bony destruction of the petrous apex.

5. Facial nerve paresis—Facial nerve paresis can occur in the setting of AOM or OME, by two different mechanisms: (1) from the release of locally produced bacteria-mediated toxins or (2) from the direct effect of inflammatory tissue adjacent to the facial nerve as it transverses the mastoid cavity. Detecting the site of lesion can be a challenge especially in the setting of grossly inflammatory diseases such as AOM, cholesteatoma, or mastoiditis. The nerve excitability, maximum nerve excitability, electromyography, and electroneurography may be beneficial in identifying a neurodestructive lesion. MRI with gadolinium can also provide additional information about inflammatory or neoplastic-mediated processes. In this context, the etiology of facial paresis differs when comparing the adult and pediatric populations. In adults, facial paresis most often occurs in the setting of cholesteatoma, whereas in children, AOM will precede the onset of facial paresis.

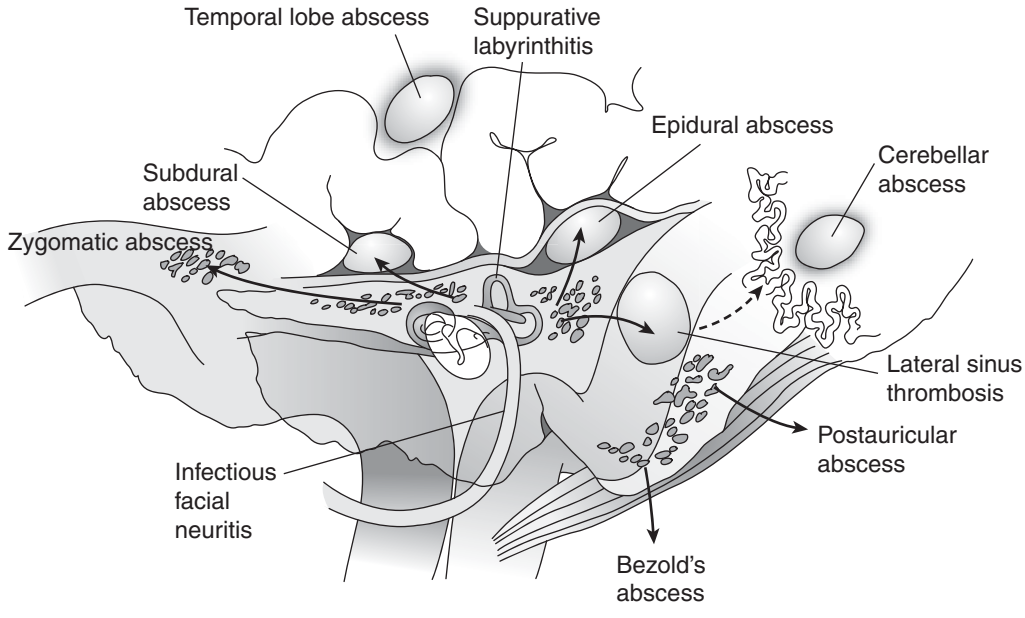
6. Labyrinthitis—Patients with labyrinthitis present with sudden sensorineural hearing loss, severe vertigo, and nystagmus accompanied by nausea and vomiting. In the setting of middle ear infection, bacterial infection can invade through the round window causing acute suppurative labyrinthitis. From the labyrinth, bacteria gain access to the cochlear aqueduct, forming a conduit between the perilymph and the cerebrospinal fluid (CSF) resulting in meningeal infiltration. It is important to diagnose and treat labyrinthitis early as to prevent the subsequent development of meningitis.

7. Intracranial complications—Intracranial complications, including meningitis, encephalitis, otitic hydrocephalus, and abscess, are rare but serious, resulting from severe or neglected AOM (Figure 49–1). In children who develop fever, headache, photophobia, fluctuating mental status, and neck rigidity within hours of AOM, meningitis should be suspected. Furthermore, if patients also present with unilateral of bilateral congenital sensorineural hearing loss and vestibular symptoms, a Mondini malformation should be considered. Mondini malformations allow for communication between the CSF and the middle ear space through the stapes footplate or round window to the vestibule or cochlea. Meningitis secondary to AOM should be treated urgently with a myringotomy.

Otitic hydrocephalus typically presents as headaches and lethargy without evidence of meningeal signs or intracranial abscess. Often associated with papilledema, otitic hydrocephalus is defined as increased intracranial pressure secondary to AOM or OME.

Extradural, subdural, and brain abscesses are all severe, uncommon complications of untreated AOM. The most commonly cultured organisms from these abscesses include streptococci, *Staphylococcus aureus, Streptococcus pneumoniae, Haemophilus influenzae, Pseudomonas aeruginosa, Bacteroides fragilis,* and *Proteus*. Once diagnosed, both brain and subdural abscesses require urgent neurosurgical intervention for drainage. In contrast, extradural abscesses can be approached via mastoidectomy while addressing underlying middle ear disease.

The sigmoid (or lateral) sinus lies in close proximity to the mastoid cavity. If virulent AOM or mastoiditis penetrates the sigmoid sinus, sigmoid sinus thrombophlebitis may occur. Patients present classically with diurnal or "picket fence" fever curves, septicemia, and torticollis. Systemic signs and symptoms occur due to the showering of infected emboli both proximally and distally to the sigmoid sinus.



▲ **Figure 49–1.** Intracranial complications of AOM (Adapted with permission from Harris JP, Kim DW, Darrow DH. Complications of chronic otitis media. *Surgery of the Ear and Temporal Bone* (Editors: JB Nadol & MJ McKenna), 2nd edition. Lippincott Williams & Wilkins, 2005. (Clinically-based reference textbook of otologic surgical management.)

MRI with gadolinium is considered to be the gold standard for diagnosis of sigmoid sinus thrombophlebitis.

Bluestone CD. Definitions, terminology, and classification. In: *Evidence-Based Otitis Media*. BC Decker; 1999. pp. 94–96 (Comprehensive, evidence-based book chapter outlining the historical progression of the definitions, terminology and classification of otitis media.)

Neely JG, Arts HA. Intratemporal and intracranial complications of otitis media. *Bailey & Johnson Head & Neck Surgery—Otolaryngology*, 4th ed. Lippincott, 2006. (Comprehensive, reference textbook in otolaryngology-head & neck surgery.)

8. Complications of OME—As noted above, substantial overlap exists in terms of complications resulting from AOM and OME. In contrast to the acute process, OME exhibits disease chronicity, symptoms expressed over longer periods of time.

9. Conductive hearing loss & speech delay—Conductive hearing loss is a well-studied complication of OME. Hsu et al. report "average duration of effusion in patients with chronic OME as 5.5 months" and "duration of AOM prior to referral as 9.3 months." While OME-associated hearing loss is temporary, it is not fleeting and can have a significant impact on development. Studies suggest that the intermittent, fluctuating hearing loss caused by OME can influence certain aspects of language including articulation, receptive vocabulary, and phonologic awareness.

10. Atelectasis—Atelectasis in the setting of OME refers to either a grossly retracted or collapsed TM. TM retraction occurs when the negative pressure in the middle ear space accumulates, most often as a result of chronic Eustachian tube dysfunction. Over time, a retracted TM may lead to ossicular erosion and conductive hearing loss, which may be salvageable only through surgical repair. In the event that the TM is partially ateletatic, a localized retraction pocket can form leading to an altered migration pattern of squamous epithelium. This disruption of migration patterns predisposes to accumulation of debris and finally, cholesteatoma formation.

11. Cholesteatoma—With long-term tympanic retraction, acquired cholesteatoma development may occur. Acquired cholesteatoma, a consequence of AOM, OME or both, can be further divided into two categories: primary or secondary. Primary acquired cholesteatomas classically arise in the epitympanum adjacent to the pars flaccida component of the ear drum. In comparison, secondary acquired cholesteatomas migrate through a TM perforation into the middle ear. In the setting of chronic Eustachian tube dysfunction, the normal migration pattern of squamous epithelium in the external auditory canal is agitated. Disruption of squamous epithelium can lead to accumulation of debris and cholesteatoma formation. Cholesteatoma will expand locally destroying local bone in its path including the scutum, ossicles, mastoid cavity, tegmen, or otic capsule. This destruction can lead to long-term serious complications including facial paralysis, labyrinthitis, meningitis, and hearing loss.

Nittrourer S. The relation between speech perception and phonemic awareness: Evidence from low-SES children and children with chronic otitis media. *J Speech Hear Res.* 1996;39:1059–1070. (A retrospective controlled study exploring the development of speech perception and phonemic awareness in low-socioeconomic status children and children with otitis media.)

Vernon-Feagans PhD. Impact of otitis media on speech, language, cognition and behavior. In: *Evidence-Based Otitis Media* BC Decker; 1999. pp. 360–363 (Review of prospective studies examining the effects of otitis media on development of speech, language, cognition and behavior over time.)

Chole RA, Sudhoff HH. Chronic otitis media, mastoiditis, petrositis. *Cummings: Otolaryngology: Head & Neck Surgery*, 4th ed. Elsevier, 2005. (Comprehensive, reference textbook in otolaryngology-head & neck surgery.)

CONCLUSION

Otitis media is a complex, global health care problem impacting both the adult and pediatric population. The sequelae of AOM and OME are serious, functionally impairing, and potentially lethal if poorly followed or inadequately treated. Diagnosis and appropriate, timely therapy of AOM and OME are essential for reducing complications and improving overall patient quality of life.

We would like to acknowledge Philip D. Yates, MB ChB, FRCS, and Shahram Anari, MD, MRCS for their contribution to this chapter in the previous editions of CDT.

50 Cholesteatoma

C.Y. Joseph Chang, MD

ESSENTIALS OF DIAGNOSIS

- Squamous epithelium in the middle ear or mastoid
- Otorrhea and conductive hearing loss
- Retraction of the tympanic membrane with a squamous debris collection or a whitish mass behind an intact tympanic membrane
- Testing includes computed tomography (CT) scanning, which can be useful in delineating disease extent but is not critical to making a diagnosis in most cases

General Considerations

A. Acquired Cholesteatoma

Cholesteatoma is the presence of squamous epithelium in the middle ear, mastoid, or epitympanum. The most common form of cholesteatoma is the acquired variety, which is classified as primary and secondary acquired cholesteatoma. **Primary acquired cholesteatoma** is the most common of these types and forms as a retraction of the tympanic membrane. In most cases, the retraction occurs in the pars flaccida, although pars tensa retractions can also occur (Figure 50–1). **Secondary acquired cholesteatoma** forms as a result of either squamous epithelial migration from the tympanic membrane or implantation of squamous epithelium into the middle ear during surgery, such as ventilation tube placement or tympanoplasty.

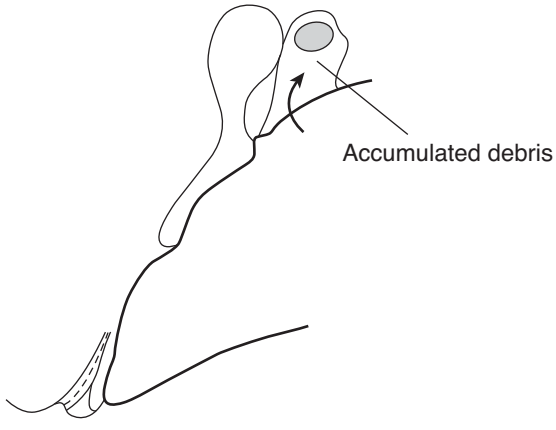
B. Congenital Cholesteatoma

Cholesteatomas that occur without tympanic membrane retraction or implantation of squamous epithelial material are considered to be congenital in origin. This comprises a minority of cholesteatoma cases. It is classically defined as an embryonic rest of epithelial tissue in the ear without tympanic membrane perforation and without a history of ear infection. This definition has been modified in recent years, but essentially it is a condition typically seen in young children without evidence of the acquired type of cholesteatoma.

Derlacki EL, Clemis JD. Congenital cholesteatoma of the middle ear and mastoid. *Ann Otol Rhinol Laryngol.* 1965;74:706 [PMID: 5834665]. (Classic definition of congenital cholesteatoma.)

Pathogenesis

The pathogenesis of primary acquired cholesteatoma remains unclear. Factors that appear to be associated with formation of cholesteatoma retractions of the tympanic membrane include poor eustachian tube function and chronic inflammation of the middle ear, as in chronic otitis media. In theory, chronic negative middle ear pressure leads to retractions of the structurally weakest area of the tympanic membrane, the pars flaccida. Once the retractions form, the normal migratory pattern of the squamous epithelium is disrupted, resulting in the accumulation of keratin debris in the cholesteatoma sac. Chronic infection and inflammation ensue, leading to biochemical changes in the local environment that foster the further growth and migration of the squamous epithelium and increased osteoclastic activity, resulting in bone resorption. The local inflammatory response further inhibits eustachian tube function, increases mucosal edema and mucous secretion, and disrupts the drainage pathways of the temporal bone. This environment also fosters the growth of bacteria, including *Pseudomonas aeruginosa, Streptococcus, Staphylococcus, Proteus, Enterobacter,* and anaerobes, which increase the host's inflammatory response and continue the cycle. It is not understood why only a small percentage of patients with poor eustachian tube function develop cholesteatoma and why some patients form pars tensa retractions rather than the more common pars flaccida retraction.



▲ **Figure 50–1.** Formation of primary acquired cholesteatoma in the pars flaccida portion of the tympanic membrane.

The pathogenesis of congenital cholesteatoma is unclear, but the most prevalent theory is the failure of involution of the epithelioid formation in the middle ear during fetal development. Other theories include metaplasia of the middle ear mucosa and, more recently, direct microretractions of the tympanic membrane near the malleus long process that are self-limited, but leave squamous epithelial rests in the middle ear.

Albino AP, Kimmelman CP, Parisier SC. Cholesteatoma: A molecular and cellular puzzle. *Am J Otol.* 1998;19:7 [PMID: 9455941]. (Review of pathogenesis.)

Sudhoff H, Tos M. Pathogenesis of attic cholesteatoma: Clinical and immunohistochemical support for combination of retraction theory and proliferation theory. *Am J Otol* 2000;21:786. [PMID: 11078064]. (Theory of cholesteatoma pathogenesis.)

Tos M. A new pathogenesis of mesotympanic (congenital) cholesteatoma. *Laryngoscope.* 2000;110:1890 [PMID: 11081605]. (New theory on congenital cholesteatoma origin and review.)

Prevention

There are currently no known methods by which congenital cholesteatoma can be prevented. Secondary acquired cholesteatomas are often iatrogenic and therefore could theoretically be prevented if the surgeon takes all steps possible to prevent implantation of squamous epithelium into the middle ear.

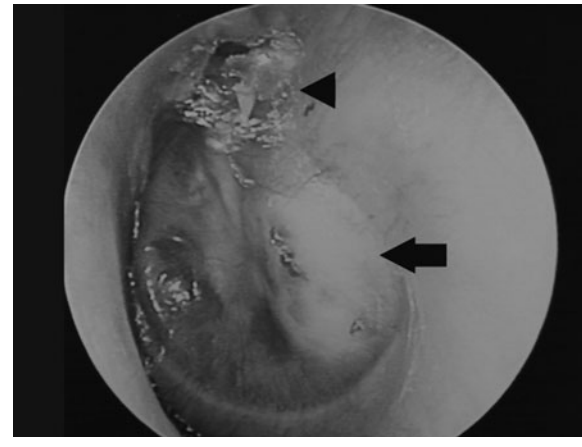
Although the pathogenesis of primary acquired cholesteatoma is not clearly understood, if it is assumed that eustachian tube dysfunction is required for its formation, restoring eustachian tube function should help prevent the formation of this type of cholesteatoma. Unfortunately, there is no way to correct eustachian tube function directly. However, providing secondary ventilation to the middle ear space can reduce the complications related to poor eustachian tube function. This can be accomplished by inserting a ventilating tube. If early progressive tympanic membrane retractions are detected, this intervention could potentially prevent future progression of the disease to cholesteatoma. In addition, the successful control of infection and the inflammatory state of the middle ear, followed by regular débridement of the cholesteatoma sac in an office setting, can prevent future progression of the cholesteatoma in some cases.

Clinical Findings

A. Symptoms and Signs

Patients with acquired cholesteatomas typically present with recurrent or persistent purulent otorrhea and hearing loss. Tinnitus is also common. However, some patients with cholesteatoma may not develop otorrhea for a long period of time. In rare cases, vertigo or dysequilibrium can result from the inflammatory process in the middle ear or, in rare cases, from direct labyrinthine erosion by cholesteatoma. Facial nerve twitching, palsy, or paralysis can also result from the inflammatory process or from mechanical compression of the nerve.

Physical findings are usually diagnostic in cases of acquired cholesteatoma. In primary acquired cholesteatoma, there will be a retraction of the pars flaccida in most cases, and less commonly in the pars tensa (Figure 50–2). Both types of retractions contain a matrix of squamous epithelium, which may or may not be visible, and often keratin debris. Other typical findings include purulent otorrhea, polyps and granulation tissue, and ossicular erosion. In secondary acquired cholesteatoma, the findings depend on



▲ **Figure 50–2.** Photograph of primary acquired cholesteatoma in the pars flaccida portion of the left tympanic membrane. The arrowhead points to retraction. The arrow points to the cholesteatoma sac behind the tympanic membrane.

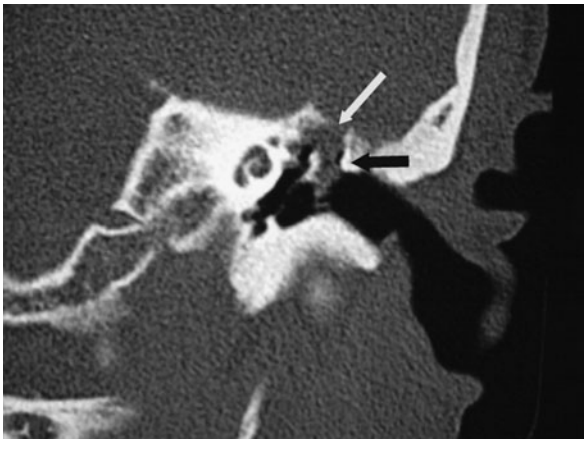
the cause. If the cholesteatoma developed from a tympanic membrane perforation, the squamous epithelial matrix, keratin debris, or both are usually visible through the perforation. If the cholesteatoma developed from either an implantation of squamous epithelium during surgery or a perforation that has closed, the tympanic membrane may in fact appear relatively normal. Once the middle ear cholesteatoma has enlarged to a sufficient size, it becomes visible behind the tympanic membrane. In patients whose tympanic membrane is opaque, further studies, such as imaging, may be required.

Congenital cholesteatomas are usually asymptomatic until the mass grows to a sufficient size that the ossicular chain function becomes disrupted and hearing loss develops. In many cases, the cholesteatoma is noted on the routine ear examination of an asymptomatic child.

In all cases, cranial nerve function, especially that of the facial nerve (CN VII), should be examined. In addition, an office evaluation for nystagmus and balance function should be considered in patients who have any evidence of vestibular dysfunction. A fistula test can be performed, but it has a low sensitivity in detecting labyrinthine fistula.

B. Imaging Studies and Special Tests

1. CT scanning—CT can be performed to delineate the extent of disease. Bone window axial and coronal cuts of 1.5-mm slices or less are ideal. It should be understood that a CT scan usually cannot make a definitive diagnosis regarding the nature of any existing temporal bone disease. CT findings that are suggestive of the presence of cholesteatoma include the erosion of bone, most commonly the scutum and ossicular chain (Figure 50–3). The presence of erosion of the labyrinth is highly suggestive of the presence of cholesteatoma, although neoplasms can also cause this finding. CT scanning cannot differentiate between fluid and tissue and, in particular, cannot distinguish between tissue types. The presence of fluid or soft tissue density in the middle ear and mastoid could indicate the presence of mucus, pus, inflammatory tissue such as granulations or polyps, thickened mucosa, cholesteatoma, neoplasm, encephalocele, or other conditions.



▲ **Figure 50–3.** Coronal CT scan of the left temporal bone, showing pars flaccida cholesteatoma. The white arrow points to cholesteatoma. The black arrow points to eroded scutum.

CT scans are especially useful in patients with a history suggestive of secondary acquired cholesteatoma in which the middle ear cannot be visualized because the tympanic membrane is opaque. In these cases, the amount of inflammatory tissue may be minimal, and the soft tissue density of the cholesteatoma may be identifiable, thereby aiding in the diagnosis. CT scanning is also useful for delineating the extent of disease in congenital cholesteatoma. This imaging modality can assist the surgeon in determining whether a tympanoplasty alone is adequate for treatment or whether a mastoidectomy will also be needed.

Many surgeons find CT scanning useful in planning any surgical intervention. A CT scan can indicate the presence of low tegmen, anterior sigmoid sinus, labyrinthine erosion, ossicular erosion, and petrous apex involvement, all of which can affect the surgeon's approach to the disease. In some cases, facial nerve dehiscence and tegmen erosion can be detected, but these conditions are more accurately determined at the time of surgery. It should be noted that CT imaging is not a requirement prior to surgical intervention, because most of the relevant information that CT scanning provides becomes apparent at the time of surgery. In fact, many surgeons do not routinely obtain imaging unless there are specific indications, such as revision surgery, suspicion of labyrinthine fistula, or the possibility of petrous apex disease.

2. Magnetic resonance imaging (MRI)—Magnetic resonance imaging (MRI) can, in theory, differentiate between tissue types and may therefore aid in the diagnosis of cholesteatoma. In practice, the small confines of the ear and mastoid, and the frequent presence of inflammatory disease, make determination of tissue characteristics difficult using the current technology. However, MRI is useful if a neoplasm or an encephalocele is suspected.

3. Audiometry—An audiogram should be obtained in all cases. Patients with cholesteatoma usually exhibit various degrees of conductive hearing loss, depending on the status of the ear canal, the tympanic membrane, and the ossicular chain. The presence of an otherwise unexplained sensorineural hearing loss should alert the surgeon to the possibility of a labyrinthine fistula, although in most cases, this hearing loss results from a chronic or recurrent inflammatory process.

▶ Differential Diagnosis

In most cases of primary acquired cholesteatoma, the diagnosis is quite clear after obtaining the history and performing

a physical examination. However, diagnostic considerations in patients with recurrent or persistent otorrhea include chronic otitis media without cholesteatoma; otitis externa; malignant external otitis; neoplasms such as squamous cell carcinoma of the ear or other rare tumors, such as adenomas; adenocarcinoma; adenoid cystic carcinoma; and cerebrospinal fluid otorrhea, such as from an encephalocele. If there is any doubt regarding the diagnosis, further workup, such as biopsy, laboratory studies, and imaging, should be considered.

The diagnostic considerations for cases in which the tympanic membrane appears intact or even normal, such as in cases of congenital and some cases of secondary acquired cholesteatoma, can be more problematic. In such children who present with conductive hearing loss, diagnostic considerations include congenital malformation of the ossicular chain, the most common of which is stapes fixation, or ossicular dysfunction resulting from either previous inflammatory disease of the ear or trauma. In adults presenting with normal tympanic membrane and conductive hearing loss, diagnostic considerations include otosclerosis and ossicular dysfunction resulting from previous inflammatory disease of the ear or trauma. A CT scan can be helpful in obtaining a diagnosis in these cases.

Complications

Cholesteatomas result in the continued slow growth of the keratin sac with chronic inflammation and infection in most cases. The major sequelae are bone erosion, which results in erosion of the ossicular chain, and otorrhea. In some cases, cholesteatomas can become complicated over time and result in sensorineural hearing loss, dizziness, facial nerve injury, and suppurative complications such as acute mastoiditis, subperiosteal abscess, sigmoid sinus thrombosis, meningitis, and brain abscess.

Treatment

A. Nonsurgical Measures

The initial goal of treatment for cholesteatomas is to reduce the level of the inflammatory and infectious activity in the involved ear. The mainstays of medical treatment are to remove infected debris from the ear canal, keep all water out of the ears to prevent further contamination, and apply ototopical agents that cover the usual bacterial organisms, which include *P aeruginosa,* streptococci, staphylococci, *Proteus, Enterobacter,* and anaerobes. Commercially available agents such as ofloxacin or neomycin-polymyxin B are usually adequate. If the middle ear is exposed, there is a theoretical danger of causing ototoxicity with the use of agents such as aminoglycosides. This risk has not been studied adequately but appears to be relatively low in cases of chronic inflammation; however, it may be in the patient's best interest to avoid ototoxic agents and instead use agents such as ofloxacin.

Some physicians favor the additional use of topical steroid agents to reduce both the level of inflammation and the volume of any inflammatory tissues that are present. The efficacy of this treatment modality has not been studied adequately, but in theory, the anti-inflammatory effects could be beneficial. However, it is also theoretically possible that steroids may inhibit the local immune responses, allowing progression of the infectious process.

In many cases, the infection fails to subside completely. This situation usually occurs in the presence of a cholesteatoma sac with infected keratin debris that is not effectively treated by any local or systemic agents. However, after surgical treatment, the otorrhea usually resolves.

B. Surgical Measures

1. Treatment goals—The definitive treatment of cholesteatoma should achieve several goals. The primary goal is to create a "dry and safe" ear. Essentially, this means that the processes that are causing bone erosion, chronic inflammation, and infection should be reversed permanently. To achieve this goal, all cholesteatoma matrices must be either removed or exteriorized. Failure to accomplish this usually results in persistent or recurrent disease. If a cholesteatoma matrix is exteriorized, as in cases of canal-wall-down tympanomastoidectomy or atticotomy, the cavity should be designed to be relatively self-cleaning so that it will not be prone to develop chronic otorrhea. A summary of surgical approaches is shown in Table 50–1.

2. Anatomic considerations—Cholesteatoma can involve any area of the middle ear, hypotympanum, protympanum, epitympanum, and mastoid. Since most cases of cholesteatoma arise from a retraction of the tympanic membrane, it follows that most cases involve the middle ear space in some form. Pars flaccida retractions are the most common. These cholesteatomas typically invade Prussak's space, which is the area between the pars flaccida laterally and the malleus neck and the lower portion of the head medially. From here, the cholesteatoma can invade the middle ear inferiorly, the attic, and then the mastoid superiorly.

A. Middle ear—The most common location of cholesteatoma in the middle ear is in the area around the stapes superstructure and incus long process. This area is usually difficult to dissect because of the presence of the facial nerve and ossicular chain. The facial recess, sinus tympani, and posterior hypotympanum are also areas where the surgeon can easily leave behind cholesteatoma because surgical access to these locations is quite limited (Figure 50–4). The remainder of the mesotympanum is usually accessed without difficulty.

B. Epitympanum—After the mesotympanum, the epitympanum is the next most common location for cholesteatoma. The ossicular chain usually obstructs adequate visualization in this area, but removal of the incus and malleus head significantly improves the exposure. The area anterior to the malleus head can harbor cholesteatoma that can escape the

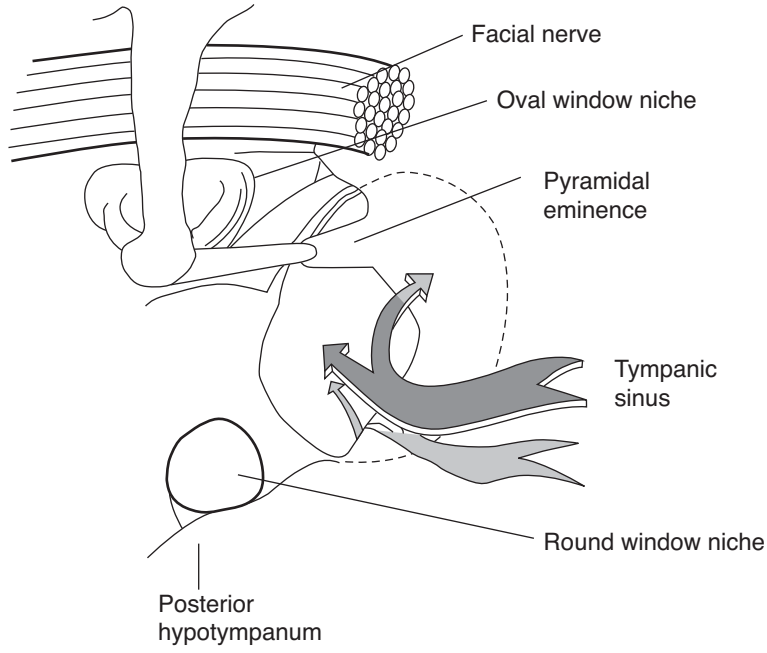
Table 50–1. Overview of Surgical Procedures for Cholesteatoma.

Procedure	End Result	Advantages after Surgery	Disadvantages after Surgery
Tympanoplasty (canal wall up) with mastoidectomy	Ear canal with tympanic membrane	Low risk of otorrhea	Risk of recurrent pars flaccida cholesteatoma
Atticotomy	Ear canal with tympanic membrane and defect into epitympanum	Intermediate risk of otorrhea	Risk of recurrent pars flaccida cholesteatoma
Modified radical mastoidectomy (canal wall down)	Mastoid cavity with tympanic membrane	Low chance of recurrent pars flaccida cholesteatoma	Significant risk of otorrhea
Radical mastoidectomy (canal wall down)	Mastoid cavity without tympanic membrane	Low chance of recurrent pars flaccida and pars tensa cholesteatoma	Significant risk of otorrhea and poor hearing

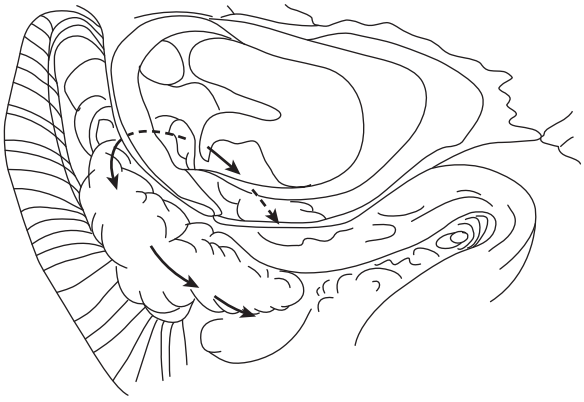
surgeon's attention unless this area is adequately exposed. In some cases, the tegmen is so inferiorly positioned that access to the epitympanum is not adequate without removing the posterior and superior canal wall.

C. Mastoid—The mastoid can contain a large amount of cholesteatoma, but access to the mastoid is relatively straightforward using standard otologic techniques (Figure 50–5). In some cases, a very low tegmen and very anterior sigmoid sinus can make the surgical exposure inadequate, in which case the canal wall will need to be removed. Once the horizontal semicircular canal has been identified, the surgeon will become oriented to important structures such as the facial nerve and the remainder of the labyrinth.

D. Petrous apex—Occasionally, the cholesteatoma invades the petrous apex through various air cell tracts. These include the subarcuate, retrolabyrinthine, supralabyrinthine, retrofacial, and infralabyrinthine tract. Petrous apex cholesteatomas usually cannot be accessed adequately using standard otologic techniques and may require neurotologic dissections, such as a middle fossa craniotomy.



▲ **Figure 50–4.** Diagram showing the anatomy of the posterior mesotympanum. Note the location of the facial nerve and ossicular chain.



▲ **Figure 50–5.** Diagram of the exposure obtained during a canal-wall-up mastoidectomy of the right ear. A cholesteatoma arising from the pars flaccida and extending into the mesotympanum, the epitympanum, and the mastoid is depicted.

3. Surgical techniques

The surgical exposure for cholesteatoma surgery usually requires either a postauricular or an endaural incision.

A. Facial nerve—Care must be taken during dissection of the posterior-superior mesotympanum to avoid injury to the horizontal course of the facial nerve and the stapes or stapes footplate. The facial nerve in the horizontal segment is at greatest risk for surgical injury since dehiscences of the fallopian canal are common here. In general, identification of the horizontal course of the facial nerve in a severely diseased middle ear is easiest from the antrum and attic, just anterior and inferior to the horizontal semicircular canal.

B. Facial recess and epitympanum—Adequate exposure of the posterior-superior mesotympanum usually requires dissection of the facial recess. This can be accomplished with either the canal-wall-up or canal-wall-down tympanomastoidectomy in most cases. The canal-wall-down technique provides reliable access to this area. If the canal wall is kept up, the facial recess exposure needs to be extended into the attic by removing the incus buttress and the incus itself to provide adequate exposure.

The epitympanum is usually best exposed using the canal-wall-down technique, but an adequate exposure is usually obtainable using the canal-wall-up technique as long as there is adequate space between the top of the external auditory canal and the tegmen.

C. Canal wall considerations—The issue of whether a canal-wall-up or a canal-wall-down surgery should be performed is based on various factors. The first consideration relates to the surgeon's training level and experience often influences the choice. The second consideration is the anatomy of the patient's temporal bone. In some cases, adequate exposure can be obtained with either approach, in which case the surgeon may choose the approach based on other factors. In other cases, the canal-wall-down approach is necessary because anatomic features such as a low tegmen or an anterior sigmoid sinus do not allow adequate exposure with any other technique.

The third consideration in surgical approach is the issue of recurrent disease and recidivistic (residual) disease. There are diverse opinions about whether the canal-wall-up procedure leads to a higher incidence of recurrent or residual disease (or both). In general, the canal-wall-down procedure provides superior surgical exposure during chronic ear surgery, but in select cases, the canal-wall-up procedure with appropriate facial recess and epitympanum dissection provides an equivalent level of exposure. There are conflicting reports on whether the incidence of residual disease is higher in canal-wall-up cases, but the results are likely highly dependent on individual surgical techniques and the experience of the surgeon. However, there is compelling evidence that recurrence of cholesteatoma arising from the pars flaccida after the initial surgical treatment (new disease) is significantly higher in patients who have undergone the canal-wall-up procedure. Currently, this type of recurrence can be prevented only by performing canal-wall-down surgery, which essentially exteriorizes potential areas of recurrence such as the attic and the mastoid, or by obliterating these areas if the canal-wall-up or a canal-wall-reconstruction technique is used.

A cholesteatoma recurrence from the pars tensa is a less common problem, but this should be an important consideration, especially if the initial cholesteatoma was of this type. The preventive options include inserting a ventilation tube, placing cartilage grafts to stiffen the tympanic membrane, or obliterating the middle ear space by performing a radical mastoidectomy. The radical mastoidectomy is the most effective technique for preventing pars flaccida retractions, but this approach is not used routinely because patients' postoperative hearing results are uniformly poor.

D. Mastoid cavity—The canal-wall-down tympanomastoid surgery, whether it is a radical or modified radical mastoidectomy, results in a mastoid cavity. There is a substantial amount of data pointing to a relatively high incidence of otorrhea and debris collection in mastoid cavities, even without the presence of residual or recurrent cholesteatoma. There are many suggested causes for this, but the most common causes, excluding cholesteatoma, are anatomic problems such as a high facial ridge and the presence of mucosal tissue within the mastoid cavity. Anatomic problems occur as a result of technical failure by the surgeon in creating an appropriately shaped mastoid cavity. The mastoid cavity must not have any residual bony ledges, which could cause the retention of squamous debris. A meatoplasty that allows for the adequate inspection and cleaning of the cavity in the

office setting is also critical. The formation of mucosal tissue within the mastoid cavity typically occurs when a canal-wall-down procedure is performed in a mastoid that is well pneumatized, and therefore, a canal-wall-up surgery should be considered in these cases.

If the canal wall must be taken down, options include reconstructing the canal wall, obliterating the mastoid cavity with local flaps, such as the temporalis muscle or mastoid periosteum, and covering all exposed areas of mucosa with fascia grafts. The key concept in preventing mucosal overgrowth within the mastoid cavity is to suppress the growth of mucosa by removal or coverage.

E. Staging—Another controversial area in the surgical treatment of cholesteatoma is whether treatment should be staged. The reasons for planning a second surgical procedure include removal of any residual cholesteatoma and the reconstruction of the ossicular chain. Although complete cholesteatoma removal is the goal during the primary procedure, the surgeon, in some cases, may suspect that small pieces of cholesteatoma that are not readily visible could have been left in the surgical field. The most common areas of recurrence include the mesotympanum, in the area of the ossicular chain, and secondarily in the epitympanum. Residual disease in the mastoid is much less common.

Second-look surgery, usually performed 8–12 months after the initial surgery, is often performed after canal-wall-up surgery and less commonly performed after canal-wall-down surgery. The mastoid and epitympanum are highly unlikely to harbor residual cholesteatoma if these areas have been adequately exteriorized during the initial surgery.

A reason for delaying the ossicular chain reconstruction is to prevent adhesion formation around the reconstruction, which may adversely affect the hearing results. If there has been significant mucosal damage in the area of the oval window niche, the surgeon may elect to place a sheet of polymeric silicone (ie, Silastic) or other material to allow the mucosa to heal and form an adequately aerated middle ear space. Once this has been achieved, the surgeon may elect to perform a secondary surgery to reconstruct the ossicular chain. The choice of primary versus delayed ossicular reconstruction is based on the surgeon's experience and the surgical findings.

F. Perilymph fistula—In general, cholesteatoma in the oval window niche is removed toward the end of the procedure so that management of any potential fistula into the vestibule can be instituted without the risk of compromising the repair during further dissection. The repair of an oval window or round window fistula usually consists of patching the defect with fascia or other soft tissue grafts.

Brown JS. A ten-year statistical follow-up of 1142 consecutive cases of cholesteatoma: The closed vs. the open technique. *Laryngoscope.* 1982;92:390 [PMID: 7070181]. (Comparison of results of closed vs. open techniques, showing a difference in recurrence rates.)

Jackler RK. The surgical anatomy of cholesteatoma. *Otolaryngol Clin North Am* 1989;22:883 [PMID: 2694067]. (Review of surgical anatomy.)

Quaranta A, Cassano P, Carbonara G. Cholesteatoma surgery: Open vs. closed tympanoplasty. *Am J Otol.* 1988;9:229 [PMID: 3177606]. (Comparison of results of closed vs. open techniques, showing no difference in recurrence rates.)

Prognosis

There is a high rate of recurrent and residual cholesteatoma disease after primary surgical intervention. Over a time frame of 5 years or more, the combined rate of recurrent and residual disease has been reported to be as high as 40%. Many large series report a rate of 15–25% on follow-up of up to 10 years. The problem seems to be higher in the pediatric population.

The medical and surgical treatments that are available at this time cannot reverse all of the underlying physiologic elements in the ear that were responsible for the initial formation of the cholesteatoma. Chronic infection can usually be corrected, but if the underlying cause is significant eustachian tube dysfunction, this cannot be corrected primarily. The various surgical techniques discussed previously can help reduce the incidence of recurrent disease, but current techniques are not fully effective. Therefore, regular examinations over a course of 10 years or more after definitive treatment remain a critical part of the patient's care.

In most cases, patients are examined in the office setting once a year with the microscope. Symptoms suggestive of recurrent cholesteatoma are similar to those of an initial cholesteatoma, which were described previously. A recurrent cholesteatoma is relatively easy to detect based on the physical examination, at which point prompt treatment should be instituted to prevent both further damage to the temporal bone and other complications.

Parisier SC, Hanson MB, Han JC, Cohen AJ, Selkin BA. Pediatric cholesteatoma: An individualized, single-stage approach. *Otolaryngol Head Neck Surg.* 1996;115:107 [PMID: 8758639]. (Rate of recurrence increases over 10-year follow-up.)

Vartiainen E. Factors associated with recurrence of cholesteatoma. *J Laryngol Otol.* 1995;109:590 [PMID: 7561462]. (Pediatric recurrence rates are higher than those of adults.)

Otosclerosis

51

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ESSENTIALS OF DIAGNOSIS

- Slowly progressive unilateral or bilateral conductive hearing loss
- Most commonly presents by the third and fourth decades
- Family history of otosclerosis
- Normal otoscopic examination or positive Schwartze sign
- Audiogram with Carhart notch and abnormal or absent stapedial reflexes.

General Considerations

Otosclerosis is a disease process unique to the temporal bone and unlike other generalized bone dyscrasias such as Paget disease and osteogenesis imperfecta; it nearly exclusively involves the otic capsule. Disease progression is characterized by abnormal removal of mature dense otic capsule bone by osteoclasts, and replacement with the woven bone of greater thickness, cellularity, and vascularity. While otosclerosis may potentially involve any part of the bony labyrinth, it carries a distinct predilection for the region near the anterior border of the oval window (fissula ante fenestram). When disease involves the annular ligament of the oval window and stapes footplate, a conductive hearing loss (CHL) invariably occurs. Involvement of other parts of the otic capsule may result in sensorineural hearing loss (SNHL) and vestibular symptoms.

The true prevalence of histological otosclerosis is unknown. Estimates reported for clinical disease (ie, clinical otosclerosis) range from 0.5% to 1.0%. However, the incidence of subclinical disease (ie, histologic otosclerosis) in unselected autopsy series has been reported as high as 13%. About 15 million people in the United States have been diagnosed with otosclerosis, and it is considered among the most common causes of acquired hearing loss. Compared to caucasians, otosclerosis is half as prevalent among Asians (0.5%) and one-tenth as common in African-American patients (0.1%). In practice, otosclerosis is seen more often in women than in men by the ratio of approximately 2:1. However, it has been proposed that the incidence may be the same in both sexes and that hormonal influences during pregnancy might cause a more rapid progression in women, bringing them to clinical attention. Symptoms rarely become apparent before late teens, with most patients presenting between the age of 20 and 45.

Declau F, Van Spaendonck M, Timmermans JP. Prevalence of otosclerosis in an unselected series of temporal bones. *Otol Neurotol*. 2001;22(5):596. [PMID: 11568664] (The prevalence of otosclerosis correlated well with the rate of clinically significant disease.)

Lippy WH, Berenholz LP, Burkey JM. Otosclerosis in the 1960s, 1970s, 1980s, and 1990s. *Laryngoscope*. 1999;109(8):1307. [PMID: 10443838] (The audiometric patterns at presentation have changed over the past 37 years.)

Pathogenesis

The otic capsule and stapes form from a cartilaginous anlage, which begins endochondral ossification by the 19th week of embryogenesis and is complete by the end of the first year of life. The vestibular surface of the footplate remains cartilaginous throughout life. Bone turnover, which is normally seen in other parts of the body, does not occur in the "healthy" otic capsule after initial development. However, with otosclerosis there is increased osteoblastic and osteoclastic activity and vascular proliferation. The otosclerotic focus is defined by an area of increased bony turnover and metabolic activity and the term "otospongiosis" is most descriptive of the histologic appearance at this stage of the disease. As the disease stabilizes or "burns out," the normal bone of the otic capsule is replaced with a focus of metabolically quiescent,

dense mineralized bone. The most common location of the otosclerotic focus is the region of the otic capsule anterior to the stapes footplate (the region of the fissula ante fenestram). Fixation of the stapes begins as the lesion spreads to involve the annular ligament. Extension over the footplate is uncommon but may lead to total obliteration of the footplate. Less frequently, lesions may extend into the inner ear resulting in hyalinization of the spiral ligament and SNHL. Rare cases of pure SNHL from isolated cochlear otosclerosis without ossicular involvement have been reported.

The inciting stimulus for the abnormal bone remodeling in otosclerosis is unknown and has been attributed to both genetic and environmental factors. In most cases, the disease is inherited as a simple autosomal dominant trait with incomplete penetrance and variable expressivity. Recent findings suggest an association between the measles virus and otosclerosis; whether the measles virus is a factor that can initiate the otospongiotic process remains to be determined.

Thys M, and Van Camp G. Genetics of otosclerosis. *Otol Neurotol.* 2009;30:1021. [PMID: 19546831] (Discussion of the etiopathogenesis of otosclerosis.)

Clinical Findings

A. Symptoms and Signs

The typical patient with otosclerosis presents with a history of slowly progressive hearing loss that is usually bilateral and asymmetric, although unilateral disease may occur in up to 30% of patients. Patients with CHL including those with otosclerosis may also report improved hearing with background noise, a paradoxical phenomenon known as paracusis of Willis. Hearing deficits typically become apparent when they reach a 25–30 dB loss whereat the patient has difficulty understanding speech. Tinnitus is a common complaint and may be an indication of sensorineural degeneration. Fluctuations in hearing are uncharacteristic but may occur during times of hormonal instability (eg, during pregnancy) and patients rarely have complaints of vertigo.

B. Physical Exam

Otoscopic examination is essential and best performed with an operating microscope. The goal of the exam is to exclude other causes of a CHL, such as cholesteatoma, tympanosclerosis, and middle ear effusion or masses. Even with advanced otosclerosis, the tympanic membrane is normal, the middle ear space is pneumatized, and the malleus should move with pneumatic otoscopy. In active disease, the astute clinician may appreciate a reddish blush (Schwartze sign) over both the promontory and the oval window niche owing to the prominent vascularity associated with an otospongiotic focus.

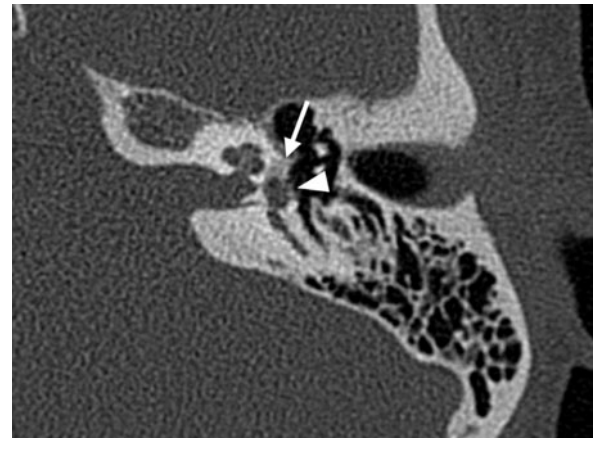
Tuning fork tests (Rinne and Weber) should be carefully performed at 256, 512, and 1024 Hz to confirm the findings of the audiogram. Weber testing should lateralize to the ear with the greatest conductive deficit and a negative Rinne test (bone conduction greater than air conduction) at 512 Hz usually indicates an air-bone gap of at least 25 dB (Table 51–1).

Table 51–1. Classic Audiometric Findings.

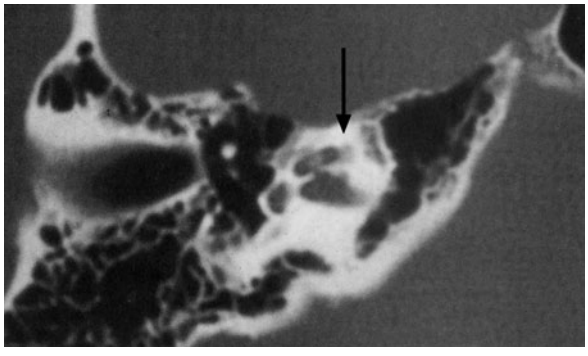
Low-frequency CHL
Carhart notch
Type A or A_s (shallow) tympanogram
Biphasic or absent reflexes
Negative Rinne test (BC > AC)

C. Imaging Studies

1. Computerized tomography (CT) scanning—High-resolution CT scanning (less than 1 mm slices) provides excellent visualization of the anatomy of the middle ear and otic capsule and for this reason is the initial imaging modality of choice when the diagnosis is in question. It is valuable in assessing the pathology of the oval window and footplate, and the extent of otic capsule involvement and may also be helpful in identifying contralateral subclinical disease. CT scanning may show subtle areas of demineralization, which are typically located just anterior to the oval window (Figure 51–1), as well as thickening of the footplate. In a recent study examining 209 cases of otosclerosis, 95.8% of patients having confirmed otosclerosis had identifiable preoperative findings on CT. With cochlear involvement, there is a demineralization of the otic capsule (Figure 51–2), which yields the so-called halo sign or double ring sign seen on CT as a low-density zone outlining the basal turn of the cochlea.



▲ **Figure 51–1.** High-resolution axial CT of the left temporal bone demonstrating a focal area of demineralization (arrow) in the region of the anterior oval window (triangle) termed the fissula ante fenestram.



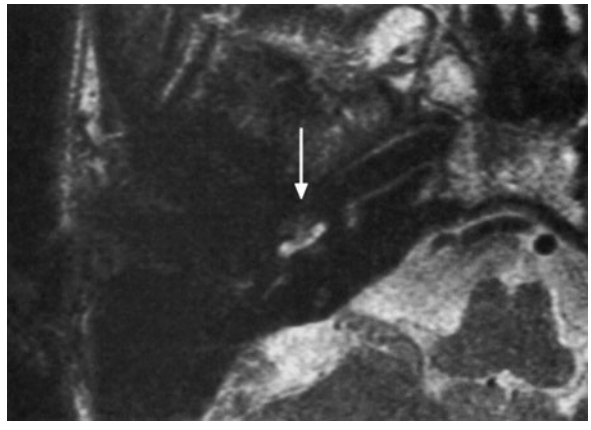
▲ **Figure 51–2.** Axial CT scan demonstrating an area of radiolucent demineralization of the otic capsule (arrow).

In the sclerotic phase of disease or after fluoride therapy, remineralization may occur and CT findings may be indistinguishable from the normal otic capsule. A CT scan is not necessary in most cases but should be considered when the patient has vertigo, SNHL, poor word recognition or if there is a concern for superior semicircular canal dehiscence syndrome. A CT scan is routinely obtained in pediatric patients given the extremely low prevalence in this age group and because of the higher risk of otic capsule and temporal bone malformations.

2. Magnetic resonance imaging (MRI)—MRI provides very limited information regarding otic capsule pathology and is not obtained for routine cases of otosclerosis. In patients with an atypical presentation (pediatric onset, vertigo, SNHL) MRI may detect congenital anomalies of the labyrinth, fibrosis within the cochlea and can exclude retrocochlear pathology, such as an acoustic neuroma. During active disease, T1-weighted images show a loss of normal signal void from the otic capsule. Soft tissue or intermediate signal density may be noted in or around the otic capsule, and contrast-enhanced T1-weighted images can show enhancement of the pericochlear otic capsule. T2-weighted images may be beneficial for preoperative cochlear implant evaluation; a reduction or loss of the normal fluid signal from the membranous labyrinth depicts intracochlear fibrosis or bone deposition, which may hinder full electrode insertion (Figure 51–3).

D. Special Tests

Given the relatively normal exam findings, audiometric testing is one of the most important tools in evaluating a patient suspected of having otosclerosis. Testing patients who have a mixed hearing loss or far-advanced otosclerosis can be problematic because of masking dilemmas and audiometer limits. An experienced audiologist is invaluable in providing accurate and complete information on this type of testing.

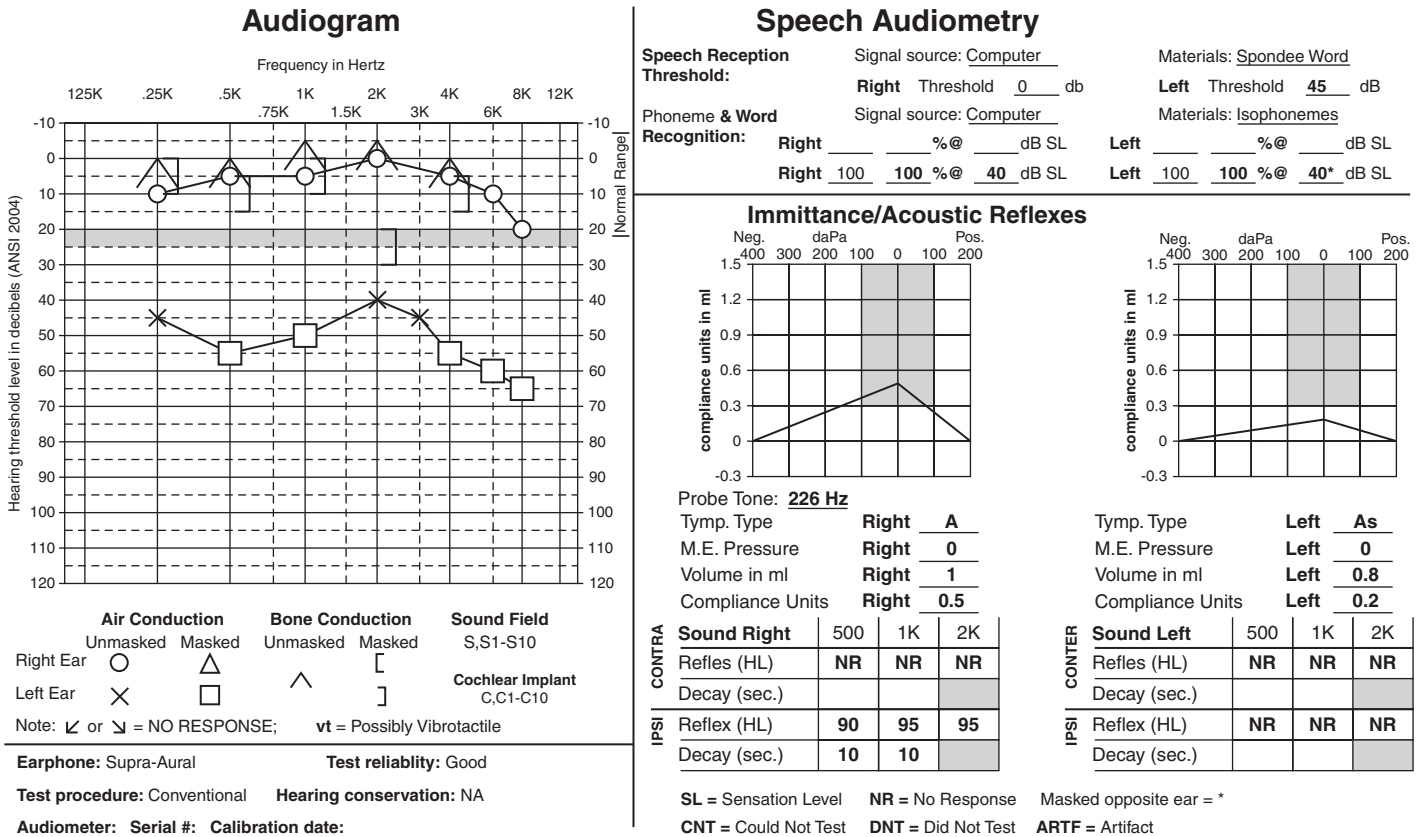


▲ **Figure 51–3.** Axial T2-weighted scan demonstrating the lack of normal fluid signal from the cochlea due to inflammation or obliteration (or both) of the lumen (arrow). This scan correlates fairly, closely, and anatomically to the axial CT scan of the same patient presented in Figure 51–2.

1. Pure-tone audiometry—On pure-tone audiometry, patients with early otosclerosis present with progressive low-frequency CHL. As otosclerosis spreads to involve the entire stapes, an increase in mass compounds the progressive increase in stiffness, resulting in (1) progression of loss in the high frequencies, (2) a gradual widening of the air-bone gap, and (3) a flat audiogram configuration. In the absence of SNHL, pure conductive loss seen with a completely fixed stapes are limited to a 60 to 65 dB hearing level with a maximum air-bone gap across the frequency range. As the disease spreads to involve the cochlea, bone conduction thresholds increase, resulting in a mixed hearing loss in which most of the conductive components are confined to the low frequencies. Decreased bone conduction levels in high frequencies usually represent a true SNHL.

The hallmark of bone conduction thresholds in otosclerosis is the Carhart notch (Figure 51–4). This is characterized by the elevation of bone conduction thresholds of approximately 5, 10, and 15 dB at 500, 1000, and 2000 Hz, respectively. The Carhart notch is thought to result from the disruption of normal ossicular resonance, which is approximately 2000 Hz. It is therefore a mechanical phenomenon and not a true reflection of cochlear reserve since it reverses after successful surgery (see Table 51–1).

2. Tympanometry—The gradual stiffening of the ossicular chain produced by progressive stapes fixation leads to specific patterns of change on tympanometry. Because middle ear aeration is not affected by otosclerosis, patients with early- and mid-stage disease characteristically have a normal Type A tympanogram. Progressive stapes fixation results in a Type A_S (A-shallow) tympanogram (Figure 51–4).



▲ **Figure 51–4.** Audiogram demonstrating a CHL with a characteristic elevated bone threshold near 2000 Hz (Carhart notch). A type As tympanogram is caused by decreased tympanic membrane compliance. This pattern is often seen in otosclerosis but other conditions such as tympanosclerosis can mimic this finding.

3. Acoustic reflex (stapedial reflex)—One of the earliest signs of otosclerosis is an abnormal acoustic reflex pattern often preceding the development of an air-bone gap. In the normal hearing ear, the configuration of the acoustic reflex pattern is one of a sustained decrease in compliance owing to the contraction of the stapedial muscle that lasts the duration of the stimulus. In contrast, with early otosclerosis a pathognomonic biphasic "on-off" pattern characterized by a brief increase in compliance at the onset and at the termination of the stimulus occurs. With disease progression, a reduction in the reflex amplitude is seen, followed by elevation of ipsilateral, then contralateral thresholds, and finally, the disappearance of the response. The most common finding at presentation is absent reflexes.

Goh JP, Chan LL, Tan TY. MRI of cochlear otosclerosis. *Br J Radiol.* 2002;75(894):502. [PMID: 12124236] (Cochlear otosclerosis can be diagnosed on MRI scans.)

Lagleyre S, Sorrentino T, Calmels MN, Shin YJ, Escudé B, Deguine O, Fraysse B. Reliability of high-resolution CT scan in diagnosis of otosclerosis. *Otol Neurotol.* 2009;30(8):1152. [PMID: 19887979] (HRCT is 95% sensitive for identifying otosclerotic lesions.)

Lopponen H, Laitakari K. Carhart notch effect in otosclerotic ears measured by electric bone conduction audiometry. *Scand Audiol Suppl.* 2001;(52):160. [PMID: 11318454] (Conventional and electric bone conduction testing both demonstrate the Carhart effect.)

Differential Diagnosis

The diagnosis of otosclerosis may be strongly suspected based on the history, physical exam, audiometric findings, and CT scan. However, the diagnosis is confirmed at the time of surgery or upon histologic study of the temporal bone. Other lesions that may cause a CHL are numerous (Table 51–2).

Table 51–2. Lesions That May Cause CHL.

Tympanic Membrane Lesions
Tympanic membrane perforation
Tympanosclerosis
Middle and Inner Ear Lesions
Otitis media with effusion
Chronic adhesive otitis media
Cholesteatoma
Ossicular discontinuity
Malleus or incus fixation
Congenital footplate fixation
Middle ear tumor
Superior semicircular canal dehiscence
Systemic Connective Tissue and Bone Diseases
Paget disease
Osteogenesis imperfecta (van der Hoeve syndrome)
Ankylosing rheumatoid arthritis

Treatment

Patients with otosclerosis may be managed by (1) observation, (2) pharmacologic therapy, (3) amplification, and (4) surgery or a combination thereof. The advantages and disadvantages of each should be discussed with the patient to guide informed consent.

A. Observation

Observation is the most inexpensive and least risky option. It is often the strategy preferred for patients with unilateral disease and those with a mild CHL. If the patient is not troubled by the degree of hearing loss, then no intervention is indicated and audiograms are usually obtained on yearly basis. The natural history of disease progression would predict further hearing loss over time and ultimately this might prompt intervention.

B. Nonsurgical Measures

Therapeutic strategies to prevent the progression of otosclerosis have been directed toward the suppression of bone remodeling with fluorides and bisphosphonates. However, the efficacy of these agents has not been definitively proven and otologists vary widely in their recommendations regarding their use.

1. Sodium fluoride therapy—Fluoride reduces osteoclastic bone resorption and increases osteoblastic bone formation. Together, these actions may promote recalcification and reduce bone remodeling in actively expanding osteolytic lesions. Sodium fluoride is also thought to inhibit proteolytic enzymes that are cytotoxic to the cochlea and that may lead to SNHL.

Many otologists recommend the use of sodium fluoride in patients with new-onset otosclerosis, rapidly progressive disease, or inner ear symptoms such as SNHL and dizziness. The treatment is usually continued for 1–2 years. Patients with cochlear otosclerosis may be treated for longer periods of time or even indefinitely.

2. Bisphosphonates—Bisphosphonates are potent antiresorptive agents that are useful for the prevention and treatment of osteoporosis and other conditions characterized by increased bone remodeling. They have been widely used in the treatment of osteoporosis and hold some promise in controlling otosclerosis. Following oral intake, bisphosphonates are incorporated into the bone, where they inhibit the osteoclastic activity. The most promising bisphosphonates in clinical use include alendronate, etidronate, risedronate, and zoledronate. These bisphosphonates potently inhibit bone resorption without significantly affecting bone deposition.

3. Amplification—Most patients with otosclerosis have normal cochlear function with excellent speech discrimination and are therefore good hearing aid candidates. Before proceeding with surgery, patients should be encouraged to try a hearing aid (or aids). Some patients become successful

hearing aid users and can therefore avoid surgery and its risks. However, although there is little risk to the patient with hearing aid use, there are some significant disadvantages when compared with the result of a successful surgery. The disadvantages include a poorer sound quality, cosmesis, cost, maintenance requirements, being able to hear only when the aid is in use, occlusion effect, and potential discomfort. In practice, most patients with good sensorineural reserve prefer to have surgery.

Patients with a severe to profound mixed hearing loss may require surgical correction of the conductive loss in order to gain benefit from a hearing aid. For patients who gain limited benefit from conventional hearing aids cochlear implantation is an effective alternative.

C. Surgical Measures

1. Indications for surgery—Most patients with CHL due to otosclerosis can be treated surgically (Table 51–3). The average patient with otosclerosis and a bone conduction level of 0–25 dB in the speech range (250–4000 Hz) and an air conduction level of 45–65 dB is a suitable candidate for surgery; an air-bone gap of at least 15 dB and speech discrimination scores of 60% or better are preferred. Clearly, those with a larger preoperative air-bone gap have more to gain from surgical intervention. If bilateral disease is present, generally the poorer hearing ear should be chosen. If the patient is a candidate for bilateral surgery, the poorer ear should undergo surgical correction first. It is recommended that the surgery on the contralateral ear be delayed at least 6 months to allow the patient to adjust to the first ear and assure stability of the hearing result.

A subset of patients with a severe-to-profound mixed hearing loss have been referred to as having far-advanced otosclerosis. In such cases, the otosclerotic process has progressed to the point where there is minimal to no detectable air conduction threshold and bone conduction is difficult to interpret at high levels because of vibrotactile sensations. Many such patients have been successfully treated with stapedotomy with postoperative amplification. Patients who do not gain sufficient benefit with amplification should be considered for cochlear implantation.

Table 51–3. Contraindications to Surgery.

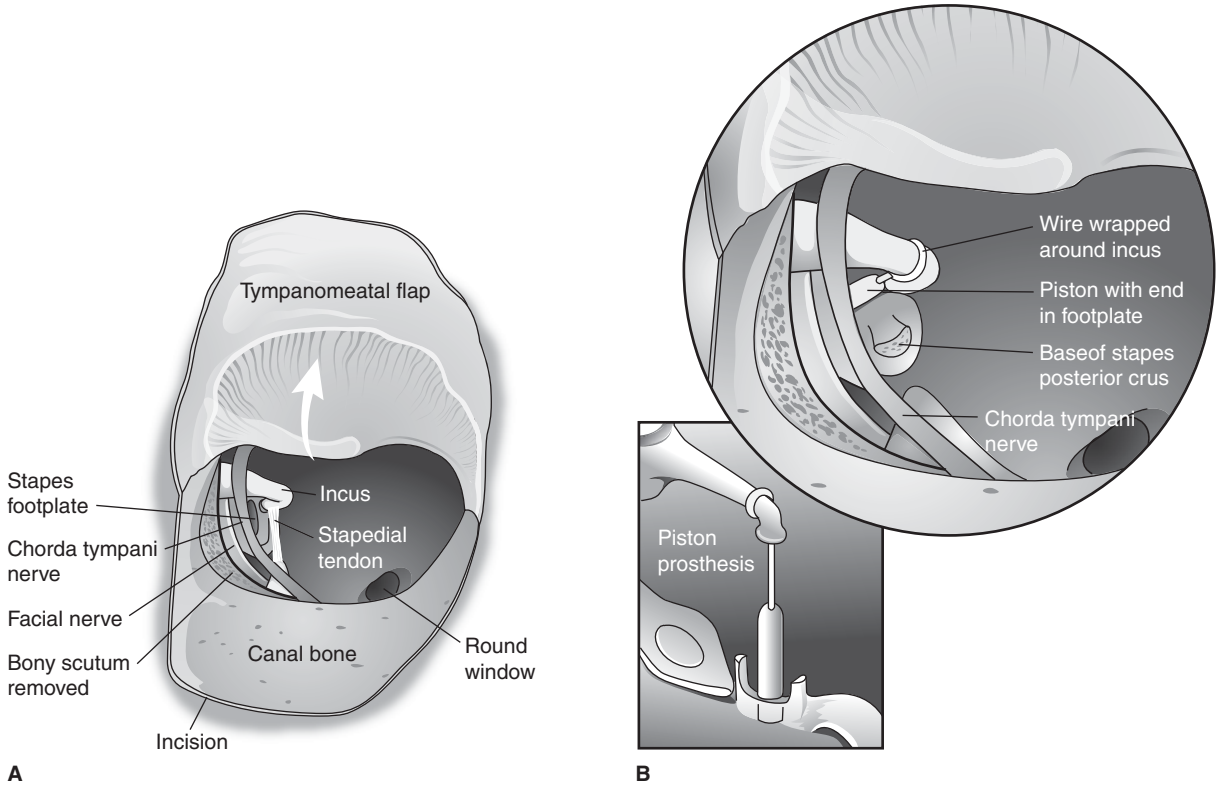
1. Active otitis externa or otitis media.
2. Perforated tympanic membrane.
3. An only-hearing ear that does well with amplification.
4. Presence of vertigo and clinical evidence of labyrinthine hydrops.
5. Occupational considerations. Surgery may be inadvisable in individuals whose occupation or activities demand considerable physical strain or precise balance (eg, pilots, scuba divers, and construction workers).
6. Inner ear malformation.
7. Patients with unrealistic expectations.

2. Preoperative counseling—Surgery for otosclerosis is an elective procedure and should be preceded by a thorough explanation of all treatment alternatives. With refined techniques and new technologies, excellent outcomes (air-bone gap closure of less 10 dB) should be expected in over 90% of cases; however, the patient must be informed about the potential for short-term and long-term failure, the possible need for revision surgery and potential complications. In the long term, patients with otosclerosis lose inner ear function at a more rapid rate than the general population, and they are therefore more likely to eventually need a hearing aid even despite a successful surgery.

3. Preoperative considerations—Surgery may be performed under local or general anesthesia depending on the preference of both the patient and the surgeon. There are several advantages to local anesthesia. (1) The patient's hearing can be tested after prosthesis placement by repositioning the tympanic membrane and either talking with the patient, performing tuning fork tests or even abbreviated intraoperative audiometry. (2) If the patient complains of vertigo during the procedure, the surgeon can alter his or her technique to reduce vestibular irritation. (3) The patient can avoid the postoperative nausea that often accompanies general anesthesia; the newly reconstructed ear is therefore not subjected to the potential extreme pressures associated with arousal from anesthesia. Despite these potential advantages the use of a general anesthetic is preferred by many surgeons. Patients operated under local anesthesia may experience pain, become anxious, and move unpredictably resulting in a more difficult and risky surgery.

4. Surgical technique—Over the years there have been numerous advancements that have led to the currently employed surgical strategy. Many subtle variations of technique are used by surgeons but the basic concept and steps of the procedure are similar.

After adequate cleaning of the ear and administration of both a local anesthetic and a vasoconstrictive agent, a tympanomeatal flap is elevated to expose the middle ear space. If the stapes cannot be well visualized, the scutum is removed with a curet or drill. The ossicular chain is inspected and palpated to confirm the diagnosis of otosclerosis. Once the diagnosis is made, there is considerable variation in how a surgeon can handle the stapes superstructure and footplate. Typically, the incudostapedial joint is separated, the stapes superstructure removed and either a small fenestra stapedotomy or a total stapedectomy is performed, and the prosthesis is placed from the incus through the opening into the vestibule (Figure 51–5). The mobility of the prosthesis is assessed by gentle palpation of the malleus. Tissue or blood is used to seal the area around the prosthesis, and the tympanic membrane is repositioned. If surgery is performed under local anesthesia, intraoperative hearing improvement can be confirmed at this point by whispering in the patient's ear, the use of tuning forks or even abbreviated intraoperative audiometric testing. Most surgeons allow the patient to return home the day of the surgery.



▲ **Figure 51–5.** **(A)** An intraoperative view is shown of a right middle ear after elevating and reflecting the tympanomeatal flap. Bone may need to be curetted or drilled away in order to offer the surgeon a view including the long process of the incus, the anterior and posterior crus of stapes, and the footplate. **(B)** After removal of the stapes suprastructure a small fenestra stapedotomy is made with a drill or laser and a prosthesis is connected to the long process of the malleus with the distal piston positioned just into the vestibule through the stapedotomy.

5. Laser use—Lasers are commonly used in otosclerosis surgery. The cited advantages of laser use are an improved ability to prepare a bloodless fenestra, precise ablation of the footplate, and a reduced risk of footplate subluxation. Lasers are also used to generate heat to activate shape memory or self-crimping Nitinol prostheses. Various types of lasers have been safely used, including the CO_2, KTP, and argon.

6. Cochlear implantation—Patients with severe to profound hearing loss secondary to otosclerosis usually derive excellent benefit from cochlear implantation. However, implantation can be complicated by ossification or soft tissue fibrosis within the cochlea that may preclude a routine full electrode insertion. Preoperative imaging should alert to the surgeon to this possibility and the need for more advanced surgical maneuvers such as drilling the basal turn, placement in the scala vestibuli or other modification of the standard insertion technique.

After device activation there is a reported higher incidence of facial nerve stimulation from current spread through the otosclerotic bone. Reprogramming the device and eliminating the offending channels can usually eliminate this undesirable side effect. In a more recent study, increased speech perception outcomes were associated with less severe signs of otosclerosis on CT scan, full insertion of the electrode, little or no facial nerve stimulation, and a limited need for channel inactivation.

7. Revision surgery—Most patients should be encouraged to try a hearing aid before a revision because of the increased risk of SNHL with the second procedure. Only experienced stapes surgeons should perform revision surgery. The reasons for failure of the initial surgery can include incus necrosis, displacement of the prosthesis from the incus or oval window, insufficient stapedotomy size, and reobliteration of the oval window. It is also important to consider the possibility of previously unrecognized diagnosis such as malleus or incus fixation or superior semicircular canal dehiscence syndrome. Because the risk of hearing loss is higher in revision surgery, it is advisable to approach the

surgery with an idea of exploring the ear and proceeding with the revision surgery only if it appears favorable.

Patients with SNHL are less likely to benefit from revision surgery. In a large series, up to 80% of patients with postoperative SNHL had no identifiable cause on revision exploration. It is now recommended that for those with postoperative SNHL, only patients with a history of trauma or dizziness be considered for revision. Such circumstances might be caused by a persistent perilymphatic fistula and be amenable to surgical correction.

8. Stapes surgery in children—With the increased risk of congenital malformations and the low overall incidence of pediatric disease, CT is always recommended on younger patients suspected of having otosclerosis. Owing to the rarity of juvenile otosclerosis, the effectiveness of stapedectomy surgery in children has been less critically reviewed. Pediatric patients are more likely to require the use of a drill ("drill-out stapedotomy") for obliterative otosclerosis as compared to their adult counterparts. Despite this finding, reports have disclosed up to a 91.7% success rate in achieving a 10 dB air-bone gap after five or more years of follow-up. Other studies reported an 82% success rate in primary otosclerosis cases but only a 44% success rate in cases of congenital footplate fixation.

The optimal time for surgery in children remains a point of controversy. With the higher incidence of otitis media during childhood, there is concern for the potential spread of infection through the oval window resulting in meningitis. Moreover, most children benefit from amplification, and delaying surgery until they are older is an acceptable option.

Derks W, de Groot JA, Raymakers JA, Veldman JE. Fluoride therapy for cochlear otosclerosis? An audiometric and computerized tomography evaluation. *Acta Otolaryngol*. 2001;121(2):174. [PMID: 11349772] (Discusses fluoride therapy rest at the progression of sensorineural hearing loss in low and high frequencies.)

Lesinski SG, Palmer A. Lasers for otosclerosis: CO_2 versus argon and KTP-532. *Laryngoscope*. 1989;99:1. [PMID: 2498587] (The optical properties of the CO_2 laser are preferable to those of the argon and KTP-532 lasers.)

Rotteveel LJ, Snik AF, Cooper H, Mawman DJ, van Olphen AF, Mylanus EA. Speech Perception after Cochlear Implantation in 53 Patients with Otosclerosis: Multicentre Results. *Audiol Neurootol*. 2009;15(2):128. [PMID: 19690406] (Patients with otosclerosis receive excellent hearing rehabilitation with cochear implantation).

Intraoperative issues & Postoperative Complications of Otosclerosis Surgery

Table 51–4 details some of the potential complications that may result from stapes surgery.

Table 51–4. Potential Postoperative Complications of Stapedial Surgery.

Sensorineural loss
Tinnitus
Dysgeusia
Serous labyrinthitis
Infection
Prosthesis displacement or loose wire
Incus necrosis
Tympanic membrane perforation
Dizziness
Fibrosis and adhesion formation
Otosclerotic regrowth
Perilymphatic fistula
Postoperative granuloma
Hyperacusis and phonophobia
Facial nerve paralysis

A. Tympanic Membrane Perforation

If a tympanic membrane perforation is created during flap elevation this is repaired with a soft tissue underlay technique using temporalis fascia. Occasionally, the surgeon will find that the elevated flap is too short after bone has been removed from the scutum; such defects maybe repaired with temporalis fascia, or tragal perichondrium.

B. Dysgeusia

All efforts should be made to preserve the chorda tympani nerve and minimize manipulation. The nerve is particularly vulnerable during the removal of scutum. Injuring the nerve may result in dysgeusia causing a salty or metallic taste. Although controversial, many authors suggest sharply dividing a stretched or torn chordae tympani nerve to reduce the risk of taste disturbance postoperatively. Typically, taste changes gradually resolve over a few weeks or months; but occasionally they do persist indefinitely.

C. Abnormalities of the Facial Nerve

Histological dehiscence of the facial nerve occurs in as many as 40% of temporal bone specimens and clinically may be seen in the vicinity of the oval window in about 0.5% of cases. A dehiscent or aberrant facial nerve course may restrict safe access to the footplate and early recognition is critical to preventing injury, particularly if a laser is used. A facial nerve monitor may also be of benefit in preventing nerve injury. If one's view is only mildly hindered the experienced surgeon may cautiously proceed; however, in the rare case of extreme overhang, the case may be terminated given the unfavorably high risk of facial nerve injury.

After surgery, a patient may experience an acute facial nerve weakness due to the injection of local anesthetic either in the pretragal area or from excess anesthetic entering the middle ear and bathing a dehiscent portion of the facial nerve. This weakness should abate over 2–4 h as the medication effects dissipate. Occasionally, a patient develops

a delayed paralysis 5–7 days after surgery. This paralysis is likely due to a viral reactivation within the nerve, analogous to Bell's palsy, and is treated with prednisone and an antiviral medication. In this scenario, the prognosis is excellent and the patient can expect full recovery.

D. Malleus and Incus Fixation

After the middle ear has been exposed, it is important to palpate the long process of the malleus and assess the mobility of the malleus, incus, and stapes. The mobility of the stapes can be evaluated with light palpation by (1) pushing the superstructure side-to-side and (2) gently pushing toward the vestibule on the long process of the incus. With experience, it is possible to appreciate partial stapes fixation and subtle abnormalities in ossicular mobility. If the stapes is mobile and the malleus or incus is fixed, the surgeon must decide whether to close the ear and recommend a hearing aid or proceed to address the ossicular fixation utilizing other standard ossiculoplasty techniques.

E. Perilymphatic "Gusher"

High perilymphatic outflow after performing a stapedectomy or stapedotomy is termed as perlymphatic "gusher." Excessive perilymphatic outflow is the result of either an abnormally patent cochlear aqueduct or malformation of the lateral end of the internal auditory canal allowing for a high flow communication of intracranial cerebrospinal fluid (CSF) to the inner ear. It is more common in patients who have a congenitally fixed footplate, those with an enlarged vestibular aquaduct syndrome, or patients with mondini malformations. Given the higher prevalence of such conditions in the pediatric population, a preoperative CT scan is highly recommended for younger patients or for patients who manifest hearing loss at a young age. If these conditions are suspected preoperatively, surgery is contraindicated because of a high risk of causing complete SNHL. If this complication occurs during surgery, fat or muscle grafts may be used to seal the leak. Postoperatively, the patient should be maintained in a head-elevated position and placed on stool softeners. Severe leaks may require packing the middle ear and placing a temporary lumbar drain to reduce CSF pressure postoperatively.

F. Floating or Submerged Footplate

A floating or submerged footplate presents a difficult technical challenge. The footplate may become mobile during curetting due to inadvertent contact with the ossicular chain, while attempting to fracture the stapes superstructure or during manipulation of the footplate. If the footplate becomes mobile prior to the separation of the incudostapedial joint and removal of the crura, it may be best to terminate the procedure; the result may be quite satisfactory. If refixation occurs, the ear can be re-explored at a later date. If the footplate is mobilized during or after removal of the crura there are several options. The procedure can be terminated, a prosthesis can be placed on the mobile footplate, or a stapedotomy can be performed with the laser and the is operation completed. A mobile footplate presents a surgical challenge but poses little threat to the inner ear function. On the contrary, a submerged footplate places the patient at higher risk of having vestibular or cochlear dysfunction. No effort should be made to retrieve a submerged footplate from the vestibule. A graft can be placed over the oval window and a prosthesis placed.

G. Obliterative Otosclerosis

Obliterative otosclerosis describes the condition where excessive bony overgrowth has occurred to the point that the oval window is nearly indistinguishable from the surrounding promontory. In such cases, surgery is more difficult and the results are often less satisfying. If surgery is attempted, the obliterative bone should be removed by saucerizing (drilling on a broad front) around and over the footplate until a thin blue area is created. At this point, either a laser or drill-assisted stapedotomy may be performed and a prosthesis inserted.

H. Vertigo

During stapes surgery, vertigo may result from several causes including diffusion of the anesthetic agent into the labyrinth, aspiration of perilymph, manipulations within the vestibule, a displaced footplate, or the introduction of a prosthesis that may be too long. One of the advantages of using local anesthesia is that, in a patient who is awake, vertigo is readily monitored and maneuvers resulting in vertigo may be averted. A delayed onset of vertigo may be the result of a perilymphatic fistula, an excessively long prosthesis, or labyrinthitis.

I. Sensorineural Hearing Loss

Severe to profound SNHL is one of the most feared complications of stapes surgery and occurs in approximately 1% of patients after primary surgery and in up to 10% of patients after revision surgery. Mild to moderate losses occur more commonly, particularly in the high frequencies, but the incidence is not known.

Hearing loss may be either early or late. Possible causes of early hearing loss include intraoperative trauma, labyrinthitis, postoperative infection, granuloma formation, and a perilymphatic fistula. Patients with postoperative SNHL should be treated with a course of prednisone and antibiotics in an attempt to halt or potentially reverse losses. The cause of a delayed loss is unknown. Many surgeons prefer to wait at least 6 months and often 1 year before considering surgery on the second ear because of this risk. In addition, some patients with clinical bilateral disease may find that after their first surgery their hearing is adequate and they may forgo surgery in the contralateral ear.

J. Tinnitus

Most often tinnitus that is present preoperatively improves after surgery. If a SNHL has occurred due to surgery, then any existing tinnitus may worsen. Preoperative preparation for this possible complication is exceedingly important; an inadequately informed patient who develops even a mild case of postoperative SNHL and tinnitus is frequently very dissatisfied.

K. Incus Dislocation, Fracture, and Necrosis

If the incus is moderately mobilized, it can simply be repositioned and the integrity of the ossicular chain will be preserved. If it is truly subluxated, repositioning and terminating the procedure may result in the incus becoming stable again allowing for a standard surgical procedure in the future. Alternatively, a malleus-to-footplate prosthesis could be used. If during crimping the long process is fractured, a number of options exist. A groove can be drilled proximally along the long process and the wire crimped in this location. A shape-memory (Nitinol) prosthesis may fit well without drilling a groove. Alternately, a prosthesis designed to fit under the long process of the incus can be used. If the incus is too short, a malleus-to-footplate wire can be used. Lastly, bone cements continue to improve and may be helpful in stabilizing a prosthesis in this situation. Incus necrosis is the most common finding at revision surgery and is addressed in the same manner. The cause of incus necrosis has been ascribed to devascularization, thermal injury or, a prosthesis wire that is too tight or too loose. It is important to have available a variety of prostheses for each surgery and to be facile with different reconstructive techniques.

L. Loose Wire Syndrome

Loose wire syndrome may result from a lax union between the prosthesis and its connection to the incus. Patients will often complain of a "tinny" or distorted sound and they generally have a normal audiogram. Observation and reassurance is reasonable in patients with minimal symptoms however those with severe and constant symptoms, revision surgery with tightening of the wire, prosthesis replacement or fixation with cement will usually correct the problem.

Prognosis

The immediate success rate after stapedial surgery declines slowly over time owing to delayed CHL and potentially further SNHL. In one series reporting on primary stapedectomy cases, an air-bone gap closure of ≤10 dB was reported in 95.1% of cases after 1 year, in 94.7% after 2–5 years, and in 62.5% after 30 years. In revision cases, the reported rates of an air-bone gap closure measuring ≤10 dB was 71.1% after 1 year, 62.4% after 2–5 years, and 59.4% after 6–36 years. In a similar review, a residual air-bone gap of ≤10 dB was reported in 79% of primary cases, with a follow-up period ranging from 1 to 21 years, with a mean of 7 years. The decline in hearing after stapedotomy and stapedectomy has been estimated to occur at a rate of 3.2 dB and 9.5 dB per decade, respectively. Based on this predicted deterioration rate, it is estimated that a typical stapedectomy patient will reach the critical level of 40 dB, which will require amplification 13 years after surgery. In contrast, stapedotomy patients are not expected to reach this level for 21 years.

Shea JJ Jr. Forty years of stapes surgery. *Am J Otol*. 1998;19(1):52. [PMID: 9455948] (Results of 14,449 stapedectomy operations performed by the author over a 40-year period.)

We would like to acknowledge Derek Kofi O. Boahene, MD for his contribution to this chapter in the previous editions.

Sensorineural Hearing Loss

52

Anil K. Lalwani, MD

ESSENTIALS OF DIAGNOSIS

- May affect patients of all ages
- For patients who have unilateral hearing loss
- Weber tuning fork test lateralizes to the unaffected side
- Rinne tuning fork test demonstrates air conduction greater than bone conduction
- Pure-tone thresholds result in equally diminished air and bone conduction
- Speech discrimination testing less than 90% correct.

General Considerations

Hearing loss is extremely common and has a wide spectrum ranging from a nearly undetectable degree of disability to a profound loss of ability to function in society. Nearly 10% of the adult population has some hearing loss. Often, this impairment presents early in life. One to three of every 1000 newborn in the United States is completely deaf, and more than 3 million children have hearing loss. However, hearing loss can present at any age. Between 30% and 35% of individuals over the age of 65 have a hearing loss sufficient to require a hearing aid. Forty percent of people over the age of 75 have hearing loss.

Hearing loss can result from disorders of the auricle, external auditory canal, middle ear, inner ear, or central auditory pathways. In general, lesions in the auricle, external auditory canal, or middle ear cause conductive hearing loss. The focus of this chapter is sensorineural hearing loss that tends to result from lesions in the inner ear or eighth nerve. See Table 52–1 for a list of the common causes of hearing loss.

Classification

Sensorineural hearing loss may result from damage to the hair cells caused by intense noise, viral infections, fractures of the temporal bone, meningitis, cochlear otosclerosis, Meniere disease, and aging. The following drugs can also produce sensorineural hearing loss: ototoxic drugs (eg, salicylates, quinine, and the synthetic analogs of quinine), aminoglycoside antibiotics, loop diuretics (eg, furosemide and ethacrynic acid), and cancer chemotherapeutic agents (eg, cisplatin).

A. Age-Related Hearing Loss (Presbycusis)

Presbycusis, age-associated hearing loss, is the most common cause of hearing loss in adults. Initially, it is characterized by symmetric, high-frequency hearing loss that eventually progresses to involve all frequencies. More important, the hearing loss is associated with a significant loss in clarity.

B. Congenital Hearing Loss

Congenital malformations of the inner ear cause hearing loss in some adults. Genetic predisposition alone or in concert with environmental influences may also be responsible.

C. Neural Hearing Loss

Neural hearing loss is due mainly to cerebellopontine angle tumors such as vestibular schwannomas (acoustic neuromas) or meningiomas; it may also result from any neoplastic, vascular, demyelinating (eg, multiple sclerosis), infectious, or degenerative disease, or trauma affecting the central auditory pathways.

D. HIV-Related Hearing Loss

Human immunodeficiency virus (HIV) infection leads to both peripheral and central auditory system pathology and is associated with sensorineural hearing impairment.

Table 52–1. Etiology of Sensorineural Hearing Loss.

Category	Example
Developmental and hereditary	
Syndromic	Alport syndrome, Usher syndrome
Nonsyndromic	Large vestibular aqueduct syndrome
Infectious	Otitis media, CMV, syphilis, labyrinthitis
Pharmacologic toxicity	Aminoglycosides, loop diuretics, antimalarials, salicylates
Trauma	Head injury, noise-induced, barotraumas, irradiation
Neurologic disorders	Multiple sclerosis
Vascular and hematologic disorders	Migraine, cryoglobinemia, sickle cell, blood dyscrasia
Immune disorders	Polyarteritis nodosa, HIV
Bone disorders	Otosclerosis, Paget disease
Neoplasms	Vestibular Schwannoma, meningioma
Unknown etiology	Presbycusis, Meniere disease

E. Mixed Hearing Loss

A person can have both conductive and sensory hearing loss, which is termed mixed hearing loss. Mixed hearing losses are due to pathology that can affect the middle and inner ear simultaneously; causes include otosclerosis involving the ossicles and the cochlea, transverse and longitudinal temporal bone fractures, head trauma, chronic otitis media, cholesteatoma, and middle ear tumors. Some inner ear malformations can also be associated with mixed hearing loss. These include large vestibular aqueduct, lateral semicircular canal dysplasia, superior canal dehiscence, and a bulbous lateral end of the internal auditory canal (IAC); the latter is associated with the absence of the bony partition between the basal turn of the cochlea and the IAC (as seen in the stapes gusher syndrome).

Etiology

A. Nongenetic Causes

The predominant etiology of hearing impairment in children has evolved with advances in medical knowledge and therapeutics. Historically, infectious disorders such as otitis media, maternal rubella infections, cytomegalovirus (CMV), and bacterial meningitis as well as environmental factors such as intrauterine teratogenic exposure or ototoxic insult were the dominant causes of congenital and acquired hearing losses. The introduction of antibiotics and vaccines, along with improved knowledge and enhanced awareness about teratogens, has led to a decline in hearing loss resulting from infections and environmental agents.

B. Genetic Causes

Currently, more than half of childhood hearing impairment is thought to be hereditary; hereditary hearing impairment (HHI) can also manifest later in life. HHI may be classified as either **nonsyndromic hearing loss,** in which hearing loss is the only clinical abnormality, or **syndromic hearing loss,** in which hearing loss is associated with anomalies in other organ systems.

Pathogenesis

Hearing occurs by air conduction and bone conduction. In **air conduction**, sound waves reach the ear by propagating in the air, entering the external auditory canal, and setting the tympanic membrane in motion; the movement of the tympanic membrane, in turn, moves the malleus, incus, and stapes of the middle ear. The structures of the middle ear serve as an impedance-matching mechanism, improving the efficiency of energy transfer from the air to the fluid-filled inner ear. Hearing by **bone conduction** occurs when the sound source, in contact with the head, vibrates the bones of the skull; this vibration produces a traveling wave in the basilar membrane of the cochlea.

Cochlear neurons send fibers bilaterally to a network of auditory nuclei in the midbrain, and impulses are transmitted through the medial geniculate thalamic nuclei to the auditory cortex in the superior temporal gyri. At low frequencies, individual auditory nerve fibers can respond more or less synchronously with the stimulating tone. At higher frequencies, phase locking occurs so that neurons alternate in response to particular phases of the sound wave cycle. Three things encode the intensity of sound: (1) the amount of neural activity in individual neurons, (2) the number of neurons that are active, and (3) the specific neurons that are activated.

Nearly two thirds of hereditary hearing impairments are nonsyndromic and the remaining one third is syndromic. Between 70% and 80% of nonsyndromic HHI is inherited in an autosomal recessive manner; another 15–20% is autosomal dominant. Less than 5% is X-linked or maternally inherited via the mitochondria.

Extensive progress has been made in the identification of genes responsible for syndromic and nonsyndromic HHI. Over 110 loci harboring genes for nonsyndromic HHI have been mapped with an equal number of dominant and recessive modes of inheritance; of these, 51 different genes have been cloned. In general, the hearing loss associated with dominant genes has its onset in adolescence or adulthood and varies in severity (mimicking presbyacusis), whereas the hearing loss associated with recessive inheritance is congenital and profound. Among the genes associated with human deafness, GJB2 encoding for connexin 26 is significant for being associated with nearly 20% childhood deafness. Furthermore, two frame-shift mutations, 35delG and 167delT, account for more than 50% of the cases making

population screening feasible. The 167delT mutation is primarily prevalent in the Ashkenazi Jews where it is predicted that 1:1765 individuals will be homozygous and affected. The hearing loss associated with GJB2 mutations can be variable but is generally severe to profound at birth. In addition, the hearing loss can be variable among the members of the same family, suggesting that other genes likely influence the auditory phenotype.

The contribution of genetics to presbycusis or age-associated hearing loss is also better understood. Several of the nonsyndromic genes are associated with hearing loss that progresses with age. Recently, genome-wide association studies demonstrated that a common allele of GRM7 (gene encoding metabotropic glutamate receptor type 7) contributes to an individual's risk of developing age-related hearing loss. Therefore, it is likely that presbycusis has both environmental and genetic components. Presbycusis is characterized by a loss of discrimination for phonemes, recruitment (abnormal growth of loudness), and particular difficulty in understanding speech in noisy environments. Between 30% and 35% of people over 65 years of age have a hearing loss that is sufficiently great to require a hearing aid.

More than 200 syndromes are associated with hearing loss. Common syndromic forms of hearing loss, among others, include the following: (1) **Usher syndrome** (retinitis pigmentosa and hearing loss), (2) **Waardenburg syndrome** (pigmentary abnormality and hearing loss), (3) **Pendred syndrome** (thyroid organification defect and hearing loss), (4) **Alport syndrome** (renal disease and hearing loss), and (5) **Jervell** and **Lange–Nielsen syndromes** (prolonged QT interval and hearing loss). As a direct result of the rapid advances in the fields of molecular biology and molecular genetics, the responsible genes for the aforementioned syndromes have all been identified. In addition, rapid progress in understanding the basis of these and related disorders has revealed a number of complexities. For example, identification of myosin 7A as the responsible gene for both syndromic and nonsyndromic deafness has led to the abandonment of the "one gene, one disease" dogma. Also, a single gene may cause syndromic or nonsyndromic forms of deafness or may be associated with autosomal dominant or autosomal recessive mode of inheritance.

Prevention

A. Vaccination

The vaccination of infants against *Haemophilus influenzae* type B meningitis prevents a major cause of acquired deafness, as have immunizations for measles, mumps, and rubella. A vaccine against Streptococcus pneumoniae, the most common organism associated with otitis media, is also available and is having a positive impact on the reduction in the incidence of ear infections.

B. Noise Avoidance

Ten million Americans have noise-induced hearing loss and 20 million are exposed to hazardous noise in their employment. Noise-induced hearing loss can be prevented by avoiding exposure to loud noise or by the regular use of earplugs or fluid-filled muffs to attenuate intense sound. Noise-induced hearing loss results from recreational as well as occupational activities and often begins in adolescence.

1. High-risk activities—High-risk activities for noise-induced hearing loss include wood- and metalworking with electrical equipment as well as target practice and hunting with small firearms. All internal-combustion and electric engines, including snowblowers and leaf blowers, snowmobiles, outboard motors, and chain saws, require that the user wear hearing protectors.

2. Education—Almost all noise-induced hearing loss is preventable through education, which should begin before adolescence. Industrial programs of hearing conservation are required when the exposure over an 8-hour period averages 85 dB on the A scale. Workers in such noisy environments can be protected with preemployment audiologic assessment, the mandatory use of hearing protectors, and annual audiologic assessments.

Clinical Findings

A. Evaluation Goals

In a patient with auditory complaints, the goals in the evaluation are to determine: (1) the nature of the hearing impairment (conductive or sensorineural); (2) the severity of the impairment (mild, moderate, severe, profound); (3) the anatomy of the impairment (external ear, middle ear, inner ear, or central auditory pathway pathology); and (4) the etiology.

B. Symptoms and Signs

Initially, the history and the physical examination are critical in identifying the underlying pathology leading to the auditory deficit. The history should elicit hearing loss characteristics, including the duration of deafness, the nature of the onset (sudden or insidious), the rate of progression (rapid or slow), and the involvement of the ear (unilateral or bilateral). In addition, the presence or absence of the following conditions should also be ascertained: tinnitus, vertigo, imbalance, aural fullness, hyperacusis, otorrhea, headache, facial nerve dysfunction, and head and neck paresthesia. Information regarding head trauma, ototoxic exposure, occupational or recreational noise exposure, and a family history of hearing impairment may also be critical in the differential diagnosis.

1. Sudden onset—A sudden onset of unilateral hearing loss, with or without tinnitus, may represent an inner ear

viral infection or a vascular accident. Patients with unilateral hearing loss (sensory or conductive) usually complain of reduced hearing, poor sound localization, and difficulty hearing clearly with background noise.

2. Gradual progression—Gradual progression in a hearing deficit is common with otosclerosis, noise-induced hearing loss, vestibular schwannoma, or Meniere disease. People with small vestibular schwannomas typically present with any or all of the following conditions: asymmetric hearing impairment, tinnitus, and imbalance (although rarely vertigo). Cranial neuropathy, especially of the trigeminal or facial nerve, may accompany larger tumors. In addition to hearing loss, Meniere disease or endolymphatic hydrops may be associated with episodic vertigo, tinnitus, and aural fullness. Hearing loss with otorrhea is most likely due to chronic otitis media or cholesteatoma.

3. Family history—In families with multiple affected members across multiple generations, the family history may be crucial in delineating the genetic basis of hearing impairment. The history may also help identify environmental risk factors that lead to hearing impairment within a family. Sensitivity to aminoglycoside maternally transmitted through a mitochondrial mutation can be discerned through a careful family history. Susceptibility to noise-induced hearing loss or age-related hearing loss (presbycusis) may also be genetically determined.

C. Physical Examination

1. Examination of the ear—The physical examination should evaluate the auricle, external ear canal, and tympanic membrane. In examining the eardrum, the topography of the tympanic membrane is more critical than the presence or absence of the often-cited light reflex. The pars tensa (the lower two thirds of the eardrum) and the pars flaccida (the short process of the malleus) should be examined for retraction pockets that may be evidence of chronic eustachian tube dysfunction or cholesteatomas. Insufflation in the ear canal is necessary to assess tympanic membrane mobility and compliance.

2. Examination of other structures—A careful inspection of the nose, nasopharynx, and upper respiratory tract is indicated. Unilateral serous effusion in the adult should prompt a fiberoptic examination of the nasopharynx to exclude neoplasms. Cranial nerves should be carefully evaluated with special attention to trigeminal and facial nerve function as the dysfunction of these two nerves is most commonly associated with tumors involving a cerebellopontine angle.

3. Evaluation with a tuning fork—Evaluating hearing with a tuning fork can be a useful clinical screening tool to differentiate between conductive and sensorineural hearing loss. By comparing the threshold of hearing by air conduction with that elicited by bone conduction with a 256- or 512-Hz tuning fork, one can infer the site of the lesion responsible for hearing loss. The Rinne and Weber tuning fork tests are used widely both to differentiate conductive from sensorineural hearing losses and to confirm the audiologic evaluation results.

A. Rinne tuning fork test—The Rinne tuning fork test is sensitive in detecting conductive hearing losses. A Rinne test compares the ability to hear by air conduction with the ability to hear by bone conduction. The tines of a vibrating tuning fork are held near the opening of the external auditory canal, and then the stem is placed on the mastoid process; for direct contact, it may be placed on either teeth or dentures. The patient is asked to indicate whether the tone is louder by air conduction or bone conduction. Normally and in the presence of sensorineural hearing loss, a tone is heard louder by air conduction than by bone conduction. However, with a 30-dB or greater conductive hearing loss, the bone-conduction stimulus is perceived as louder than the air-conduction stimulus.

B. Weber tuning fork test—The Weber tuning fork test may be performed with a 256- or 512-Hz fork. The stem of a vibrating tuning fork is placed on the head in the midline, and the patient is asked whether the tone is heard in both ears or in one ear better than in the other. With a unilateral conductive hearing loss, the tone is perceived in the affected ear. With a unilateral sensorineural hearing loss, the tone is perceived in the unaffected ear. As a general rule, a 5-dB difference in hearing between the two ears is required for lateralization.

The combined information from the Weber and Rinne tests permits a tentative conclusion as to whether a conductive or sensorineural hearing loss is present. However, these tests are associated with significant false-positive and -negative responses and therefore should be used only as screening tools and not as a definitive evaluation of auditory function.

D. Audiologic Assessment

The minimum audiologic assessment for hearing loss should include the following measurements: (1) pure-tone air-conduction and bone-conduction thresholds, (2) speech reception threshold, (3) discrimination score, (4) tympanometry, (5) acoustic reflexes, and (6) acoustic-reflex decay. This test battery provides a comprehensive screening evaluation of the whole auditory system. It allows the clinician to determine whether further differentiation of a sensory (cochlear) from a neural (retrocochlear) hearing loss is indicated. Refer to Chapter 45, Audiologic Testing, for additional details on audiologic assessment.

E. Imaging Studies

Appropriate radiologic studies may be needed to evaluate both the temporal bone and the auditory pathway. The radiologic evaluation of the ear is largely determined by what structures are being evaluated: the bony anatomy of

the external, middle, and inner ear; or the auditory nerve and brain. Both computed tomography (CT) and magnetic resonance imaging (MRI) are capable of identifying inner ear malformations; they are equally able to determine the cochlear patency in the preoperative evaluation of patients for cochlear implantation.

1. CT scans—Axial and coronal CT of the temporal bone with fine 0.6-mm cuts is ideal for determining the caliber of the external auditory canal, the integrity of the ossicular chain, and the presence or absence of middle ear or mastoid disease, and for detecting inner ear malformations. To reliably identify inner ear malformations, measurement of the cochlear height, lateral semicircular canal bony island width, and the vestibular aqueduct should be routinely performed on all temporal bone studies. CT scanning is also ideal for the detection of bone erosion often seen in the presence of chronic otitis media and cholesteatoma.

2. MRI—MRI is superior for imaging retrocochlear pathology such as vestibular schwannomas, meningiomas, other lesions of the cerebellopontine angle that may present with hearing loss, demyelinating lesions of the central nervous system, and brain tumors.

Most patients with conductive hearing losses should have axial and direct coronal CT scans of the temporal bones to evaluate the external and middle ear. Patients with unilateral or asymmetric sensorineural hearing losses should have an MRI of the head with gadolinium enhancement to exclude tumors of the cerebellopontine angle. In the presence of vestibular symptoms, patients may require electronystagmography and caloric testing.

Differential Diagnosis

Synthesis of the findings on clinical history, otologic and physical examination, and audiologic testing is usually sufficient to establish both the nature and the probable cause of a hearing impairment (Table 52-1).

Treatment

A. Creating a Favorable Environment for Hearing

A variety of simple interventions can significantly enhance the ability to understand speech in people who are hard of hearing. A critical first step is to eliminate or reduce unnecessary noise (eg, radio or television) to enhance the signal-to-noise ratio. Speech comprehension is aided by lip reading; therefore, the impaired listener should be seated so that the face of the speaker can be seen at all times. Speaking directly into the ear is occasionally helpful; however, more is usually lost than gained in communication when the speaker's face cannot be seen. In addition, the lighting of the speaker's face should be considered. A person who is hard of hearing should sit with his or her back to the window so that the light is on the speaker's face. Speech should be slow enough to make each word distinct, but overly slow speech is distracting and loses contextual and speech-reading benefits. Although speech should be in a loud, clear voice, in sensorineural hearing losses in general and in elderly hearing-impaired individuals in particular, recruitment (the ability to hear loud sounds normally loud) may be difficult. Above all, optimal communication cannot take place unless both parties give it their full and undivided attention.

B. Amplification

Patients with mild, moderate, and severe sensorineural hearing losses are rehabilitated regularly with hearing aids that vary in configuration and strength. Hearing aids have been improved to provide greater fidelity and also have been miniaturized. A new hearing aid, the Lyric, has been introduced that is placed deep in the ear canal and is completely hidden.

In general, the more severe the hearing impairment, the larger the hearing aid required for auditory rehabilitation. Digital hearing aids lend themselves to programming for the individual; in addition, multiple and directional microphones at the ear level help some individuals with the difficulty of using a hearing aid in noisy surroundings. Since all hearing aids amplify noise as well as speech, the only absolute solution to the problem is to place the microphone closer to the speaker than to the noise source. This arrangement is not possible with a self-contained, cosmetically acceptable device; it is cumbersome and requires a user-friendly environment. For unilateral deafness, implantation of a bone anchored hearing aid (BAHA) may be considered. Like the contralateral routing of signal hearing aid, the BAHA serves to transmit the sound to the better hearing ear.

In many situations, including at lectures and at the theater, hearing-impaired persons benefit from assistive devices that are based on the principle of having the speaker closer to the microphone than to any source of noise. Assistive devices include infrared and FM transmission; they also include an electromagnetic loop placed around the room for transmission to the individual's hearing aid. Hearing aids with telecoils can also be used with properly equipped telephones in the same way.

C. Cochlear Implants

In the event that a hearing aid provides inadequate rehabilitation, cochlear implants are appropriate (see Chapter 69). Cochlear implants are neural prostheses that convert sound energy to electrical signals and can be used to stimulate the auditory division of the eighth nerve directly. In most cases of profound hearing impairment, the auditory hair cells are lost, but the spiral ganglion cells of the auditory division of the eighth nerve are preserved. Cochlear implants are a specialized hearing prosthesis for the rehabilitation of profound deafness that convert mechanical sound energy into electrical signals that are delivered to the neurons of the cochlear nerve. The basic operation of the implant is as follows: a

microphone is used to pick up acoustic information that is sent to an external speech processor (located on the body or at ear level). This processor converts the mechanical acoustic wave into an electric signal that is transmitted via the surgically implanted electrode array in the cochlea to the auditory nerve. A patient with cochlear implants experiences sound that helps with speech reading, allows open-set word recognition, and helps in modulating the individual's own voice.

The criteria for implantation undergo constant revisions; an adult candidate has severe to profound hearing loss with a score of 60% or less on Hearing-in-Noise Test (HINT) under the best-aided conditions. Children 1 year or older with congenital and acquired profound hearing impairment who have failed a hearing aid trial are also appropriate candidates for cochlear implantation; many are being implanted as early as 6 to 9 months. Usually within 3 months of implantation, adult patients can understand speech without visual cues. With the current generation of multichannel cochlear implants, almost 75% of the patients with these implants are able to converse on the telephone. Bilateral cochlear implants are increasingly common and serve to enhance sound localization and improve understanding of speech in background noise.

D. Brainstem Auditory Implant

For individuals who have had both eighth nerves destroyed by trauma or bilateral vestibular schwannomas (eg, patients with neurofibromatosis II), severely malformed ears, or patients with congenital absence of the eighth nerve, a brainstem auditory implant placed near the cochlear nucleus may provide auditory rehabilitation. With additional advances in brainstem auditory implant technology, patients may eventually obtain benefits similar to individuals who have cochlear implants.

E. Therapy for Tinnitus

Tinnitus, a perception of abnormal sounds such as ringing or roaring noises, can often accompany hearing loss. The treatment of tinnitus is particularly problematic; the treatment does not cure it, and therapy is usually directed toward minimizing the appreciation of tinnitus.

The relief of tinnitus may be obtained by masking it with background sound. Hearing aids also are helpful in tinnitus suppression, as are tinnitus maskers, devices that present a sound to the affected ear that is more pleasant to listen to than the tinnitus. The use of a tinnitus masker is often followed by several hours of inhibition of the tinnitus. Antidepressants are also beneficial in helping patients deal with tinnitus although the exact mechanism by which they work is unknown.

Prognosis

A. Temporary Hearing Loss

Hearing loss due to an incident of noise exposure generally produces a temporary loss that recovers within 24 to 48 hours. However, if the noise is of high enough intensity or is repeated often enough, permanent hearing loss results.

B. Irreversible Hearing Loss

Sensorineural hearing loss is a condition that is generally irreversible. Presbycusis is a type of sensorineural hearing loss that is both progressive (1–2 dB/year) and irreversible.

Acoustic trauma consists of a single exposure to a hazardous level of noise resulting in a permanent loss without an intervening temporary loss. Given the poor prognosis for most causes of sensorineural hearing loss, the primary goals in management are the prevention of further losses and functional improvement with amplification and auditory rehabilitation. The future holds the promise of molecular therapy to arrest or reverse hearing loss.

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Sprinzl GM, Riechelmann H. Current trends in treating hearing loss in elderly people: A review of the technology and treatment options—A mini-review. *Gerontology*. 2010;56(3):351–358. [Epub ahead of print] [PMID: 20090297]. (An excellent review of hearing loss and its treatment in the elderly.)

We would like to acknowledge Derek D. Mafong, MD, for his contribution to this chapter in the previous editions of CDT.

The Aging Inner Ear

Anil K. Lalwani, MD

53

ESSENTIALS OF DIAGNOSIS

Presbycusis

- High-frequency hearing loss.
- Reduced clarity of hearing.
- Absence of retrocochlear pathology.

Presbystasis

- Generalized imbalance.
- Absence of vertigo.

General Considerations

According to the World Health Organization, the proportion of population that are elderly is increasing at a rapid rate—by 2025, nearly 1.2 billion people will be over the age of 60! Consequently, the prevalence of age-related auditory and vestibular dysfunction will increase. Genetically determined and environmentally affected, the inner ear, like other organ systems, undergoes degenerative changes with aging. These changes result in a variable functional disability. In the United States, hearing difficulty is reported by 25–30% of people in the age group of 65–70 years and by nearly 50% of those over 75 years of age. It has been estimated that between 1.5% and 3.0% of the total population would benefit from hearing aids. Vestibular dysfunction is also common in the elderly, with reported prevalence of vertigo, dysequilibrium, or imbalance to be as high as 47% in men and 61% in women over the age of 70. The incidence of falling in individuals over the age of 65 is between 20% and 40% in those living at home and is twice as frequent for the institutionalized elderly. These falls are associated with significant morbidity and mortality and constitute one of the leading causes of death among the elderly.

The specialized neural cells of the auditory and vestibular systems are nonmitotic and thus cannot undergo replication and renewal. During the course of a lifetime, DNA transcription errors and insoluble pigments accumulate, and protein synthesis becomes increasingly inefficient. In addition, environmental and external factors such as noise trauma, physical trauma, ototoxic substances, and medications contribute to senescence. More recently, the contribution of genetics to age-related hearing loss is being appreciated.

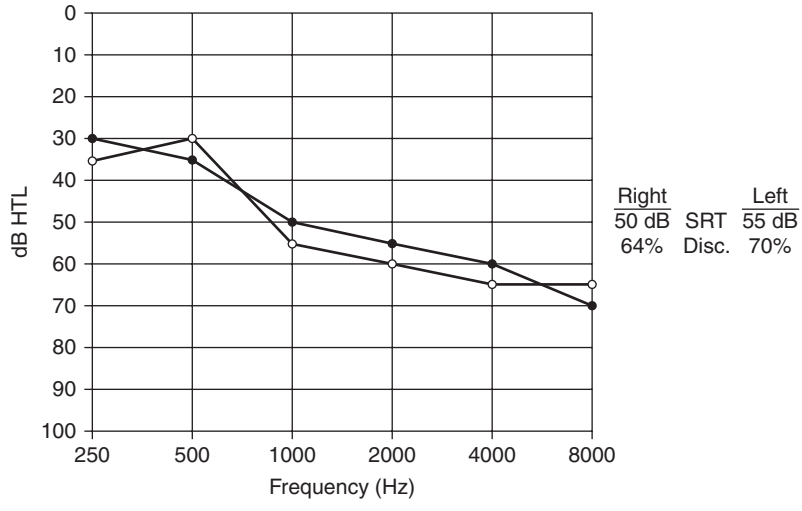
Pathogenesis

A. Age-Related Hearing Loss

Hearing loss in the elderly is multifactorial and is due to the convergence of various risk factors. **Presbycusis** is the otherwise unexplained, slowly progressive, predominantly high-frequency symmetric hearing loss due to the aging process (Figure 53–1). Progressive high-frequency hearing loss has been clearly documented by numerous studies in populations over the age of 40 (Figure 53–2A). Older patients with presbycusis also have more diminished speech discrimination than younger patients with the same level of pure-tone averages (Figure 53–2B). This suggests that neural processing is affected in addition to end-organ dysfunction.

Central pathology includes increased synaptic time in the auditory pathway, increased information processing time, and decreased neural cell population in the auditory cortex. Thus, the older patient is handicapped by decreased hearing as well as the decreased ability to discriminate between similar words. The ability to discriminate between words further deteriorates in a noisy background. In addition, the ability to identify very small interaural time differences deteriorates. Consequently, there is a decrease in directional hearing, further limiting the understanding of speech.

The hearing loss that occurs with aging is not inevitable. Some individuals reach advanced age and maintain perfectly normal hearing. For example, the Mabaans, a Sudanese tribe who live in an almost silent environment, exercise daily, and



▲ **Figure 53–1.** Presbycusis. The audiogram shows a moderate to severe downsloping sensorineural hearing loss, with a decreased speech discrimination score.

abstain from smoking and eating animal fats, have significantly better hearing than age-matched control groups from industrialized areas in the United States. Similarly, other studies have shown that hearing loss is associated not only with noise exposure, but with hyperlipidemia, hypertension, and vascular disease. This has led some clinicians to consider presbycusis as "socioacusis" and to suggest that preventive measures such as limiting exposure to noise may substantially reduce the hearing loss that accompanies aging. Through military, industrial, and recreational (eg, hunting or target practice) activities, men typically receive significantly greater noise exposure than women. Thus, the higher incidence and greater severity of presbycusis in men also argues in favor of the role of environmental causes.

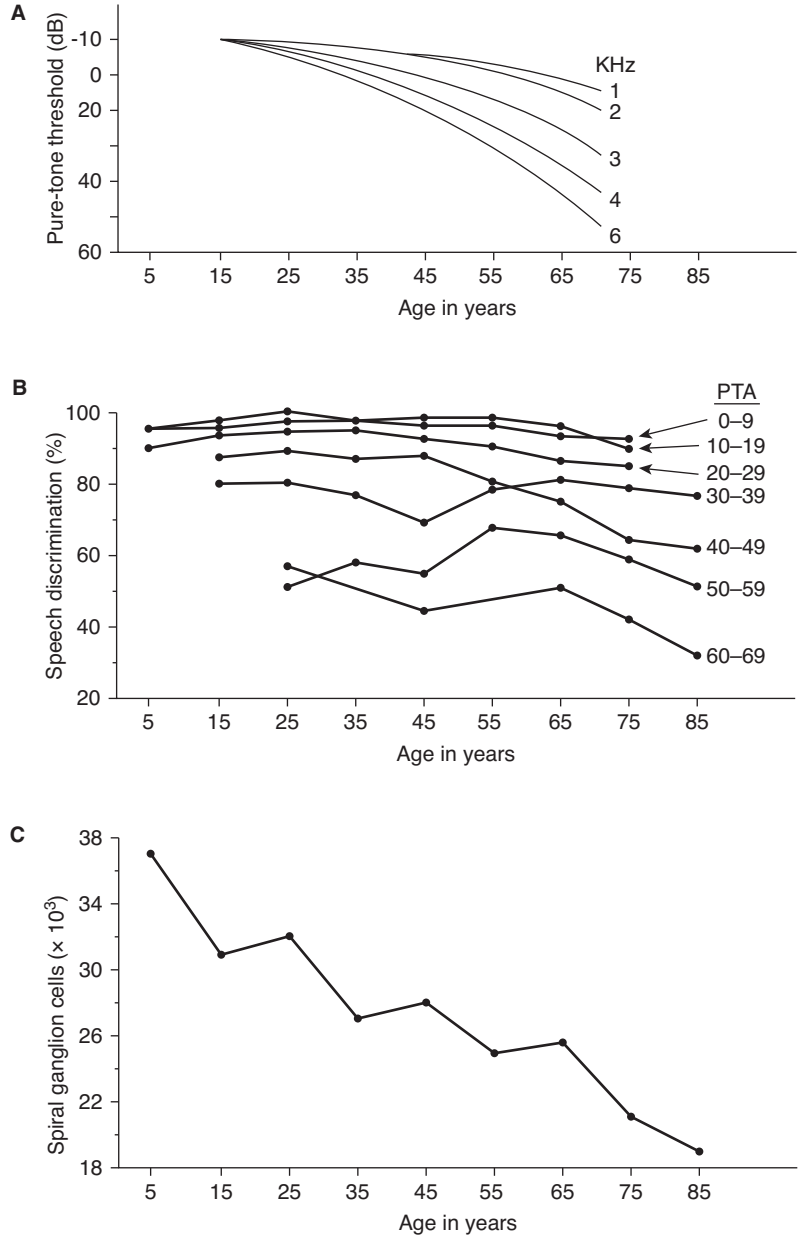
Morphologic studies of human temporal bones have demonstrated an age-related loss of inner and outer hair cells and supporting cells, with the greatest loss being in the basal turn of the cochlea. There is greater loss of outer hair cells compared with inner hair cells; however, these changes have not been directly correlated with auditory function. Age-related loss in spiral ganglion cells, eighth nerve fibers, and neurons in cochlear nuclei have been demonstrated (Figure 53–2C). Some studies have reported changes in the brainstem-evoked response with aging, suggesting alteration at the level of the superior olivary complex, the lateral lemniscus, or the inferior colliculus. Thus, age-related auditory dysfunction results from aggregate deterioration of the entire auditory pathway.

The exact cause of presbycusis remains speculative, in part because of the difficulty in separating the contribution of various etiological factors such as diet, nutrition, metabolism, arteriosclerosis, ototoxic exposure, and noise trauma. Many believe that genetic predisposition alone makes age-related biologic degeneration of the auditory system inevitable. Lifelong acoustic trauma and genetically programmed senescence are the most likely causes of age-related hearing loss. Recently, genome-wide association studies demonstrated that a common allele of GRM7 (gene encoding metabotropic glutamate receptor type 7) contributes to an individual's risk of developing age-related hearing loss.

B. Age-Related Balance Disturbance

Degenerative changes and atrophy have been noted throughout the vestibular apparatus, including the otoconia, vestibular epithelium, vestibular nerve, Scarpa's ganglion, and cerebellum. In the otolithic organs (the utricle and saccule), statoconia progressively demineralize and fragment, resulting in a decreased responsiveness to gravity and linear acceleration. The migration of degenerated otoconial debris into the dependant ampulla of the posterior semicircular canal may result in positional balance disturbances (cupulolithiasis or benign paroxysmal positional vertigo). After age 70, there is also a 20% decrease in the number of hair cells in the maculae of otolith organs and a 40% decrease in cristae of the semicircular canals. Type I hair cells are affected more than Type II hair cells.

In the sensory epithelium, there is accumulation of inclusion bodies, lipofuscin, and vacuoles. Atrophy and scar formation are also present in the sensory epithelia. A reduction in the number of ganglion cells in the Scarpa's ganglion occurs earlier, by age 60. Beginning at age 50, there is a loss of nerve fibers between the vestibule and the Scarpa's ganglion. The greatest loss occurs among the thick myelinated fibers of the cristae. Lipofuscin accumulation in the vestibular nuclei has also been observed. In the cerebellum, there is loss of Purkinje cells beginning in the fifth decade. **Presbyastasis** is a dysequilibrium that occurs with aging and should be used only as a diagnosis of exclusion.



▲ **Figure 53–2. (A)** Hearing level as a function of age. Pure-tone hearing level increases with age, and higher frequencies are affected more than the lower frequencies (adapted from Glorig A, Davis H. Age, noise and hearing loss. *Ann Otol Rhinol Laryngol* 1961;70:5571). **(B)** Speech discrimination as a function of age. For a given pure-tone hearing loss, the speech discrimination decreases with aging (adapted from Jerger J. Audiologic findings in aging. *Adv Otorhinolaryngol* 1973;20:115). **(C)** Total ganglion cell population versus age. There is progressive loss of cochlear neurons as a function of aging (adapted from Otte J, Schuknecht HF, Kerr AG. Ganglion cell populations in normal and pathological human cochleae. Implication for cochlear implantation. *Laryngoscope* 1978;88:1234).

Table 53–1. Characteristics of Hearing Loss in Presbycusis.

Type	Pure Tones	Speech Discrimination
Sensory	High tones, abrupt slope	Related to frequencies lost
Neural	All frequencies	Severe loss
Strial	All frequencies	Minimal loss
Cochlear conductive	High tones, gradual slope	Related to steepness of high-tone loss

Clinical Findings

A. Presbycusis

Classically, four types of presbycusis have been defined: sensory, neural, metabolic or strial, and conductive (Table 53–1). These types may occur in isolation or in combination.

1. Sensory presbycusis—Sensory presbycusis is audiometrically characterized as bilateral, symmetric high-tone hearing loss with an abruptly sloping threshold pattern that begins in middle age. Speech discrimination is directly correlated with the preservation of high-frequency hearing. Histologically, there is a loss of both hair cells and supporting sustentacular cells isolated to the basal turn of the cochlea. The initial flattening of the organ of Corti is followed by secondary neural degeneration. The middle and apical turns of the cochlea containing the speech frequencies are usually spared. These pathologic changes are similar to those seen with noise trauma.

2. Neural presbycusis—Neural presbycusis is characterized by a loss of cochlear neurons involving the whole cochlea and is associated with a significant loss of speech discrimination. The loss of speech discrimination is more profound than would be predicted on the basis of a pure-tone threshold level alone. Although it may occur at any age, hearing difficulty is not noted until the neuronal population falls below a critical number. A downward-sloping audiogram with a variable slope is characteristic. It has been shown that the magnitude of speech discrimination loss directly correlates with the extent of cochlear neuronal loss in the region corresponding to the speech frequencies in the cochlea.

3. Strial presbycusis—Strial presbycusis is characterized by a flat pure-tone audiogram with excellent speech discrimination. The stria vascularis is a metabolically active region of the cochlea that is responsible for the secretion of endolymph and the maintenance of ionic gradients across the organ of Corti. In strial presbycusis, a slowly progressive hearing loss begins in middle age. Pathologically, there is a patchy atrophy of the stria vascularis in the middle and apical turn of the cochlea, without loss of cochlear neurons. Strial atrophy may also involve the entire cochlea. The magnitude of atrophic changes correlates directly with the level of the hearing loss. The quality of endolymph is thought to be affected by strial degeneration, resulting in a loss of energy available to the end organ.

4. Conductive presbycusis—Changes in the mechanical characteristics of the basilar membrane have been suggested as causative of the gradually sloping high-frequency hearing loss of middle age. Cochlear conductive presbycusis lacks discernible pathological changes within the inner ear. Without confirmation from direct micromechanical measurements, cochlear conductive presbycusis remains a theoretical category of presbycusis. The speech discrimination is said to be diminished in relation to the magnitude of pure-tone loss.

B. Noise Trauma

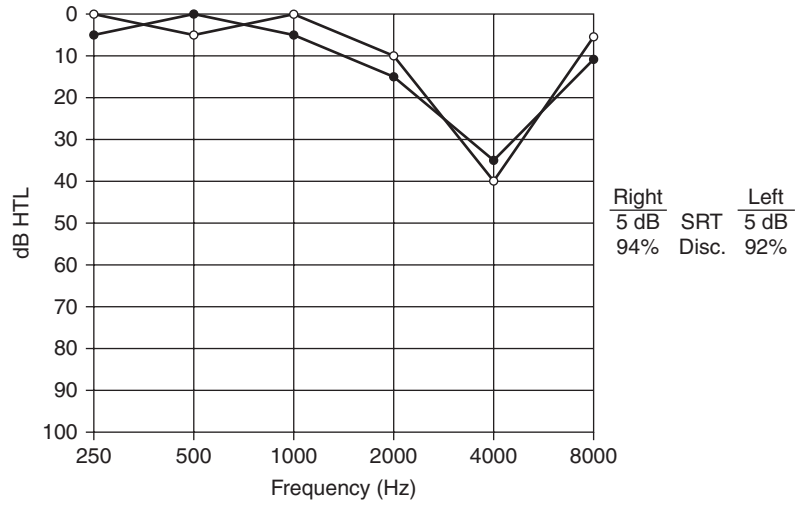
Noise trauma, in addition to presbycusis, is an important cause of sensorineural hearing loss in the elderly. Exposure to sounds greater than 85 dB for prolonged periods of time is potentially injurious to the cochlea and may result in a high-frequency biased hearing loss that is typically maximal at 4000 Hz (Figure 53–3). With continued acoustic trauma, the hearing loss progresses to involve the primary speech frequencies and therefore further affects speech communication. Because of the similarities between noise-induced hearing loss and presbycusis, assessing the relative contribution of each to auditory dysfunction in the elderly is often difficult. Preventive measures, including monitoring noise levels in the workplace, wearing earplugs and ear-muffs, and avoiding loud noise exposure, should aid in diminishing noise-induced hearing loss.

C. Presbystasis

Vertigo is the cardinal symptom of vestibular disease. Although it is usually described as a rotatory sensation, it may take the form of any illusion of movement such as rocking, ground rolling, or a sense of falling forward or backward.

Dysequilibrium is a sense of poor coordination with erect posture or during a purposeful movement. Vertigo is usually episodic; dysequilibrium is typically continuous. The term **imbalance** implies an orthopedic (eg, hip disease) or neurological (eg, hemiparesis) problem. **Dizziness** is an all-encompassing term used by the patient and may include vertigo, dysequilibrium, or imbalance. It may also be used to denote a light-headed feeling, as in postural hypotension or hypoglycemia, or to indicate an inability to concentrate.

Equilibrium problems are common in the elderly. Like the auditory system, the vestibular and balance systems also undergo degenerative changes, resulting in significant clinical disability. An estimated 50–60% of elderly patients living



▲ **Figure 53–3.** Noise-induced hearing loss. The audiogram shows a typical bilateral high-frequency sensorineural hearing loss, most severe at 4000 Hz, with a normal speech discrimination score.

at home and 81–91% of patients in an outpatient geriatric clinic complain of dizziness. By age 80, one in three people will have suffered a fall associated with significant morbidity. Vestibular symptoms precede these falls in more than half of the patients. The diagnostic evaluation of elderly patients complaining of dizziness yields a specific diagnosis in less than a third of the patients.

D. Patient Evaluation

A thorough vestibular evaluation begins with a complete history, a general physical examination, and a specialized neurotological examination.

E. Imaging Studies

In the presence of asymmetric or sudden hearing loss or vestibular symptoms with associated neurological findings, a magnetic resonance imaging (MRI) scan with contrast enhancement is indicated to rule out retrocochlear pathology. When inner ear malformations or superior canal dehiscence is suspected, computed tomography (CT) of the temporal bone may be revealing.

F. Special Tests

Further evaluation may include electronystagmography, CT scanning, and MRI. **Electronystagmography** is a graduated series of evaluations of the vestibular and vestibuloocular systems that includes caloric responses. It may be useful in establishing the degree of vestibular function in an ear, determining the side of the pathology, and differentiating central from peripheral diseases. **Posturography** assesses the ability of the subject to maintain balance with changing visual and somatosensory input.

Rotational testing is available to evaluate the vestibuloocular reflex. After age 70, the elderly exhibit a decline in caloric response. The relative energy required to maintain balance on the posturography test increases linearly with age until age 70. Studies of the vestibuloocular reflex in the elderly have shown a decreased sensitivity and shorter time constants over a wide range of frequencies of rotational stimuli. Overall, aging affects the vestibular, visual, and proprioceptive information available for central processing, as well as the ability of the central nervous system to process the sensory information and effect motor response.

▶ Differential Diagnosis

A. Hearing Loss

1. Ototoxicity—Not all hearing loss in the elderly is presbycusis. Ototoxic drugs such as aminoglycoside antibiotics, loop diuretics, and antineoplastic agents (especially cisplatin) may contribute to hearing loss in the elderly. Patients especially at high risk for injury to the auditory system from ototoxic drugs include those with a preexisting hearing loss, those undergoing simultaneous treatment with multiple ototoxic drugs, and those with renal insufficiency. The risk of ototoxic injury can be significantly reduced by monitoring ototoxic exposure with **serial audiometry**. Of course, serum peak-and-trough levels should be measured to establish the lowest possible dose compatible with therapeutic efficacy. Substitution with nontoxic therapy, whenever feasible, is paramount for prevention.

2. Sudden sensory hearing loss—Sudden loss of hearing in one ear is a relatively common occurrence in the elderly. Most cases are the result of thrombotic or embolic obstruction of the internal auditory artery. Although complete losses seldom recover, most partial losses experience some degree of spontaneous improvement within a few weeks to months. Empirical therapy with oral prednisone appears to be of some benefit. Although most sudden losses are idiopathic and presumably vascular, other etiologies, such as acute endolymphatic hydrops, perilymphatic fistula, tertiary syphilis, brainstem ischemia or infarction, demyelinating disease, and vestibular schwannoma, should be considered.

3. Asymmetric hearing loss—Most hearing losses in the elderly are bilateral and symmetric. Unilateral or asymmetric sensorineural hearing loss is atypical and demands further investigation to exclude disease of the central auditory system, such as vestibular schwannoma. The most common symptoms of **vestibular schwannoma** are sensorineural hearing loss, tinnitus, and dysequilibrium.

The initial screening test for the evaluation of asymmetric hearing loss is the **auditory brainstem response** (ABR), which records the changes in the electroencephalogram evoked by sound stimulation. Five waves may be observed in the first 10 ms, corresponding to the activation of the eighth cranial nerve (Wave I), the cochlear nucleus (Wave II), the superior olive (Wave III), the lateral lemniscus (Wave IV), and the inferior colliculus (Wave V). Absent ABR response or interaural latency differences in Wave V >0.3 ms are suggestive of retrocochlear pathology and warrant further radiological evaluation. Gadolinium-DTPA-enhanced MRI scanning is the gold standard for evaluating diseases involving the cerebellopontine angle and the internal auditory canal. MRI scanning may also detect brainstem pathology, such as multiple sclerosis or infarction, which can mimic the clinical presentation of vestibular schwannoma.

4. Other types of hearing losses—Less common causes of sensorineural hearing loss in the aged are numerous and include metabolic derangements (eg, diabetes, hypothyroidism, hyperlipidemia, and renal failure); infections (eg, measles, mumps, and syphilis); autoimmune disorders (eg, polyarteritis and lupus erythematosus); physical factors (eg, radiation therapy); and hereditary syndromes (eg, Usher syndrome). The identification of metabolic, infectious, or autoimmune sensory hearing loss is especially important because these hearing losses are occasionally reversible with medical therapy.

B. Balance Disturbance

1. Vertebrobasilar insufficiency—In the elderly, vertebrobasilar insufficiency is an important cause of vertigo and dysequilibrium. It usually results from arteriosclerosis with insufficient collateral circulation, but may also be due to compression of vertebral arteries by cervical spondylosis, postural hypotension, or the subclavian steal syndrome. The full-blown clinical presentation of vertebrobasilar ischemia includes vertigo with head motion (especially looking up), dysarthria, numbness of the face, hemiparesis, headache, and diplopia. Less frequently, visual disturbances occur including oscillopsia, field defects, transient blindness, cerebellar ataxia, and dysphagia; drop attacks may also occur, reflecting ischemia of the brainstem and cerebellum. Vertigo or dysequilibrium may occur without other neurological signs or symptoms. A definitive diagnosis may be established by **four-vessel cerebral angiography**, but is seldom indicated. Presently, there is no effective medical or surgical treatment for vertebrobasilar insufficiency, although rehabilitative measures may be beneficial.

2. Systemic disorders—A plethora of systemic disorders may affect equilibrium and balance in the elderly, including cardiovascular disease, cerebrovascular disease, peripheral vascular disease, neurological disorders, visual impairment, metabolic disease, and musculoskeletal problems. Therapeutic drugs are frequently responsible for dysequilibrium and postural instability, especially the antihypertensive, antidepressant, and sedative-hypnotic classes.

3. Peripheral vestibular disorders—A host of peripheral vestibular disorders may cause vertigo, including benign paroxysmal positional vertigo (BPPV) or cupulolithiasis, labyrinthitis, vestibular neuronitis, Meniere syndrome, labyrinthine concussion due to trauma, superior canal dehiscence, and perilymph fistulas, among others. In younger patients, BPPV is usually secondary to trauma, whereas in the elderly it is usually a result of degenerative processes. Patients complain of intermittent, irregular episodes of vertigo precipitated by rapid head motion. Vestibular suppressant medications are of limited usefulness except during periods of exacerbation. The severity of symptoms may diminish with repetition because of habituation. Patients usually respond to vestibular exercises, and spontaneous resolution occurs within 1 year in most cases.

4. Meniere syndrome—Meniere syndrome is characterized by episodic severe vertigo, fluctuating sensorineural hearing loss, tinnitus, and ear "fullness." Pathologically, there is distention of the endolymphatic system throughout the inner ear, presumably due to dysfunction of the endolymphatic sac. The clinical course is highly variable, with clusters of severe episodes interspersed with periods of remission of variable duration. Management may include a sodium-restricted diet, diuretics, vasodilators, vestibular suppressants, and, occasionally, surgery to decompress the endolymphatic system.

5. Acute labyrinthitis—Probably a viral infection of the inner ear, acute labyrinthitis, causes both severe vertigo and hearing loss. Typically, it runs its course over a period of 1–2 weeks, although residual hearing loss and the periodic recurrence of vertigo are common sequelae. Vestibular neuronitis also presents with vertigo similar to labyrinthitis, but is unaccompanied by auditory symptoms.

Treatment

A. Rehabilitation of Hearing Loss

1. Hearing aids—Nearly 30 million people, or 10% of the US population, have hearing problems in one or both ears. In the elderly, the reduced ability to discriminate sounds and to understand speech in a noisy background can be minimized with auditory rehabilitation, usually through amplification. Contemporary hearing aids are comparatively free of distortion and have been miniaturized to the point where they often may be contained entirely within the ear canal. To optimize the benefit, a hearing aid must be carefully selected to conform to the nature of the hearing loss. Digitally programmable hearing aids have recently become available and promise substantial improvements in speech intelligibility, especially under difficult listening circumstances.

2. Assistive devices—Aside from hearing aids, many assistive devices are available to improve comprehension in individual and group settings to help with hearing television and radio programs and to assist in telephone communication.

A. Television devices—Television devices include headphones that plug into the listening jack of the television, listening loops for use with the telecoil on a hearing aid, and wireless infrared devices that send the television signal directly to the listener via a receiver.

B. Telephone amplifiers and devices—Portable and nonportable telephone amplifiers are available to increase the loudness of the telephone audio signal. Handset amplifiers built directly into the telephone base or earphones are widely available. Telephone devices for the deaf using message screens or paper printouts are available for severe or profoundly hearing-impaired individuals.

C. Cochlear implants—The cochlear implant, an electronic device that is surgically implanted to stimulate the auditory nerve, is playing an increasingly important role in the audiologic rehabilitation of the elderly with severe or profound sensorineural hearing loss.

B. Rehabilitation of Vestibular Dysfunction

1. Nonsurgical measures

A. Pharmacologic agents—Many drugs have been used for the symptomatic relief of vertigo. The most commonly used drugs are antihistamines, sedative-hypnotics, and anticholinergics. Therapy with a combination of pharmacological agents may be efficacious when single-drug therapy has been ineffective.

(1) Vestibular suppressants—Vestibular suppressants should be used to lessen the unpleasant sensation and alleviate vegetative symptoms such as nausea and vomiting. However, they should be used only for a short duration of 1–2 weeks because they adversely affect the process of central compensation following acute vestibular disease. In acute, severe vertigo, diazepam, 2.5–5.0 mg administered intravenously, may abate an attack.

(2) Antiemetics—Relief from nausea and vomiting usually requires an antiemetic delivered intramuscularly or by rectal suppository (eg, prochlorperazine, 10 mg intramuscularly, or 25 mg rectally, every 6 hours).

(3) Antihistamines—Antihistamines may be used for less severe vertigo. Examples include meclizine or dimenhydrinate, 25–50 mg administered orally every 6 hours.

(4) Anticholinergic medications—Transdermal scopolamine, which is in widespread use for the suppression of motion sickness, is also useful in the management of vertigo. In the elderly, however, anticholinergic therapy is frequently complicated by mental confusion and urinary obstruction; the latter is found especially in males. The use of transdermal scopolamine may also be limited owing to the side effects of dry mouth and blurred vision and is contraindicated in glaucoma patients. A therapeutic effect with fewer side effects may be achieved by cutting the patch in half or even to one quarter of its size. Careful hand washing after handling the patches is necessary to prevent inadvertent eye contact, which could result in prolonged pupillary dilatation and possible acute narrow-angle glaucoma.

B. Exercise and physical therapy—After nausea and vomiting have resolved, exercise should be encouraged to enhance central compensation following peripheral labyrinthine dysfunction. Physical activity is the single most important element in functional recovery after acute labyrinthine dysfunction. Patients should be instructed to repeatedly perform maneuvers that provoke "vertigo-up" to the point of nausea or fatigue in an effort to habituate them. Many patients find vestibular exercise programs (eg, Cawthorne exercises) helpful. A formal physical therapy program designed to identify and correct maladaptive compensation strategies may also prove beneficial.

2. Surgical measures—Surgical intervention may be helpful in selected patients who continue to have disabling symptoms despite a prolonged and varied course of medical therapy. Surgical therapy may include sectioning of the vestibular nerve in a hearing ear or a labyrinthectomy in a deaf ear.

Prognosis

Hearing loss associated with aging is progressive. However, the rate of progression is variable. Age-related hearing loss usually progresses at a rate of 1– dB/year. Rehabilitation of the older deaf individual is often less than satisfactory. Amplification, though helpful in making sound audible, usually does not adequately address the reduction in clarity.

Cochlear implantation offers the hope of restoring audition and clarity to profoundly deaf individuals.

Imbalance can often be stabilized, but normal balance cannot be restored. Physical activity can play a critical role in the functional recovery of patients, allowing them to tend to routine daily activities with greater assurance.

Friedman RA, Van Laer L, Huentelman MJ, et al. GRM7 variants confer susceptibility to age-related hearing impairment. *Hum Mol Genet* 2009;18(4):785–796 [PMID: 19047183]. (This study showed that common alleles of GRM7 contribute to an individual's risk of developing age related hearing loss.)

Sprinzl GM, Riechelmann H. Current trends in treating hearing loss in elderly people: A review of the technology and treatment options—A mini-review. *Gerontology* 2010 Jan 12 [Epub ahead of print] [PMID: 20090297]. (An excellent review of hearing loss and its treatment in the elderly.)

Vaz Garcia F. Disequilibrium and its management in elderly patients. *Int Tinnitus J* 2009;15(1):83–90 [PMID: 19842350]. (A broad overview of disequilibrium in the elderly.)

Hereditary Hearing Impairment

54

Nicolas Gürtler, MD

ESSENTIALS OF DIAGNOSIS

- In most cases, sensorineural hearing loss of unknown origin
- Positive family history often present
- Vestibular symptoms possible, but rare
- In syndromic cases, associated with other clinical abnormalities

General Considerations

Hearing loss is the most common sensory deficit in humans. The prevalence of congenital hearing loss in newborns is approximately 1–3 cases per 1000. More than 60% of these prelingual cases (ie, hearing loss before the acquisition of speech) are attributed to genetic causes. A further 1 in 1000 children becomes deaf before adulthood. In patients over 60 years of age, approximately half show a hearing loss >25 dB HL. A large percentage of these populations is estimated to be likely affected by genetic influences, although age-related epidemiologic studies of the genetic contribution to hearing loss are not available. Finally, more than 100 deafness genes are believed to exist. These figures illustrate the impact of hearing loss on the public health system and the importance of genetic factors.

Classification

The most common and useful distinction in hereditary hearing impairment is syndromic versus nonsyndromic hearing impairment. Seventy percent of hereditary hearing impairments are nonsyndromic, whereas a minority of 15–30% are syndromic (Figure 54–1).

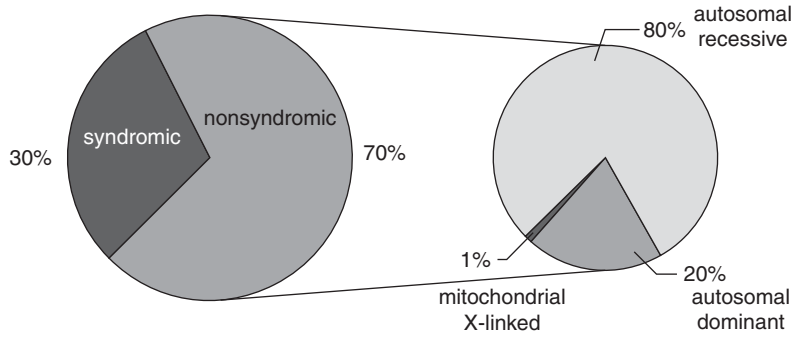
A. Nonsyndromic Hereditary Hearing Impairment

Nonsyndromic hereditary hearing impairment is classified by the mode of inheritance. Autosomal recessive transmission (designated by prefix DFNB) is implicated in approximately 80% of cases, autosomal dominant transmission (DFNA) is present in approximately 20% of cases, and X-linked (DFN) and mitochondrial transmission are responsible for <2% of cases (see Figure 54–1). One single gene, *GJB2* (*Gap-Junction Beta 2* encoding for connexin 26), has emerged to be the most common cause of recessive deafness, and up to 40% of the onset of sporadic prelingual hearing impairment can be attributed to defects in this gene both in Europe and the United States. The prevalence is higher in southern Europe than in northern Europe, mainly owing to one single gene mutation, c.35delG. In a stretch of six guanines extending from position 30 to 35, one base pair is deleted. The high incidence of this mutation seems to be due to a common ancestor. Other common mutations include c.167delT in Ashkenazi Jews and c.235delC in the Japanese population. Also, a common digenic pattern of inheritance involving *GJB2* and *GJB6* has been detected. Patients with a monoallelic mutation in *GJB2* harbor in addition a deletion of *GJB6*.

Mitochondrial genes constitute a small and unique group. Inheritance is entirely through the mother, because the maternal oocyte is the sole contributor of mitochondria. Although hearing loss occurs frequently in mitochondrial diseases, it is much more seldom the only symptom. The c.A1555G mutation in the *MT-RNR1* gene is the most important one among inherited hearing impairment with mitochondrial transmission.

B. Syndromic Hereditary Hearing Impairment

Syndromic hearing impairment means that hearing loss is accompanied by other clinical abnormalities. More than 400 syndromes that include hearing loss have been described in



▲ **Figure 54–1.** Causes and distribution of genetic deafness.

detail. Currently, syndromic hearing loss is categorized as follows: (1) syndromes due to cytogenetic or chromosomal anomalies; (2) syndromes transmitted in a classic monogenic or mendelian inheritance; or (3) syndromes due to multifactorial influences, in which the phenotype results from a combination of genetic and environmental factors. The breakdown of the genetic code of the various syndromes will most certainly lead to a classification based on molecular-genetic findings.

Hilgert N et al. Forty-six gene causing nonsyndromic hearing impairment: Which ones should be analyzed in DNA diagnostics?. Mut Res. 2009; 681:189–196. (Detailed description of today's understanding of the molecular findings in hereditary hearing loss and clinical application.)

Del Castillo I, Villamar M, Moreno-Pelayo M et al. A deletion involving the connexin 30 gene in nonsyndromic hearing impairment. *NEJM*. 2002;346(4):243. [PMID: 11807148] (First evidence for a digenic pattern of inheritance in hereditary hearing impairment.)

Pathogenesis

Several distinctions are typical of hereditary hearing impairment. Usually, the disease is genetically highly heterogeneous, with many different genes responsible for auditory dysfunction. To complicate things further, different mutations in one gene can cause variable phenotypes (eg, connexin genes in the skin or the ears) or even syndromic and nonsyndromic hearing loss as seen in genes *SLC26A4* (Pendred syndrome and DFNB4), *MYH9* (May-Hegglin/Fechter syndrome and DFNA17), and *WFS1* (Wolfram syndrome and DFNA6/DFNA14). Finally, a mutated gene can cause dominant and recessive forms of hearing loss. Typical examples include *GJB2* and *TECTA*.

A. Nonsyndromic Hereditary Hearing Impairment

Most of the nonsyndromic genes that cause deafness are not restricted to the cochlea; the inner ear seems to be more sensitive to disruption of some cellular functions than are other organs. In most cases, the function of these genes is only slightly understood. Several genes involved in ion homeostasis and cytoskeleton (ie, hair-cell) structure that lead to deafness have been identified. Other genes include cell-to-cell interaction, transcription factors, extracellular matrix and a few genes with unknown functions. Nonsyndromic genes discovered by the end of 2009 are listed in Table 54–1, which includes their function and mode of inheritance.

1. Homeostasis—In the homeostasis group, the gap-junction proteins (connexins) are the most well known. Three types of connexin genes have been discovered; *GJB2* is the most prevalent. The protein encoded by *GJB2* (connexin 26) is involved in intercellular transport of ions, metabolites, and second messengers. Based on its expression in the human cochlea in the stria vascularis, the basement membrane, the limbus, and the spiral prominence, as well as in animal studies, the role of *GJB2* seems to lie in recycling potassium ions back to the endolymph of the cochlear duct after stimulation of the sensory hair cells.

2. The gene—*OTOF* is responsible for synaptic exocytosis of neurotransmitters in auditory hair cells.

3. Hair-cell structure—Unconventional and conventional myosins represent the largest group of genes involved in hair-cell structure and motility. Myosins are actin-dependent molecular motors. Unconventional myosins are found in different locations in the inner ear, including the hair cells. Their various functions include endocytosis, the regulation of ion channels, the movement of vesicles in the cytoplasm, and anchoring stereocilia.

4. Transcription factors—Transcription factors are important for regulating the expression of other genes. The EYA4 protein, for example, regulates the early development of the organ of Corti and maintains its continued function postdevelopmentally.

Delmaghani S. et al. Mutations in the gene encoding pejvakin, a newly identified protein of the afferent auditory pathway, cause DFNB59 auditory neuropathy. *Nat Genet*. 2006;38(7): 770–777. (Interesting deafness gene study in mice and men in various regards)

Table 54–1. Nonsyndromic Hereditary Hearing Impairment: Genes (as Identified by the End of 2009) According to their Function and Type of Inheritance.

Gene	Function	Transmission
KCNQ4	Homeostasis	Autosomal dominant
WFS1		
CRYM		
CLDN14		
TRIC		Autosomal recessive
SLC26A4		
GJB2 (Connexin 26)		
GJB3 (Connexin 31)		both
GJB 6 (Connexin 30)		
TMC1		
OTOF	Exocytosis of neurotransmitter	Autosomal recessive
MYH9	Cytoskeletal system	Autosomal dominant
ACTG1		
DIAPH1		
CCDC50		
USH1C		
PCDH15		
MYO15		
TRIOBP		
MYO3A		
THMS		
SLC26A5		
WHRN		Autosomal recessive
CDH23		
RDX		
MYO7A		
MYO6		both
ESPN		
EYA4	Transcription factors	Autosomal dominant
TFCP2L3		
POU4F3		
POU3F4		X-linked
ESRRB		Autosomal recessive
COCH	Extracellular matrix	Autosomal dominant
OTOA		Autosomal recessive
STRC		
TECTA		both
COLL11A2		
MYO1A	Unknown	Autosomal dominant
DFNA5		
MYH14		
TMPRSS3		Autosomal recessive
TMIE		
PJVK		

B. Syndromic Hereditary Hearing Impairment

The list of genes responsible for syndromic hearing impairment encompasses diverse molecules, such as enzymes, transcription factors, and cytoskeletal and extracellular matrix components. Although syndromic deafness is mostly inherited in an autosomal dominant fashion, in some cases, the transmission from parents to children does not occur. A classic example is neurofibromatosis, in which approximately 50% of genetic mutations are spontaneous. A summary of genetic findings is listed in Table 54–2.

1. Pendred syndrome—The gene for Pendred syndrome is named *SLC26A4*. Findings based on mouse model suggest a role as an anion exchanger that is likely to mediate HCO3—secretion into the endolymph.

2. Waardenburg syndrome—Of the six genes identified in Waardenburg syndrome, four belong to the family of transcription factors that bind DNA and regulate its transcription. The other two genes are members of the group of endothelins and are involved in the development of neural crest-derived cells, which evolve into neurogenic or nonneurogenic sublineages, such as melanocyte precursors.

3. Usher syndrome—Among the 10 mapped loci connected to Usher syndrome, nine genes are identified. The best-studied gene is MYO7A, which is implicated in development and functioning of stereocilia.

4. Alport syndrome—Mutated collagen genes are responsible for the phenotype in Alport syndrome. Abnormalities in the basement membrane due to defective collagen Type IV have been demonstrated.

5. Branchio-Oto-Renal syndrome—Another transcription factor, EYA1, plays a predominant role in the pathologic mechanisms of Branchio-oto-renal syndrome. Sixty percent of sporadic cases are accounted for by mutations in this gene.

6. Neurofibromatosis Type II—Merlin, the neurofibromatosis Type II gene product, acts as a tumor suppressor and is important for cell movement, cell shape, and communication.

7. Jervell–Lange–Nielsen syndrome—Disturbances in the hemostasis of endolymph through the defunct subunits of potassium channels (eg, KCNE1 and KVLQT1) cause Jervell–Lange–Nielsen syndrome.

8. Treacher-Collins syndrome—Most mutations in Treacher Collins syndrome result in the introduction of a stop codon with premature termination of the protein product, which disrupts ribosome biogenesis of the neural crest cells, the progenitors cells of bone and connective tissue of the the head.

9. Stickler syndrome—Mutated collagen genes are also responsible for the phenotype in Stickler syndrome. Some evidence points to the organ of Corti as the target organ, at least in Type III.

Table 54–2. Syndromic Hereditary Hearing Impairment: Clinical Findings Besides Hearing Loss and Known Associated Genes (Most of the Molecular Analysis in Regard to Function and Localization of the Gene is Based on the Mouse Model).

Syndrome	Clinical Findings	Gene		
		Name	Function	Localization
Pendred syndrome	Goiter	*PDS*	Anion exchanger	Endolymphatic duct and sac, utricle, saccule, cochlea
		FOXI1		
Waardenburg syndrome	Dystopia canthorum; pigmentary abnormalities of hair, iris and skin	*MITF, PAX3, SOX10, SNAI2*	Transcription factors	Neural-crest-derived cells
		EDN3, EDNRB	Cell development	Melanoblast, neuroblast precursors
Usher syndrome	Retinitis pigmentosa	*MYO7A*	Complex protein network for development, functioning and maintenance of hair cells (stereocilia, tip links, synapses)	Hair cells
		USH1C		Organ of corti, saccule, utricle
		CDH23		Inner, outer hair cells
		PCDH15		Sensory epithelium inner ear
		SANS		Hair cells
		USH2A		Basement membrane
		VLGR1		?
		WHRN		Hair cells
		USH3		hair cells, spiral ganglion
Alport syndrome	Renal dysfunction (hematuria with progressive renal failure) ocular abnormalities (lenticonus and retinal flecks)	*COL4A3, COL4A4, COL4A5*	Collagen formation	Outer sulcus, inner sulcus, basilar membrane, spiral ligament of cochlea
Branchio-oto-renal syndrome	Branchial derived anomalies (cleft, cysts or fistulas) renal malformations	*EYA1*	Role in development of inner ear	Vestibular organ, inner ear, sensory epithelium inner ear
		SIX1		
		SIX5	Transcription factor	?
Neurofibromatosis Type II	Bilateral vestibular schwannomas meningioma, schwannoma, glioma neurofibroma in scalp juvenile subcapsular cataract	*NF2*	Tumor suppressor gene	Schwannoma cells
Jervell–Lange–Nielsen syndrome	Prolonged QT interval with syncopal attacks	*KVLQT1, KCNE1*	Potassium channel	stria vascularis
Treacher collins syndrome	Hearing loss due to malformations in the middle and inner ear craniofacial abnormalities (mandibulofacial dysostosis)	*TCOF1*	Regulator ribososome biogenesis	Neural folds, branchial arches
Stickler syndrome	Conductive hearing loss possible eye findings (high myopia, cataract) arthropathy (spondyloepiphyseal dysplasia) cleft palate	*COL2A1, COL11A1, COL11A2, COL9A1*	Collagen protein	tectorial membrane

Kremer H. et al.Usher syndrome: molecular links of pathogenesis, proteins and pathways. *Hum Mol Genet*. 2006; 15:R262–270. (Good summary of the protein network functioning in Usher syndrome.)

Prevention

It is most important to detect infants born with nonsyndromic hearing loss early in order to support normal language development. The appropriate management of auditory function is greatly facilitated by early diagnosis. Children in whom intervention begins before 6 months of age can acquire normal language development, in contrast to late intervention, with developmental language quotients of only 50–60%. Even in using risk factors for the proper identification of these children, 50% of infants born with hearing loss will not be identified. Therefore, universal hearing screening programs have been established. They are based

on the measurement of otoacoustic emissions and auditory brainstem responses. These methods have been proved to be objective and highly sensitive in identifying infants with greater than mild hearing loss. Only about 15% of hearing-impaired children will be missed by newborn hearing screening because their hearing loss will manifest postnatally, sometimes as late as school age.

Clinical Findings

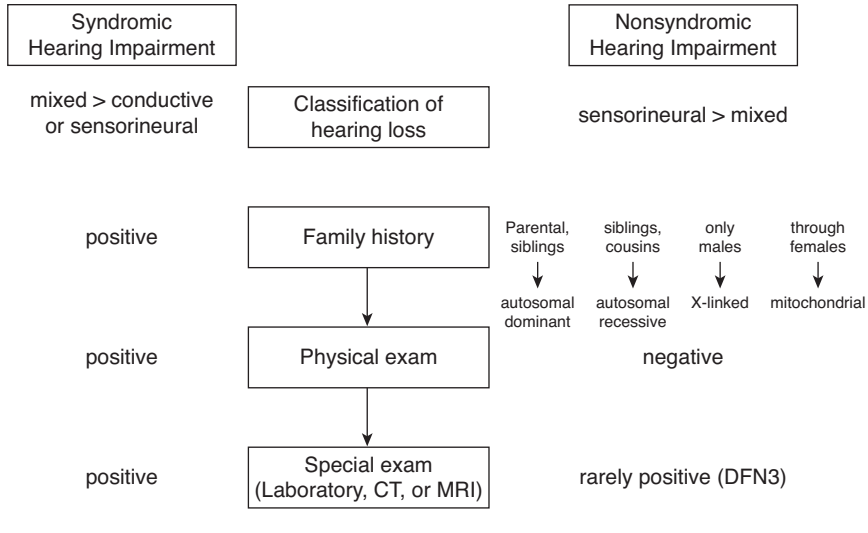
A. Symptoms and Signs

A thorough history should be considered because it easily allows the physician to separate hereditary hearing impairment from other causes. Questions should cover embryopathies such as rubella, toxoplasmosis, or cytomegalovirus, as well as any ototoxic drug use. An audiologic assessment is mandatory and should include both parents and siblings. A pure-tone audiogram is usually sufficient. In children, testing of the auditory brainstem response and otoacoustic emissions can be performed. All forms of hearing loss can be seen in hereditary hearing impairment. Guidelines on how to approach patients with hereditary hearing impairment are outlined in Figure 54–2.

A careful physical examination is recommended, especially to detect syndromic hearing loss. The patient's ears should be examined for abnormalities such as auricles and preauricular pits; in addition, one should look for pigmentary changes in the skin and hair and for a possible goiter. To complete a thorough assessment, an ophthalmologic examination and urinanalysis/renal ultrasound have to be taken into account. In addition, other specialists, such as pediatricians, ophthalmologists, cardiologists, and others, should be consulted as a part of the proper evaluation of these children.

1. Nonsyndromic hereditary hearing impairment—Most cases of profound prelingual hearing loss are associated with DFNB and are almost exclusively due to cochlear defects. In postlingual cases, an autosomal dominant inheritance is predominant; the hearing loss is less severe and besides sensorineural defects, conductive impairments are found. In X-linked disease, hearing impairment in males is earlier in onset and more severe than in females since the disease is transmitted only through female family members. Either all of the frequencies or the high frequencies are affected.

Patients with nonsyndromic hereditary hearing impairment demonstrate a few common features. Usually, the hearing loss is symmetric. The U-shaped or "cookie-bite" form is classically indicative for hereditary hearing impairment. In most cases, the hearing threshold is sloping in the middle and high frequencies; rarely, only the low frequencies are affected. The hearing loss can vary from moderate to profound and can be either stable or progressive. One of the best-studied genes, *GJB2*, which accounts for the majority of inherited deafness, has only been associated with a prelingual onset. The phenotype of patients with *GJB2* mutations varies enormously, even among siblings, from mild to profound, with audiometric curves that are either flat or sloping, and even in patients harboring the same mutation (c.35delG), indicating the presence of a hitherto unknown modifier gene. Some audio profiles are indicative of the possible underlying mutation. Moderate midfrequency hearing loss and autosomal recessive inheritance are seen in *TECTA* mutations; low-frequency hearing loss together with a dominant inheritance pattern points to mutations in *WFS1*.



▲ **Figure 54–2.** Guidelines for evaluating patients with hereditary hearing impairment.

Table 54–3. Clinical Classification of Waardenburg Syndrome and Corresponding Genes.

Sensorineural Hearing Deficit Iris Pigmentary Abnormality Hair Hypopigmentation ▼			
Type I + dystopia canthorum *PAX3*	**Type II** – dystopia canthorum *MITF,SNAI2, 2 unknown*	**Type III** + dystopia canthorum + upper limb abnormalities *PAX3*	**Type IV** – dystopia canthorum + Hirschsprung disease *EDNRB, EDN3, SOX10*

Auditory neuropathy is characterized by the presence of otoacoustic emissions and absence of auditory brainstem responses. *OTOF* mutations seem to be the major cause for this form hearing impairment, the other gene being *PJVK*.

2. Syndromic hereditary hearing impairment—Syndromic hearing loss may be conductive, sensorineural, or mixed; other clinical features must be considered to allow for the recognition of a distinct entity. More than 400 syndromes that include hearing loss have been described. Most of these syndromes are characterized only clinically, with their underlying molecular mechanisms still unknown. At present, auditory–pigmentary diseases are the largest and best-characterized group and include more than 55 syndromes.

The clinical features of the syndromes that follow are summarized in Table 54–2.

A. Pendred syndrome—Pendred syndrome is the most common syndromic form of deafness, accounting for approximately 10% of cases. It presents with sensorineural hearing loss and goiter. Usually, the goiter is evident before puberty, but an adult onset has also been noted. Thyroid function is evenly divided with 50% euthyroid patients and 50% hypothyroid patients. In most cases, the hearing loss is congenital, bilateral, moderate to profound, and sloping in the higher frequencies and progressive in most cases. An enlarged vestibular aqueduct is a consistent finding, and Mondini-type malformations have also been associated. In various studies, caloric testing showed diverging results, with both normal and depressed vestibular function.

B. Waardenburg syndrome—This syndrome is seen in at least 2–5% of patients with congenital hearing loss and includes the following clinical signs: dystopia canthorum; pigmentary abnormalities of the hair, iris, and skin; and sensorineural deafness in 20–50% of patients, depending on the classification type. Four clinical subtypes exist (Table 54–3). Abnormal functioning of the peripheral vestibular system can be found more often than hearing loss.

C. Usher syndrome—Three different types of Usher syndrome, the most common eye/ear syndrome, can be distinguished clinically by the type of hearing impairment, the absence or presence of vestibular responses, and the onset of retinitis pigmentosa (Table 54–4). The genetic classification is incomplete and includes 11 genes. The prevalence of this disorder among deaf children may be as high as 8%. The advancing failure of vision has the greatest impact on the quality of life in patients with this syndrome.

D. Alport syndrome—Alport syndrome is distinguished by hematuria with progressive renal failure, initial high-tone sensorineural hearing loss, and ocular abnormalities such as lenticonus and retinal flecks. The syndrome is seen in at least 1% of patients with congenital hearing impairment.

Table 54–4. Classification of Usher Syndrome by Clinical Type and its Corresponding Genes.

Type	IB-F[a]	IIA/IIC[a]	III
Hearing impairment	Profound, congenital	Sloping, congenital	Progressive
Vestibular response	Absent	Normal	Variable
Onset of retinitis pigmentosa	First decade	First or second decade	variable
Genes	*MYO7A, USH1C, CDH23, PCDH15, SANS*, 1 unknown	USH2A, *VLGR1*, WHRN, 1 unknown	*USH3*

[a]USH1A/USH2B: withdrawn, original linkage was spurious.

E. Branchio-oto-renal syndrome—The symptoms of this syndrome can be derived from its name: (1) branchial anomalies (clefts, cysts, or fistulas), (2) otologic anomalies (malformed pinna, preauricular pits, and hearing loss), and (3) renal malformations (hypoplastic kidneys and vesicoureteric reflux). Its prevalence is 2% in profoundly affected children. Sensorineural, conductive, or, most often, mixed hearing loss is seen. Hearing is affected with approximately 80% penetrance.

F. Neurofibromatosis type ii—Neurofibromatosis Type II is characterized by bilateral tumors of the eighth cranial nerve (the vestibulocochlear nerve) and any of the following: meningiomas, schwannomas, gliomas, or juvenile subcapsular cataracts. The symptoms mostly begin in late childhood to early adulthood. Hearing loss, predominantly unilateral, presents in approximately 50% of patients. A molecular diagnosis in sporadic patients is less reliable because a high percentage of mosaicism for mutations is seen. Genetic screening should be considered in an asymptomatic, undiagnosed child, who is at risk for NF2 disease.

G. Jervell-Lange-Nielsen syndrome—The frequency of Jervell–Lange–Nielsen syndrome among those patients with a profound congenital hearing loss is approximately 0.25%. Sensorineural hearing loss is accompanied by syncopal attacks due to a prolonged QT interval. Death occurs in childhood if not treated.

H. Treacher collins syndrome—In Treacher Collins syndrome, the clinical diagnosis is facilitated as distinct craniofacial abnormalities are found. The hearing loss can be related to radiographic findings of malformed cochlear and vestibular apparatus, including the ossicles and external ear canal.

I. Stickler syndrome—Three phenotypes corresponding to three defective genes have been described in Stickler syndrome. The clinical signs include eye symptoms (eg, myopia, astigmatisms, and cataracts), arthropathy, cleft palate, and sensorineural hearing loss. Hearing loss can be mild to profound, progressive, affecting all or the high frequencies.

Hoornaert KP et al. Stickler syndrome caused by COL2A1 mutations: genotype-phentoype correlation in a series of 100 patients. *Eur J Hum Genet*. 2010 Aug;18(8):872–880. (Good illustration of the complexity in genetic hearing impairment).

B. Laboratory Findings

Laboratory tests are helpful in distinguishing nonsyndromic from syndromic hereditary hearing impairment. However, full laboratory and radiographic evaluations are expensive, and the rate for obtaining a definite diagnosis is reported to be approximately 40–70%, although a thorough analysis has not been done. Therefore, laboratory tests should be undertaken after careful deliberation. Urinanalysis is easy to perform and assesses the presence of proteinuria or hematuria (Alport syndrome). If Pendred syndrome is suspected, thyroid function tests should be requested.

C. Imaging Studies

CT or MRI (fast-spin echo technique or gadolinium-enhanced) are the imaging studies of choice. Abnormalities in the bony structures of the inner ear are detectable on a CT scan. A CT scan is generally recommended in the evaluation of childhood sensorineural hearing loss to detect inner ear malformations (for example large vestibular aqueduct–which is also the most common abnormality) that are associated with the higher risk of cerebrospinal fluid leak, meningitis, or traumatic hearing loss.

D. Special Tests

1. Mutation screening—Various mutation detection methods exist and are in use. The methods are based on either conformation-based techniques such as single-stranded conformational polymorphism (SSCP) or on base-mismatch recognition such as denaturing gradient gel electrophoresis (DGGE). The former is more common. Both methods—SSCP, because of its simplicity, and DGGE, because of its high sensitivity—are the favored techniques. Another method DHPLC—denaturing high-performance liquid chromatography—is suitable for rapid, automated mutation screening. However, each of these methods has significant shortcomings, including expense, time, and limited sensitivity. Direct sequencing of the gene is the only technique available to identify any number and type of mutations. In the future, array-based automatic screening methods, which allow for analyzing multiple genes and mutations concurrently, will become popular.

2. Perchlorate challenge test—The perchlorate challenge test can be performed with Pendred syndrome, although it is not specific and its sensitivity is unknown.

E. Special Examinations

An ophthalmologic examination (vision acuity, fundoscopy, and electroretiongramm to detect retinitis pigmentosa) is recommended to detect syndromic features (especially Alport, Stickler, and Usher syndromes) and to distinguish syndromic from nonsyndromic hereditary hearing impairments. Vestibular symptoms are not a typical feature of hereditary hearing impairment. However, if a patient reports dizziness or balance problems, functional testing of the peripheral vestibular system should be performed. For instance, absent vestibular responses can be seen in Usher syndrome Type I and in some forms of autosomal recessive deafness (DFNB4, etc.). Renal ultrasound scan may reveal dysplasia in Branchio-Oto-Renal syndrome. In suspected Jervell–Lange–Nielsen syndrome, an electrocardiogram should be performed.

Gorlin RJ, Toriello HV, Cohen MM Jr. Hereditary Hearing Loss and Its Syndromes. Oxford University Press, 1995. (Very comprehensive and detailed description of all syndromes known to be associated with hearing loss.)
Grundfast KM, Siparsky N, Chuong D et al. Genetics and molecular biology of deafness. *Otolaryngol Clin North Am*. 2000;33:1367. [PMID: 11449793] (Very thoughtful proposal for a clinical approach to hereditary hearing disorders.)

Differential Diagnosis

In syndromic cases, the challenge lies more in correctly identifying the syndrome than in missing the inherited forms. In isolated cases of sensorineural hearing loss, all forms of cochleopathies—not just those that are due to hereditary causes—must be included in the differential diagnosis. Congenital infections such as cytomegalovirus can mimic hereditary hearing loss. In chronic noise-induced hearing loss, a history of noise exposure is pathbreaking. A dip in the hearing threshold between 3 and 6 kHz is typical for this condition. Tinnitus may be present and is much more common than in inherited hearing loss. Trauma of the labyrinth can be suggested by the patient history and often results in an asymmetric hearing loss. Metabolic disorders such as hyperlipidemia or uremia are still disputed to be causative for sensorineural hearing loss.

Cochlear otosclerosis is rare as a single entity and is usually accompanied by conductive hearing impairment. Blood and vascular disorders have been associated with hearing impairment. The use of ototoxic drugs and agents should be ascertained by taking the patient history.

Treatment

Depending on the degree and onset of the patient's hearing loss, various hearing aids, including cochlear implants, have to be evaluated in patients with hereditary hearing impairment. Gene therapy for hearing disorders has potential future applications. Currently, most studies focus on gene delivery. The problems to be overcome are the targeted correction of gene function without systemic side effects, and sustainable changes in the inner ear.

Kanzaki S. et al. Transgene correction maintains normal cochlear structure and function in 6-month-old Myo15a mutant mice. *Hear Res*. 2006;214(1–2):37–44. (One of the few reports of successful hearing restoration through molecular-genetic methods.)

Prognosis

Generally spoken an accurate prediction is difficult in almost all cases of hereditary hearing impairment. Nonetheless, some prognostic information exists. The recurrence chance for parents having a child with *GJB2*-related hearing loss is 25% for the same genotype. The outcome is excellent in these children in case they receive a cochlear-implant. In some syndromic cases like Waardenburg syndrome Type II and Usher syndrome Type III, the hearing loss may be progressive; in Alport syndrome, the hearing loss usually occurs during childhood only.

RELEVANT WORLD WIDE WEB SITES

[Centrum Medische Genetica]
http://www.uia.ac.be/cmg/
(This website is a very comprehensive list of nonsyndromic loci and many syndromic loci, including genes, mouse models, and references.)
[The Connexin-Deafness Homepage]
http://crg.es/deafness/
(This website is solely dedicated to connexin genes and deafness.)

Aural Rehabilitation & Hearing Aids

55

Robert W. Sweetow, PhD, & Troy Cascia, AuD

There has been much cynicism regarding the value of hearing aids. However, a study published in *JAMA* confirmed what audiologists have recognized for decades: Hearing aids do indeed provide substantial benefit and reduce communication problems. The National Council on Aging study on the impact of untreated hearing loss in over 2000 hearing-impaired adults and their significant others indicated that individuals with untreated hearing loss were more likely to report depression, anxiety, and paranoia, and less likely to participate in organized social activities compared to those who wear hearing aids. Other studies have indicated that hearing aid use is associated with significant improvements in the social, psychological, emotional, and physical aspects of the lives of hearing-impaired persons with all degrees of hearing loss.

Despite these findings and data indicating significant improvements in satisfaction related to advanced technological features, the percentage of hearing-impaired individuals who own hearing aids has increased only slightly since 1984 and remains below 25%. Many individuals continue to reject hearing aid use for a combination of reasons, including denial of need, stigma, cost, and lack of adequate benefit in the more difficult, noisy listening environments in which help is most needed. In addition, patients are not likely to attempt to resolve problems they are not highly motivated to address without the expressed recommendation of their physician, yet less than 15% of adults receive hearing screenings from their medical doctor.

Kochkin S. MarkeTrak VIII: twenty-five year trends in the hearing health market. *Hear Rev.* 2009;16(10):20. (A large survey of demographics and satisfaction among hearing aid users.)

National Council on Aging. The consequences of untreated hearing loss in older persons. *ORL Head Neck Nurs.* 2000;18(1):12 [PMID: 11147549]. (Untreated hearing-impaired patients showed a wide range of significant hearing and emotional problems relative to those receiving amplification.)

PATIENT CANDIDACY

Types of Hearing Loss

Decades ago, it was believed that the use of hearing aids was limited to individuals with conductive hearing impairment and would not be helpful for individuals with a sensorineural hearing loss. Patients were informed that hearing aids could make sounds louder, but would not make them clearer. Currently, technologic improvements and improved fitting strategies allow for the successful fitting of hearing aids in most individuals with a sensorineural hearing impairment.

Degree of Hearing Loss

Hearing loss is too complex to be characterized by a single measure. Indeed, an audiogram provides information only about one aspect of hearing: threshold sensitivity. The reality is that individuals rarely listen at their hearing threshold. Instead, speech occurs at suprathreshold levels, and the intensity levels that an impaired cochlea is exposed to are considerably higher than normal because of amplification. For some patients, stimulation at high intensity levels enhances auditory function, but for others, it may not. Thus, the prognostic value of amplification and determination of candidacy for hearing aids on the basis of the degree of hearing loss is, at best, a questionable practice. If necessary, however, the following broad guidelines may be used (for a motivated individual).

A. Mild Hearing Loss (20–40 dB)

Hearing aid use may be helpful depending on the patient's communicative needs. Some may prefer to use amplification only on a part-time basis.

B. Moderate Hearing Loss (45–65 dB)

Amplification is needed and is usually successful if proper fitting strategies are used.

C. Severe Hearing Loss (70–85 dB)

Amplification is necessary if the patient wishes to use the auditory channel as the primary receptive mode. Cochlear implants may be considered if hearing aids are unsuccessful.

D. Profound Hearing Loss (>85 dB)

At a minimum, amplification is useful as a warning device; at a maximum, it allows the patient auditory use and likely enhances speechreading capabilities. Its effectiveness may depend on the age at which amplification is first used. Individuals with a profound hearing loss may be strong candidates for cochlear implantation.

Audiometric Configuration

With the versatility available in digital hearing aids, audiometric configuration is not a significant issue in determining candidacy.

Word Recognition (Speech Discrimination)

In general, patients with good word recognition scores are more likely to do better with hearing aids. However, it would be a mistake to conclude that either success or failure would depend on this single factor. Word recognition assessed in a sound-treated test booth is not reflective of the variety of difficult listening environments that many hearing-impaired users encounter. Word recognition ability becomes diminished because of four main factors: (1) reduced audibility, (2) cochlear distortions producing reduced frequency and temporal selectivity and resolution, (3) abnormal central auditory processing, and (4) diminished cognitive function. Modern hearing aid technology allows the audiologist the ability to compensate for reduced audibility. The other three factors, however, may not be subject to correction by amplification; and may, in fact, render a poor prognosis for success with amplification. Furthermore, word recognition testing is typically performed in a quiet environment. It is well known that individuals with a sensorineural hearing loss have considerably more difficulty understanding speech in a noisy environment. This difficulty is often a function of both peripheral and central disorders and may be particularly emphasized in elderly populations.

Patients presenting bilateral significantly asymmetrical word recognition scores often prefer monaural amplification for the better hearing ear only. There are many exceptions; however, so unless there are other contraindications (eg, extremely poor speech discrimination ability, an extremely limited dynamic range, or medical contraindications), low discrimination scores should not, by themselves, preclude a *trial* with amplification.

Other Factors

It is not unusual to find that the most important factors determining the success or failure of hearing aids are those unrelated to audiometric findings. Specifically, one must take into consideration *all* of the following: (1) the age and general physical and mental health of the patient; (2) the patient's, as opposed to only the family's, motivation; (3) finances; (4) cosmetic considerations; and (5) communication needs.

Unfortunately, despite need, many patients resist trying hearing aids. There is an unfortunate, yet undeniable social stigma attached to wearing hearing aids. The issue of cosmetic vanity is nearly obsolete now because of the continuing trend toward miniaturization of hearing devices and the increased use of open coupler devices described and shown later in this chapter. However, not all hearing-impaired listeners are candidates for these hearing aids. It is regrettable that hearing aids are often dispensed to patients who lack motivation for amplification. A poorly motivated patient is a poor candidate for amplification regardless of the degree of hearing loss and should not be forced into trying hearing aids. It is difficult to undo the damage that may be done if a candidate prematurely tries and fails with amplification. For these patients, it may be advisable to provide them with information and to wait a while so that they may clearly perceive the need. However, encouraging patients to put forth the effort toward a trial period, with the understanding that it is possible they may be pleasantly surprised, is certainly worthwhile.

Occupational and social demands vary greatly among individuals. A judge who has a mild hearing loss may desperately need amplification, whereas a retired elderly patient with the same degree of hearing loss living alone may not. Patients must ask themselves if the ability to hear, albeit not understand, is acceptable and adequate for their needs. They must unselfishly examine whether they are becoming a burden to others, even if they do not personally recognize difficulty hearing. The critical variable is whether the patient experiences difficulty hearing or increased stress and fatigue in daily function. Amplification may simply relieve the strain of hearing, as opposed to improving word recognition or making sounds louder. This alone, however, can be a significant benefit. Thus, candidacy for amplification should be based on the patient's subjective needs rather than strictly on the basis of the audiogram.

Cox RM, Alexander GC, Gray GA. Who wants a hearing aid? Personality profiles of hearing aid seekers. *Ear Hear.* 2005;26(1):12 [PMID: 15692301]. (Candidacy issues)

NUMBER OF DEVICES REQUIRED

Over 80% of hearing aid fittings in the United States are binaural. A number of factors likely contribute to binaural superiority. Eliminating or minimizing the **head shadow** (the reduction in signal intensity from the side of the head opposite the signal) is important for listeners with a high-frequency hearing loss. Improved **localization** results from

hearing sounds from both sides. A central release from masking (**binaural squelch**) may result in better hearing in noise. With **binaural loudness summation,** absolute binaural thresholds are 2–3 dB better than monaural thresholds. This summation effect occurs near threshold but not for high intensities near uncomfortable levels. Thus, the dynamic range of listening is greater for binaural listening than for monaural listening.

Other factors to consider in choosing binaural versus monaural amplification include the possibility of tinnitus reduction regardless of a perceived dominant side because of increased stimulation to more cortical neural substrate, and the legal implications of the potential deprivation of an unaided ear.

The general rule should be that unless there is a significant asymmetry in sensitivity, tolerance to loudness, or word recognition ability, or unless a medical condition exists contraindicating the insertion of anything into the external auditory meatus, the standard should be at least to try binaural amplification. For these patients, a wired or wireless contralateral routing of signal (CROS) aid or transcranial CROS (placing a hearing aid in the "dead" ear, producing bone conduction stimulation of the "good" ear) may be tried. It should be noted that CROS devices should be applied only if the better ear has normal or near-normal hearing, and the transcranial CROS should be used only if the poorer ear has no residual hearing that might produce recruitment or other distortion factors. If the "good" ear is in need of amplification, a bilateral contralateral routing of signal (BICROS), in which microphones are located on both ears but the signal is routed only to the "good" ear, can be tried. In cases of unilateral impairment, candidacy should be based on the individual's communicative needs. It is also possible to try a bone-anchored hearing aid (BAHA) if the impaired ear is unaidable.

Hol MK, Kunst SJ, Snik AF, Cremers CW. Pilot study on the effectiveness of the conventional CROS, the transcranial CROS and the BAHA transcranial CROS in adults with unilateral inner ear deafness. *Eur Arch Otorhinolaryngol.* 2009 Nov 11 [Epub ahead of print] [PMID: 19904546]. (Study comparing the effectiveness of various treatments for unilateral sensorineural hearing loss.)

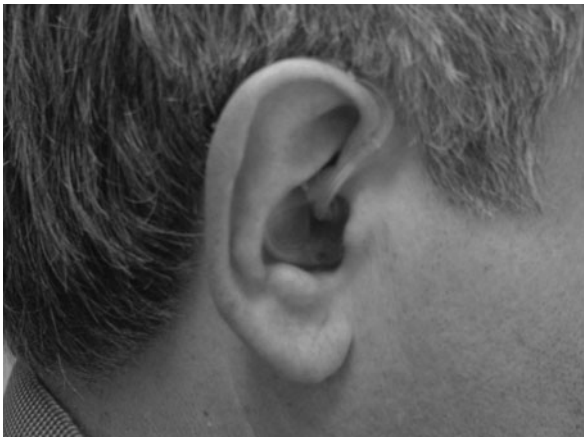
HEARING AID STYLES

Hearing aids are available in a variety of styles, as shown in Figure 55–1. The general categories of hearing aids are (1) completely in the canal (CIC), (2) custom in the canal (ITC), (3) custom in the ear (ITE), (4) behind the ear (BTE), and (5) open-fit mini BTE. Unfortunately, many patients choose a style of hearing aid based strictly on cosmetic factors. Although cosmetic considerations cannot be ignored, decisions regarding which style aid is most appropriate for a specific patient should be based on physical factors such as shape of the pinna, depth of the concha, contour, and diameter of the meatus; physical conditions such as drainage and exostoses, excessive production of cerumen, and manual dexterity; and audiologic factors such as degree of loss (patients with profound hearing loss are not candidates for CIC hearing aids), audiometric configuration (patients with regions of normal hearing, particularly in the low frequencies, are best served by systems that do not occlude the ear canal); need for special features (as discussed below); age of the patient; and cost of the devices.

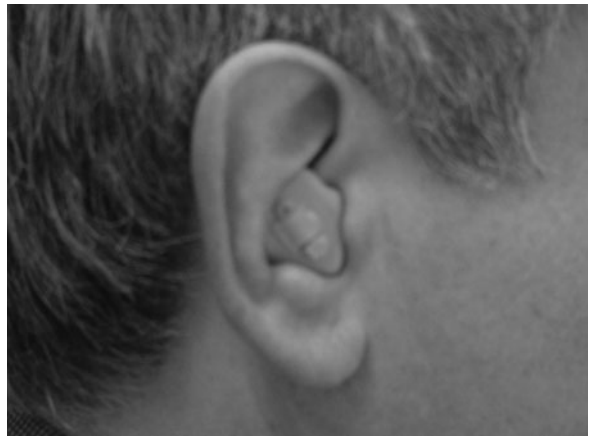
Probably the most common inquiry from patients today relates to whether they can use one of the small, "invisible" hearing aids. Hearing aids keep getting smaller, but smaller does not necessarily mean better. A canal-style hearing aid implies that no part of the hearing aid extends into the concha area. There are two types of canal-style hearing aids: the CIC and the ITC. The CIC is the smallest hearing aid and ideally is inserted several millimeters into the canal extending into the osseous portion of the meatus, and terminating within 5 mm of the tympanic membrane. The hearing aid is removed by a monofilament that lies near the tragal notch. The ITC is slightly larger, filling the cartilaginous portion (outer half) of the ear canal and is more visible than the CIC. Although CIC devices are the most cosmetically appealing for most ears, they are more difficult to keep clean because a small amount of wax can block the receiver. However, modern wax guard designs have significantly minimized this problem. They tend to be more susceptible to acoustic feedback because of the close proximity of the microphone to the receiver, although digital feedback suppression has minimized this concern. In addition, placement deep inside the meatus may produce a feeling of fullness and an occlusion effect that adversely impacts the perception of the user's own voice, giving the impression that one is talking inside a barrel. This occurs because low-frequency laryngeal vibrations are trapped inside the closed ear canal. To avoid this effect, it is often necessary to open the ear canal by venting the shell although this may be problematic for small devices.

Although less cosmetically appealing than smaller instruments, larger devices may solve many of these above-mentioned problems. The ITE fills the entire concha, whereas the BTE consists of two parts: a hearing aid that hooks onto and rests behind the pinna and a custom earmold attached by a tube that secures the aid and directs sound into the ear canal. Because the microphones are further from the receiver, these devices are less prone to acoustic feedback, thus allowing for larger venting and more amplification for severe to profound losses. Also, the larger batteries tend to last longer and are more easily handled by dexterity-challenged patients.

A new style, the open-fit mini BTE, has now become the most popular model. It combines many of the acoustic benefits of the larger styles with the cosmetic benefits of the smaller styles. Open-fit instruments consist of a small BTE device, a narrow tube that hooks over and closely follows the contour anterior to the crus of the helix, and a soft, nonoccluding coupler that directs sound into the ear canal. Another type of open fit instrument (RIC—receiver



A



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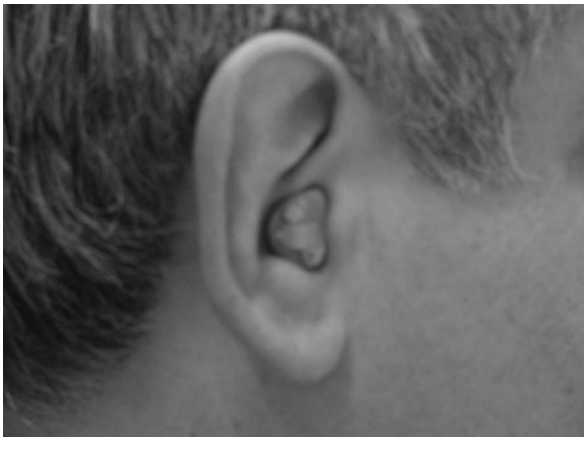

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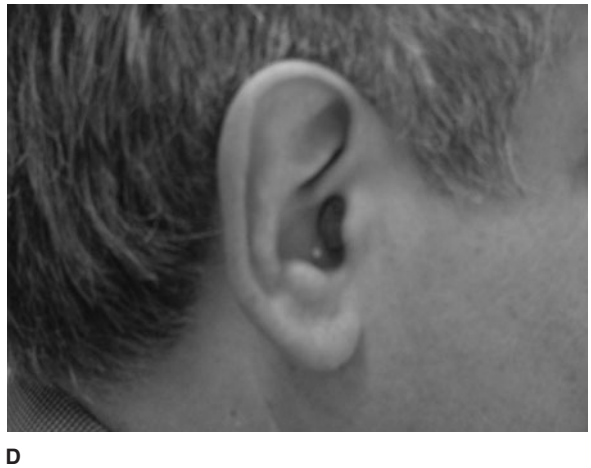
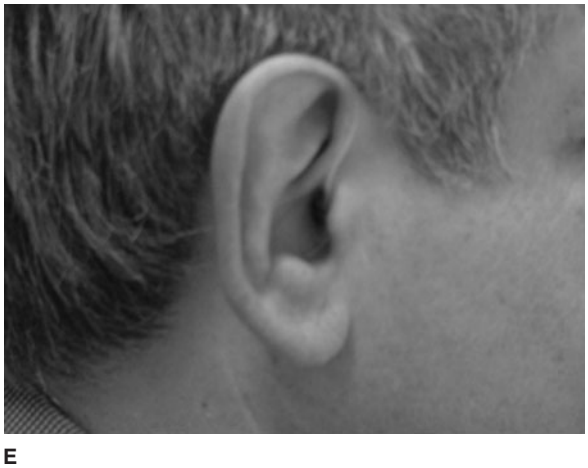


D



E

▲ **Figure 55–1.** Five styles of hearing aids. Left to right: **(A)** behind the ear (BTE), **(B)** full shell in the ear, **(C)** dual microphone in the canals (ITC), **(D)** completely in the canal (CIC), **(E)** open-fit mini BTE.

in canal) has most of the electronic components in a small BTE device behind the ear, but the receiver is located in the ear canal, and is connected to the instrument by a thin (0.8 mm) wire that follows the contour of the pinna. With both styles, the open fit greatly reduces the occlusion effect and allows natural sound to enter the ear canal for patients with good low frequency hearing. The instrument is very discreet and appealing to people with cosmetic concerns, and because it does not require custom molding, it can be programmed and fit in a single visit.

Even more recently, an extended wear, disposable hearing aid has been introduced to the market. This device, virtually invisible because it is inserted with the aid of an operating microscope into the osseous portion of the external meatus, terminates about 4 mm from the tympanic membrane. It has many virtues including ease of care (the device remains in the ear 24 hours a day for up to four months), natural sound (because the deep location allows for maintenance of the natural ear canal resonance which may be lost with conventionally placed devices), and minimization of the occlusion effect because of the location. However, the device comfortably fits into only about 50% of ears at this time, and patients who take anti-coagulants or who have immunocompromised systems are not currently candidates.

Kuk F, Baekgaard L. Hearing aid selection and BTEs: Choosing among various "open-ear" and "receiver-in-canal" options. *Hear Rev.* 2008;15(3):22–36. (Article reviewing open fit options.)

FEATURE ASSESSMENT

The last decade has brought a number of dramatic technologic advances in hearing aids. Nearly all modern hearing aids are controlled via computerized programming. Because of the great flexibility available, the choice of which instruments are appropriate for a given individual is largely based on the features offered. Some important features to be considered are (1) the type of processing, (2) compression, (3) directional microphones, (4) multiple programs, (5) frequency compression/transposition, (6) wireless connectivity and (7) the need for telecoils.

Processing Types

A. Conventional Hearing Aids

Fewer than 10% of hearing aids dispensed today fall into the conventional category. These devices are analog instruments that amplify, filter, and limit the maximum power via on-instrument screw-set controls, switches, or rotary wheels. They do not have the flexibility found in digital hearing aids. They typically use linear processing or contain relatively simple compression strategies. Many, though not all, have variable screw potentiometers that can be used to obtain a balance between low-frequency and high-frequency gain. In addition, most utilize user-operated volume controls.

B. Digital Hearing Aids

Digital hearing aids are computer-controlled devices. Digitization means that incoming sounds are converted to numbers, which are then analyzed and manipulated via a set of rules (algorithms) programmed into the chip controlling the hearing aid. Digital signal processing (DSP) allows instruments to attempt a differentiation of noise from speech, not only on the basis of spectral composition, but also on the basis of temporal characteristics. Noise and speech have quite distinct temporal patterns. DSP hearing instruments assess the modulation pattern (rate and depth) of the input signal to predict whether or not that signal is primarily speech. If it is, full amplification is provided. If not, gain is attenuated within that frequency band. Studies have consistently shown subjective preferences for digital hearing aids, but, similar to binaural amplification, this perceived benefit may not always be reflected by word recognition scores, particularly in quiet.

One of the most important advantages of DSP is digital feedback reduction. This active approach is very different from traditional feedback management approaches in that, rather than simply reducing gain in certain frequency regions (generally, the high frequencies), digital feedback control seeks out and minimizes feedback by means of phase-shifting technology. Clinical measurements have shown that these systems provide feedback margins of over10–15 dB. This can be extremely important for patients because many require significant high-frequency gain, but prefer nonoccluding open ear fittings.

Compression

Because most hearing aid users have sensorineural hearing loss and because cochlear hearing loss is characterized by a loss of the linear processing provided by outer hair cells, the vast majority of hearing aids now utilize compression (nonlinear amplification). Compression circuits provide increased amplification for soft intensities (to compensate for the loss of the nonlinear outer hair cells) and prevent the amplified signal from reaching the loudness discomfort level of the wearer by decreasing amplification for high input levels. Linear amplification provides constant **gain** (the difference in decibels between sound entering the microphone of the hearing aid and sound exiting the receiver) regardless of the input level until the output reaches a certain predetermined ceiling (saturation level). Thus, although it is useful in making soft sounds audible, louder sounds are frequently uncomfortable. Compression circuitry automatically reduces the gain when a predetermined level, referred to as the **kneepoint,** is reached.

A potential shortcoming of early compression circuits was that an input signal of any frequency reaching the kneepoint triggered a gain reduction across the frequency range, often reducing the gain of the high frequencies so much that the consonant sounds were not in the audible range of the listener. To combat this problem, many hearing aids contain **multichannel compression** (ranging from 2 to as many as

20 bands). With multichannel compression, when the offending signal is primarily low frequency-based (as is common for noise stimuli), only the low-frequency gain is reduced, thus leaving the high-frequency gain unaffected. This can preserve audibility of the important high-frequency consonant sounds. This feature also allows for greater flexibility in shaping the frequency response (gain as a function of frequency) and compensation for recruitment (the abnormally rapid loudness growth characteristic of sensorineural impairment). The pattern of recruitment in any given individual cannot be predicted simply on the basis of a pure-tone audiogram. Therefore, it is beneficial to have adjustable characteristics for the various compression parameters such as the kneepoint (the activation level), the **compression ratio** (how severely the gain is reduced), and the **release time** (how soon the aid returns to a full gain mode once the activating signal ceases).

Directional & Dual Microphones

Hearing-impaired patients frequently report that their primary communication difficulty is understanding speech in noisy environments. For these individuals to perform adequately, the signal-to-noise ratio (SNR) must be significantly higher than is necessary for individuals with normal hearing. Although the only true method of improving the SNR is to place the microphone in close proximity to the speaker's mouth using assistive listening devices like FM or infrared systems, an additional strategy is the use of directional or dual microphones. Hearing aids with a directional microphone (one microphone with two entry ports) or dual microphones (two separate microphones) function by recognizing the difference in arrival time when sound reaches the front compared with the rear microphone (or port). Through sophisticated processing, this time delay instructs the hearing aid to minimize the gain of sounds entering from the rear relative to the front, where, presumably, the person speaking would be located. Although single, omnidirectional microphones are often preferred for quiet listening, a significant improvement in noise is consistently shown in directional microphone modes. However, it should be noted that the benefits from multiple and directional microphones can be minimized by highly reverberant environments. In addition, there is a minimal space requirement of at least 3 mm for dual microphones. Therefore, CIC hearing aids remain too small for inclusion of this useful feature.

Bentler RA. Effectiveness of directional microphones and noise reduction schemes in hearing aids: A systematic review of the evidence. *J Am Acad Audiol.* 2005;16(7):473. Review. [PMID: 16295234]. (Evidence-based review of the literature on directional microphones and noise reduction.)

Ricketts TA, Hornsby BW. Sound quality measures for speech in noise through a commercial hearing aid implementing digital noise reduction. *J Am Acad Audiol* 2005;16(5):270 [PMID: 16119254]. (Controlled study of subjective impact of noise reduction.)

Ricketts TA, Hornsby BW. Distance and reverberation effects on directional benefit. *Ear Hear* 2003;24(6):472 [PMID: 14663347]. (How multiple microphone performance changes as a function of distance and reverberation.)

Multiple Programs

Many hearing aids offer multiple programs so that at the touch of a button on the aid or in a remote control, the electroacoustic characteristics of the aid can be instantly changed to better compensate for the particular acoustic environment. Some audiologists also use multiple programs to gradually introduce variations in amplified sound to the new user. For example, patients with a loss of high-frequency hearing initially may find that a sharply sloping high-frequency response sounds too "tinny." The optimal number of multiple programs to meet listening needs is unknown. Current multiple-program devices contain from two to four choices. If the device has no volume control yet the patient desires controllable changes in volume, devices having more programs might be beneficial so that program selection acts as a pseudo-volume control. In the past few years, many hearing aids have incorporated an automatic switching function dependent on internal sensors measuring the sound environment. Another use is for individuals with a fluctuating hearing loss, such as patients with Meniere's disease. Rather than having to return to the audiologist each time hearing thresholds change, various memories can be programmed in anticipation of the expected amount of shift.

Frequency Compression

A feature that has recently experienced technological improvements and an increase in popularity is frequency compression. For individuals with cochlear dead zones, (regions of nonfunctioning inner hair cells), traditional hearing aids cannot provide useful amplification for these frequencies. By shifting the amplified signal away from the frequency range of the cochlear dead zones and into an adjacent range with functioning inner hair cells, these sounds may become audible to the listener. Because the cues are now located at a different place on the basilar membrane, it may require an acclimatization period or additional training for the auditory cortex to adapt.

Glista D, Scollie S, Bagatto M, Seewald R, Parsa V, Johnson A. Evaluation of nonlinear frequency compression: clinical outcomes. *Int J Audiol* 2009;48(9):632–44 [PMID: 19504379]. (Study of performance and preference outcomes with use of frequency compression.)

Kuk F, Keenan D, Korhonen P, Lau CC. Efficacy of linear frequency transposition on consonant identification in quiet and in noise. *J Am Acad Audiol.* 2009;20(8):465–4679 [PMID: 19764167]. (Controlled study of efficacy of frequency transposition over time.)

Wireless Connectivity

Hearing aids are becoming increasingly compatible with electronic devices used for communication and entertainment. With the recent proliferation of wireless Bluetooth technology, some hearing aids can now interface via an intermediary device typically worn around the neck with cell phones, MP3 players, and other devices.

Telecoils

Many patients complain that they cannot hear well on the telephone with their hearing aids. Often, there is feedback that results from the physical proximity of the telephone receiver to the hearing aid microphone. To combat this problem, BTE and ITE hearing aids can contain a telecoil, a small inductance loop that picks up and amplifies electromagnetic leakage purposely produced from telephones. When the telecoil is activated, the microphone can be, but does not have to be, shut off, thus eliminating feedback. Telecoils also are used to interface with various assistive listening devices. The ability to program the telecoil separately from the microphone can be of great benefit. Certain cellular phones may be incompatible with telecoil usage; however, new FCC regulations are being phased in requiring increased compatibility compliance.

VALIDATION & VERIFICATION PROCEDURES

The verification and validation of a successful hearing aid fitting for patients should include the following: (1) the assessment of word and sentence recognition in quiet and noise; (2) the assessment of sound quality; (3) probe microphone measures, which verify the amount of amplified sound reaching the eardrum, or, if not available, functional gain; and (4) subjective scaling.

Assessment of Word Recognition & Sound Quality

The primary goal of amplification is to enhance communication. For some hearing aid users, this corresponds with an improvement in word recognition. For others, the goal may be to ease listening effort. Word and sentence recognition scores (or both) and an assessment of sound quality should be obtained in both quiet and noisy environments. The use of adaptive speech measures (ie, maintaining a certain subjective intelligibility level, such as 50% of connected discourse in various SNRs) may be helpful in avoiding ceiling effects (eg, word recognition scores that are too high to show improvement).

Probe Tube Measures

Probe tube measurements allow for a noninvasive, rapid measurement of the sound received within approximately 5 mm of the tympanic membrane; they therefore take into account the effects of the ear canal. The goal of all hearing aid fittings is to package the amplified speech within the listener's, **dynamic range** (defined as the range of the threshold to the loudness discomfort level). In other words, the amplified signal must be audible across the frequency range, but must not be uncomfortably loud for the listener at any frequency. Refined computer software packages are available that prescribe the amount of desired gain and output to allow conversational speech to fall within these limits. If probe microphone measures are not available, one can use functional gain, the difference between aided and unaided thresholds, for verification.

Subjective Scaling

The quality and comfort of listening might be the most important factors determining the success of amplification for certain listeners. Therefore, it is important to validate the aided benefit with self-assessment scales. Several scales have been developed for this purpose. Some ask standardized questions, whereas others allow the individual patient to identify the situations most relevant to him or her.

REF: Johnson JA, Cox RM, Alexander GC. Development of APHAB norms for WDRC hearing aids and comparisons with original norms. *Ear Hear.* 2010;31(1): 47–55 [PMID: 19692903]. (Comparison of norms for various versions of a self-assessment scale of hearing aid benefit.)

ASSISTIVE LISTENING DEVICES

Despite technologic advances, a basic problem remains for which wearable amplification falls short; that problem relates to the physical distance between the hearing aid microphone and the sound source. Intensity decreases by 6 dB for every doubling of the distance in accordance with the inverse square law. Unfortunately, background noise often surrounds the listener, so although the intensity of the speech decreases with distance, the intensity of the noise may not. This is why hearing aids transmit sound well if the speaker talks directly into the microphone, but at longer, more realistic distances, reception diminishes. Ideally, sound produced at the source would transfer directly to the listener without losing any intensity. It is obviously impractical, however, to ask the speaker to move closer to the listener's ear.

Direct Audio Input

One way of achieving this effect is with direct audio input, in which the speaker holds a microphone that is hardwired to the hearing aid itself. Many hearing aid wearers are reluctant to ask the speaker to do this, however. Fortunately, modern technology allows for a variety of wireless solutions.

Infrared, FM, & Inductance Loop Transmission

These systems are currently available in many theatres, concert halls, houses of worship, and households. Many are compatible with telecoils and many hearing aids now have built-in FM receivers. One of the best uses is for television listening. A small portable transmitter and microphone are located near the television loudspeaker. The sound picked up by the microphone is then transmitted to a receiver worn by the listener without any decrease in intensity. Other nonwearable devices that assist the hearing-impaired listener include telephone amplifiers, vibrating alarm clocks, closed-caption decoders for television, inexpensive personal handheld or body-borne amplifiers, visual alarm systems, and telecommunication devices for the deaf (TDDs).

REF: Chisolm TH, Noe CM, McArdle R, Abrams H. Evidence for the use of hearing assistive technology by adults: The role of the FM system. *Trends Amplif.* 2007;11(2):73–89 [PMID: 17494874]. (Study demonstrating efficacy of assistive listening technology, particularly FM technology.)

AURAL REHABILITATION

As professionals, our objective is to provide patients with better tools for hearing and listening. Although hearing aids are typically the vehicle for such an objective, other forms of aural rehabilitation, either in lieu of or in association with hearing aids, may be necessary. Just as physical therapy is provided to patients receiving artificial limbs, aural rehabilitation is important for hearing-impaired patients for whom central processing abilities have been compromised as a result of neural plasticity, cognitive changes, and aging processes. Adapting to hearing aid use takes time and should not be expected to occur automatically without instructions on how to manipulate the acoustic environment, supplement an impaired auditory system with visual cues, and enhance listening skills with compensatory strategies. These abilities can be abetted via individual or group aural rehabilitation sessions. In addition, patients should expect to receive written materials from their audiologist that address these issues. Because it may be difficult for some patients to return for frequent aural rehabilitation sessions, programs such as Listening and Communication Enhancement (LACE), a computerized, adaptive training program designed to assist patients' listening skills in degraded speech environments, as well as to strengthen cognitive skills (speed of processing and auditory memory), and to teach communication strategies, are available to allow patients to rehabilitate in their own home.

Sweetow R, Palmer C. Efficacy of individual auditory training in adults: A systematic review of the evidence. *J Am Acad Audiol.* 2005;16(7):494 [PMID: 16295236]. (Review of literature on evidence based studies of auditory training.)

Vestibular Disorders

56

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The value and function of the vestibular system may often be underestimated when considering the various special senses that we possess. However, of all the special senses, unilateral loss of the vestibular system may cause the most significant determent for our daily function and survival. Millions of people present annually to their physician with the complaint of dizziness. The goal of this chapter is to discuss the common disorders that affect the vestibular system and provide a framework for the evaluation, diagnosis, and treatment of patients with vestibular disorders.

Injury to the peripheral or central vestibular system causes asymmetry in the baseline input into the vestibular centers and this causes vertigo, nystagmus, vomiting, and a sense of falling toward the side of the injury. **Vertigo** is defined as the illusion of movement. However, the chief complaint of patients with injury to the vestibular system is usually not vertigo but dizziness. If the complaint is clarified to be vertigo, the duration, periodicity, and circumstance of the vertigo and the presence of other neurological signs or symptoms allow for categorization of the vertigo.

The proximity of the vestibular system to the auditory system often causes vertigo to be coupled with hearing loss. The role of the otolaryngologist includes clarifying the subset of patients who have vertigo due to injury to the vestibular system and differentiating central from peripheral vestibular disorders. The evaluation includes a complete head and neck and vestibular examination (Table 56–1). The diagnostic evaluation includes audiology, vestibular testing, and imaging. Knowing the duration of the vertigo or disequilibrium and the presence or absence of hearing loss allows for a narrowing of the differential diagnosis (Table 56–2). The vertigo may be due to injury of the peripheral or central vestibular system. Often, the presence of other neurological abnormalities leads to an investigation for a central cause of the vertigo. However, central vestibular injury due to a lesion or stroke may mimic a peripheral vestibular disorder.

Most patients with peripheral vestibular disorders have benign paroxysmal positional vertigo (BPPV), Meniere disease, or vestibular neuronitis. These patients generally improve with supportive or conservative care (medical or physical therapy). The small percentage of medically recalcitrant patients can then be helped with surgical intervention. The surgical interventions, in general, ablate the vestibular system and rely on central compensation and vestibular rehabilitation to improve the patient's condition.

The central compensation for vestibular injury occurs via the cerebellum. The cerebellum provides a "clamping" response to the injured vestibular system to reduce the effects of the abnormal vestibular signal. In an acute injury such as vestibular neuronitis, the vertiginous response lasts 3–5 days, and then the central compensation is able to modulate the signal from the injured vestibular system. In episodic injuries, such as Meniere disease, the central compensation is not able to be as effective; therefore, with each new episode, there are acute vertiginous symptoms. In a slowly evolving process such as a vestibular schwannoma, the central compensation occurs in step with the vestibular dysfunction, and the patient may have minimal to no vestibular symptoms. The central compensation is enhanced by vestibular activity and delayed by the prolonged use of medical vestibular suppression. This observation has led to the development of vestibular rehabilitation programs.

Vestibular rehabilitation programs use three strategies: (1) habituation exercises, which facilitate central compensation by extinguishing pathologic responses to head motion; (2) postural control exercises; and (3) general conditioning exercises. Vestibular rehabilitation is critically important in the elderly because their ability to have optimal central compensation is diminished.

Table 56–1. Steps in a Vestibular Evaluation.

1. **Head and neck examination, including cranial nerves**
2. **Spontaneous and gaze-evoked nystagmus with Frenzel glasses**
   Direction: fixed-peripheral, changing-central
   Form: jerk-peripheral, pendular-central
   Fixation: suppression-peripheral, enchanced-central
3. **Smooth pursuit—"Follow my fingers."**
4. **Saccades—"Look to my left or right finger when I say to."**
   Dysmetric: cerebellar
   Slow: brainstem
   Late: frontal lobe
   Disconjugate: multiple sclerosis
5. **Head thrust**
   Normal: no refixation saccade
   Abnormal: refixation saccade (peripheral)
6. **Headshake—"10 degrees, 2 cycles/second, 20 seconds."**
   Normal: no nystagmus
   Abnormal: horizontal, nystagmus-peripheral; vertical, nystagmus-central (brainstem)
7. **Dynamic visual activity—"Look at Schnell chart with head shake."**
   Normal: <3 line drop
   Abnormal: 3 or more line drop-bilateral vestibular loss
8. **Fixation suppression—"Look at your thumb during rotation."**
   Normal: no nystagmus
   Abnormal: nystagmus-central (flocculus)
9. **Positional testing—Dix-Hallpike**
   Normal: no nystagmus
   Abnormal: downbeating, fatigable, rotatory nystagmus
10. **Cerebellum—finger to nose, rapid alternating movements, heel to shin**
11. **Posture—Romberg**

Table 56–2. Differential Diagnosis of Vertigo Based on the Timeframe of Vertigo and the Presence or Absence of Hearing Loss.

Time	No Associated Hearing Loss	Hearing Loss Present
Seconds	Benign positional paroxysmal vertigo	Perilymphatic fistula Cholesteatoma
Minutes	Vertebral basilar insufficiency Migraines	
Hours	Vestibulopathy	Meniere disease
Days	Vestibular neuronitis	Labyrinthitis
Weeks	Central nervous system disorders Lyme disease Multiple sclerosis	Acoustic neuroma Autoimmune processes Psychogenic

BENIGN PAROXYSMAL POSITIONAL VERTIGO

ESSENTIALS OF DIAGNOSIS

- Sudden vertigo lasting seconds to minutes with head movement
- No associated hearing loss
- Characteristic nystagmus (latent, geotropic, fatigable) with Dix-Hallpike test.

General Considerations

BPPV is one of the most common types of peripheral vertigo, arising as a result of debris in the posterior semicircular canal. Patients complain of vertigo lasting seconds, with no associated hearing loss when in certain positions. The average age of presentation is in the fifth decade and there is no gender bias. The incidence may range from 10 to 100 cases per 100,000 individuals per year. Nearly 20% of patients seen at vertigo clinics are given the diagnosis of BPPV. Ten to fifteen percent of patients have an antecedent history of vestibular neuronitis and another 20% have a history of head trauma.

Pathogenesis

BPPV occurs because a semicircular canal has debris either attached to the cupula or free floating in the endolymph. The semicircular canal becomes stimulated by the movement of these particles in response to gravity. The study of temporal bones from patients with BPPV showed basophilic deposits adherent to the cupula; this finding was termed **cupulolithiasis**. Intraoperative findings during posterior canal occlusion in patients with resistant BPPV have shown free-floating debris in the endolymph. Electron microscopy of these particles shows that they are likely otoconia originating from the macula of the gravity-sensitive utricle. This process has been termed **canalolithiasis.**

The cupula of the semicircular canal has the same specific gravity as the endolymph and so is not sensitive to gravity. However, the debris in the semicircular canal moves in response to gravity and when the patient places the semicircular canal in a dependent position, the particles move and entrain endolymph with them and cause deflection of the cupula. The unexpected gravity-sensitive response from the semicircular canal causes vertigo. The majority of BPPV is due to debris in the posterior canal, but debris may also enter the horizontal and superior semicircular canals.

Clinical Findings

A. Symptoms and Signs

Patients usually complain of a sudden onset of vertigo that lasts 10–20 seconds with certain head positions. The

triggering positions include rolling over in bed into a lateral position, getting out of bed, looking up and back (top-shelf vertigo), and bending over. The vertigo may be associated with nausea. Patients have normal hearing (no new loss), no spontaneous nystagmus, and a normal neurological evaluation.

B. Imaging Studies

Imaging is reserved for patients who do not have the characteristic nystagmus, have associated neurological findings, or do not respond to treatment. The imaging choice is a magnetic resonance imaging (MRI) scan with gadolinium contrast to evaluate the brainstem, the cerebellopontine angle (CPA), and the internal carotid artery (IAC). The MRI is the most sensitive and specific test to identify posterior fossa tumors.

C. Special Tests

Patients should have no new hearing loss. The audiogram should show symmetric hearing with appropriate speech discrimination scores. The tympanogram should be normal. An asymmetric hearing loss calls into question the diagnosis of BPPV and further evaluation is required.

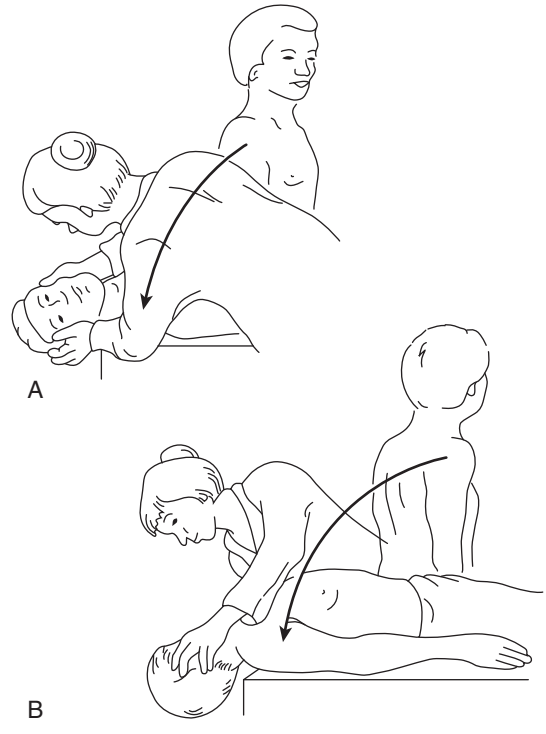
D. Special Examinations

BPPV is diagnosed by observing a characteristic nystagmus when performing the Dix-Hallpike test (Figure 56–1). There is a latency of 1–2 seconds before the onset of the nystagmus and vertigo. The nystagmus is mixed with a torsional and vertical component and is **geotropic** (down-beating, rotatory nystagmus). The nystagmus follows the Ewald law for excitation of the dependent posterior semicircular canal. The nystagmus is in the plane of the canal, and the fast phase is toward the stimulated canal. The vertigo and nystagmus increase and then decrease within 20 seconds; they are reduced with repeated Dix-Hallpike tests and so the nystagmus is fatigable. All these criteria need to be present to diagnose a patient with BPPV due to debris in the posterior semicircular canal.

Treatment

A. Nonsurgical Measures

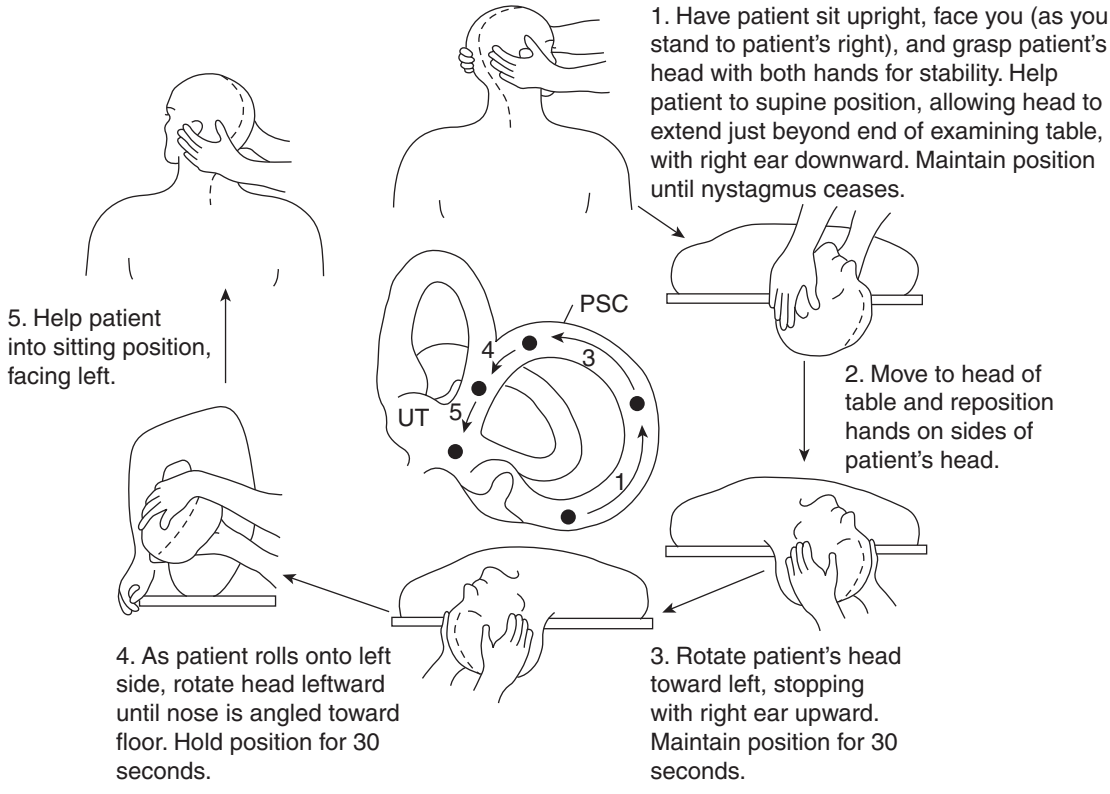
The primary management for BPPV includes maneuvers, Epley (particle or canalith repositioning procedure), and Semont (liberatory maneuver) to reposition the debris into the utricle. The most widely used Epley repositioning maneuvers is depicted in Figure 56–2. The maneuver may be repeated if the patient is still symptomatic. Eighty percent of patients are cured by a single repositioning maneuver. If the symptoms persist after a single maneuver or if patients have recurrent symptoms, the repositioning maneuver may be repeated or patient can be given exercises to perform at home.



▲ **Figure 56–1.** Dix–Hallpike test. **(A)** For testing the right posterior semicircular canal, the patient sits on the examination table and turns his or her head to the right 45°. This places the posterior semicircular canal in the sagittal plane. The examiner stands facing the patient on the patient's right side or behind the patient. **(B)** The patient is then moved by the examiner from the seated to the supine position with the head slightly hanging over the edge of the table. The right ear is down and the chin is pointing slightly up. The eyes are observed for the characteristic nystagmus.

B. Surgical Measures

Surgical treatment is available for a very small number of patients with intractable BPPV. These patients have failed repositioning maneuvers and have no intracranial pathology on imaging studies. The primary surgical option is posterior semicircular canal occlusion. A standard mastoidectomy is performed and the posterior semicircular canal is fenestrated. The membranous canal is occluded with muscle, fascia, or bone pate, or collapsed with a laser. The occlusion prevents debris and subsequent endolymph movement to deflect the cupula. There may be a temporary mixed hearing loss that usually recovers. The success rate for an occlusion of the posterior semicircular canal is high. A more technically challenging surgical option with an increased risk to hearing involves ablating the nerve supply of the posterior semicircular canal via a singular neurectomy.



▲ **Figure 56–2.** Epley maneuver. The patient is taken through four moves, starting in the sitting position with the head turned at a 45° angle toward the affected side. **(1)** The patient is placed into the Dix–Hallpike position (supine with the affected ear down) until the vertigo and nystagmus subside. **(3)** The patient's head is then turned to the opposite side, causing the affected ear to be up and the unaffected ear to be down. **(4)** The whole body and head are then turned away from the affected side to a lateral decubitus position, with the head in a face-down position. **(5)** The last step is to bring the patient back to a sitting position with the head turned toward the unaffected shoulder.

Prognosis

The natural history of BPPV includes an acute onset and remission over a few months. However, up to 30% of patients may have symptoms for longer than 1 year. Most patients improve with a repositioning maneuver. Patients may have unpredictable recurrences and remissions, and the rate of recurrence may be 10–15% per year. These patients may be retreated with a repositioning maneuver. A subset of patients who have adapted by not using certain positions in order to avoid the vertigo or who have other balance disorders can benefit from balance rehabilitation therapy.

Helminski JO, Zee DS, Janssen I, Hain TC. Effectiveness of particle repositioning maneuvers in the treatment of benign paroxysmal positional vertigo: A systematic review. *Phys Ther*. 2010 Mar 25 [Epub ahead of print] [PMID: 20338918]. (Repositioning maneuvers are highly successful in treating BPPV.)

Kansu L, Avci S, Yilmaz I, Ozluoglu LN. Long-term follow-up of patients with posterior canal benign paroxysmal positional vertigo. *Acta Otolaryngol*. 2010 Mar 18 [Epub ahead of print] [PMID: 20297928]. (Recurrent BPPV is more common in patients with a history of head trauma.)

MENIERE DISEASE

ESSENTIALS OF DIAGNOSIS

- Episodic vertigo lasting hours
- Fluctuating hearing loss
- Tinnitus
- Aural pressure.

General Considerations

Meniere disease or endolymphatic hydrops is an idiopathic inner ear disorder characterized by attacks of vertigo, fluctuating hearing loss, tinnitus, and aural fullness. The incidence of Meniere disease ranges from 10 to 150 cases per 100,000 persons each year. There is no gender bias and patients typically present in the fifth decade of life. A new diagnosis of Meniere disease in someone younger than age 20 or older than age 70 is unusual. There is no right or left ear predilection for the disease.

Pathogenesis

The cause of Meniere disease remains elusive and has been attributed to anatomic, infectious, immunologic, and allergic factors. The focus of most studies has been the endolymphatic duct and sac based on the basic premise that there is increased endolymphatic fluid owing to impaired reabsorption of endolymphatic fluid in the endolymphatic duct and sac. Histopathological studies have shown blockage in the longitudinal flow of endolymph in the endolymphatic duct, the endolymphatic sinuses, the utricular ducts, the saccular ducts, and the ductus reuniens. Studies have reported that the endolymphatic sacs in patients with Meniere disease are smaller, have less absorptive tubular epithelium, and have increased perisaccular fibrosis. Results of a blinded control study, however, did not show any difference in the connective tissue or fibrosis surrounding the endolymphatic sac in patients with Meniere disease. The vestibular duct has also been shown to be smaller in patients with Meniere disease. Recent studies have shown a decrease in Type II vestibular hair cells in cases of Meniere disease. The role and significance of the decrease in these Type II hair cells are currently not known. The endolymphatic sac has been shown to be important in inner ear metabolic homeostasis. The endolymphatic sac secretes glycoprotein conjugates in response to osmotic challenges, and preliminary studies have shown an alteration in glycoprotein metabolism in Meniere disease. There has been no conclusive proof of an infectious agent related to this disease.

The roles of allergy and immunology in Meniere disease are under active investigation. The "seat" of immunity in the inner ear may be the endolymphatic sac, which is able to process antigens and mount a local antibody response. The endolymphatic sac may be vulnerable to immunologic injury because of the hyperosmolarity of its contents and the fenestrations in its vasculature. These two properties increase the risk of immune complex deposition and injury. IgG deposition is seen in the endolymphatic sacs of patients undergoing shunt procedures of the endolymphatic sac. Patients with Meniere disease also have elevated IgM complexes and C1q component of complement, and low levels of IgA complexes in their serum. These patients have also shown vulnerability to autoimmune (cytotoxic) reactions. Thirty percent of patients with Meniere disease had autoantibodies to an inner ear antigen by Western blot analysis. The response of some patients to steroid therapy and the increased rate of expression of certain HLA antigens (eg, A3, Cw7, B7, and DR2) in patients with Meniere disease support the presence of an underlying immune mechanism.

A similar argument may be made regarding Meniere disease and allergy. A significant percentage (50%) of affected patients have concomitant inhalant or food allergies (or both), and treating these allergies with immunotherapy and diet modification has improved the manifestations of their allergies and Meniere disease.

The role of genetic influences in the pathogenesis in Meniere disease is also being elucidated. Mutation in the *COCH* gene is associated with Meniere disease. The family of water channels (AQPs) and ion channels have also been implicated.

Clinical Findings

A. Symptoms and Signs

Meniere disease occurs as episodic attacks lasting for hours. The four symptoms and signs include (1) a unilateral, fluctuating sensorineural hearing loss (often involving low frequencies); (2) vertigo that lasts minutes to hours; (3) a constant or intermittent tinnitus typically increasing in intensity before or during the vertiginous attack; and (4) aural fullness. The acute attack is also associated with nausea and vomiting and, following the acute attack, patients feel exhausted for a few days. Table 56–3 shows the diagnostic scale for Meniere disease created by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology—Head and Neck Surgery. As emphasized in the diagnostic scale, the diagnosis of Meniere disease is based on the longitudinal course of the disease rather than on a single attack.

Table 56–3. Diagnostic Scale for Meniere Disease of the AAO-HNS[a]

Certain Meniere Disease
Definitive Meniere's disease, plus histopathological confirmation
Definitive Meniere Disease
Two or more episodes of vertigo of at least 20 minutes
Audiometrically documented hearing loss on at least one occasion
Tinnitus and aural fullness
Probable Meniere Disease
One definite episode of vertigo
Audiometrically documented hearing loss on at least one occasion
Tinnitus and aural fullness
Possible Meniere Disease
Episodic vertigo without documented hearing loss
Sensorineural hearing loss, fluctuating or fixed, with disequilibrium, but without definitive episodes

[a]In all scales, other causes must be excluded using any technical methods (eg, imaging, laboratory, etc.).

B. Laboratory Findings

Meniere disease is a clinical diagnosis. The diagnostic evaluation primarily includes audiometry and a fluorescent treponemal antibody absorption (FTA-ABS) test to rule out syphilis. FTA-ABS testing is mandatory in any patient given the diagnosis of an idiopathic disease, because syphilis may perfectly imitate Meniere disease. Electrophysiologic studies, other serologic studies, and imaging are obtained as needed. The role of allergy testing continues to be defined. Initially, autoimmune ear disease may be clinically indistinguishable from Meniere disease.

The distinguishing characteristics of an autoimmune ear disease include a more aggressive course and early bilateral involvement. Autoimmune serologic tests may also be helpful. There is no diagnostic test for Meniere disease.

C. Imaging Studies

MRI with gadolinium contrast allows the exclusion of retrocochlear pathology, such as a vestibular neuroma, and should be considered in all patients with asymmetric hearing loss.

D. Special Tests

1. Audiology—Audiologic assessment initially shows a low-frequency or a low- and high-frequency (inverted V) sensorineural hearing loss. As the disease progresses, there is a flat sensorineural hearing loss. A glycerol dehydration test involves measuring serial pure-tone thresholds and discrimination scores during diuresis. The diagnosis of Meniere disease is supported if there is improvement in the patient's hearing. The test is positive in only 50% of patients suspected to have the disease and is not routinely performed in the US.

2. Electrocochleography—Electrocochleography (ECOG) measures the sound-evoked electrical potentials from the inner ear. The three phenomena measured from the external canal (tympanic membrane) or on the promontory in response to clicks include (1) the cochlear microphonic, (2) the summating potential, and (3) the action potential. The endolymphatic hydrops of Meniere disease causes a larger summating potential and so the ratio of the summating potential to the action potential (SP/AP) is elevated. ECOG lacks the specificity or sensitivity to reliably use the SP/AP ratio to consistently diagnose Meniere disease or predict the clinical course.

3. Electronystagmography (ENG)—ENG with caloric testing shows peripheral vestibular dysfunction. The caloric response decreases during the first decade of the disease and usually stabilizes at 50% of normal function.

4. Vestibular-evoked myogenic potential (VEMP) testing—VEMP is a vestibulo-collic reflex whose afferent limb arises from acoustically sensitive cells in the saccule, with signals conducted via the inferior vestibular nerve. VEMP is a biphasic, short-latency response recorded from the tonically contracted sternocleidomastoid muscle in response to loud auditory clicks or tones. VEMPs may be diminished or absent in patients with early and late Meniere disease, vestibular neuritis, BPPV, and vestibular schwannoma. On the other hand, the threshold for VEMPs may be lower in cases of superior canal dehiscence and perilymphatic fistula.

Differential Diagnosis

In addition to the vestibular system, dizziness may be caused by poor vision, decreased proprioception (diabetes mellitus), cardiovascular insufficiency, cerebellar or brainstem strokes, neurological conditions (eg, migraines, multiple sclerosis), metabolic disorders, and the side effects of medications (see Table 56–2).

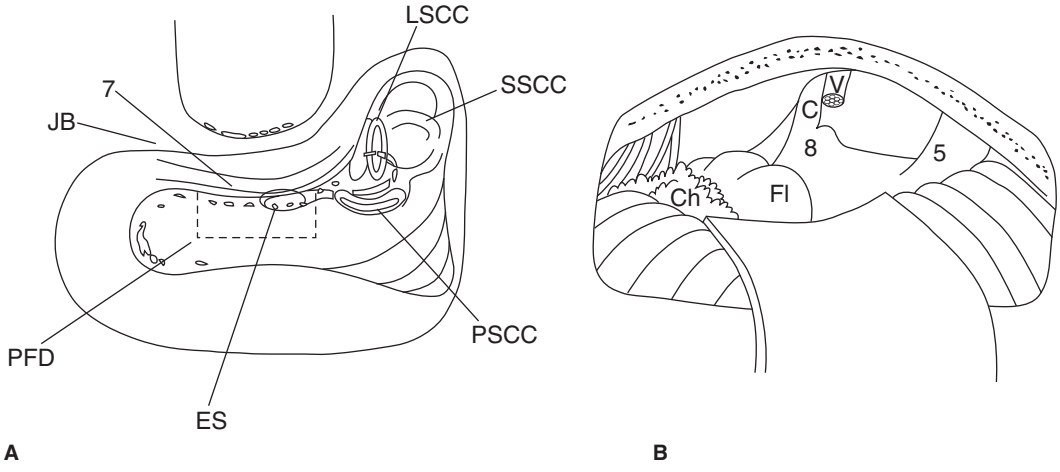
Treatment

A. Nonsurgical Measures

Since the introduction of aminoglycoside therapy in 1948, no significant conceptual advances have been made in the treatment of Meniere disease. The current treatments focus on relieving vertigo without further injuring the patient's hearing. Hearing may be temporarily improved or stabilized by the current treatments, but the hearing does not have long-term stability.

1. Dietary modifications and vestibular suppressants—The primary management of Meniere disease involves a sodium-restricted diet (≤2000 mg/d) and diuretics (eg, diazide). In a crossover placebo study of diazide, it was shown that diuretics seem to improve vestibular complaints but have no effect on hearing or tinnitus. Some patients benefit from dietary restrictions on caffeine, nicotine, alcohol, and foods containing theophylline (eg, chocolate). Acute attacks are managed with vestibular suppressants (eg, meclizine and diazepam [Valium]) and antiemetic medications (eg, prochlorperazine [Compazine] suppository). Most patients are controlled with conservative management.

2. Aminoglycoside therapy—Medically refractory patients with or without serviceable hearing may benefit from intratympanic gentamicin therapy. Intratympanic gentamicin is absorbed into the inner ear primarily via the round window and selectively damages the vestibular hair cells relative to the cochlear hair cells. Gentamicin may also decrease endolymph production by affecting dark cells in the stria vascularis. Intratympanic gentamicin has nearly a 90% vertigo control rate with a follow-up of at least 2 years; the extent of hearing loss depends on the protocol for gentamicin delivery. A variety of treatment protocols (daily, biweekly, weekly, or monthly injections) using fixed-dose or titration end-point regimens exist but a few trends are present. Treatments are stopped if there is persistent hearing loss. Vertigo control is nearly always obtained if vestibular function is ablated.



▲ **Figure 56–3. (A)** Endolymphatic sac surgery. The sac surgery involves a mastoidectomy and identifying it within the posterior fossa dura. **(B)** Vestibular nerve section. Illustration shows a vestibular neurectomy via the posterior fossa craniotomy. LSCC, lateral semicircular canal; PSCC, posterior semicircular canal; SSCC, superior semicircular canal; ES, endolymphatic sac; PFD, posterior fossa dura; JB, jugular bulb; 7, facial nerve or cranial nerve 7; Fl, flocculus; 8, audiovestibular nerve or cranial nerve 8; C, cochlear division of the audiovestibular nerve; V, vestibular division of the audiovestibular nerve; 5, trigeminal nerve or cranial nerve 5; Ch, choroid plexus.

However, the risk of hearing loss increases as the total dose and frequency of gentamicin injections are increased. Current protocols are reducing the dose and frequency of injections to decrease hearing loss and still obtain vertigo control. Vertigo control can be obtained with some residual vestibular function, and this residual function may be useful if patients develop bilateral Meniere disease. Recent studies with monthly injections have shown a nearly 90% vertigo control with a 17% (<10 dB) hearing loss.

3. Steroid therapy—Acute exacerbation of Meniere disease may respond to a short burst of oral steroids. Intratympanic steroids have also been used to treat active disease and avoid the systemic complications associated with oral steroids.

B. Surgical Measures

Occasionally, patients who fail medical and gentamicin treatment may require surgical intervention. Endolymphatic sac surgery and vestibular nerve sections preserve hearing while labyrinthectomy ablates hearing.

1. Endolymphatic sac surgery—The role of endolymphatic sac surgery in the management of Meniere disease remains controversial. One double-blinded, placebo-controlled comparison of the endolymphatic mastoid shunt versus a simple cortical mastoidectomy showed no benefit of the sac surgery. A 9-year follow-up showed a 70% control of vertigo in both surgical groups. Re-analysis of the study suggested a greater benefit in the group who had endolymphatic sac surgery, and a recent study with a 5-year follow-up showed an 88% functional level 1 or 2 response after an endolymphatic mastoid shunt operation. Endolymphatic sac surgery involves a mastoidectomy and locating the endolymphatic sac on the posterior fossa dura (Figure 56–3A). The sac is medial to the sigmoid sinus and inferior to the posterior semicircular canal. The endolymphatic sac is also located along an imaginary line **(Donaldson line)** in the plane of the horizontal semicircular canal. The endolymphatic sac may be decompressed or have a shunt placed that communicates into the subarachnoid space or mastoid cavity. Endolymphatic shunt surgery provides a nondestructive option for patients who fail medical or aminoglycoside therapy and have good hearing.

2. Vestibular nerve section—A vestibular nerve section provides a definitive treatment of unilateral Meniere disease in patients with serviceable hearing. Ninety-five percent of patients achieve vertigo control, and hearing is preserved in more than 95% of patients. The vestibular neurectomy may be approached via a retrosigmoidal or middle fossa approach (Figure 56–3B). The risk to the facial nerve is <1% in the retrosigmoidal approach and <5% in the middle fossa approach. The patients are acutely vertiginous and have nystagmus (fast phase away from the operated ear) for a few days until central compensation takes effect.

3. Labyrinthectomy—A transmastoid labyrinthectomy with fenestration of the bony semicircular canals and vestibule and removal of the membranous neuroepithelium provides control of vertigo in nearly all patients with unilateral Meniere disease and poor hearing. The rate of control may decline in 10 years owing to the development of vertebral-basilar

insufficiency (aging), poorer vision, and the development of Meniere disease in the contralateral ear. The complete loss of unilateral vestibular function due to the labyrinthectomy leads to unsteadiness in up to 30% of patients.

Prognosis

Meniere disease is characterized by remissions and exacerbations, making it difficult to predict the future behavior of the disease in any individual patient based on the patient's own history, diagnostic evaluations, or epidemiologic profiles. The initial manifestation may be vertigo or hearing loss, but within 1 year of onset, the typical syndrome—attacks of vertigo, tinnitus, fluctuating hearing loss, and aural fullness—is present. Longitudinal studies have shown that after 10–20 years, the vertigo attacks subside in most patients and the hearing loss stabilizes to a moderate to severe level (50 dB). Meniere disease is usually a unilateral disease, and the risk of developing this disease in the contralateral ear appears to be linear with time. Of the patients, 25–45% may develop disease in the contralateral ear.

Coelho DH, Lalwani AK. Medical management of Ménière's disease. *Laryngoscope*. 2008;118(6):1099–1108 [PMID: 18418279]. (A contemporary review of medical management of Meniere disease.)

Silverstein H, Wazen J, Van Ess MJ, Daugherty J, Alameda YA. Intratympanic gentamicin treatment of patients with Ménière's disease with normal hearing. *Otolaryngol Head Neck Surg*. 2010;142(4):570–575 [PMID: 20304280]. (Low dose intratympanic gentamicin is efficacious in controlling vertigo while preserving hearing.)

VESTIBULAR NEURONITIS

ESSENTIALS OF DIAGNOSIS

- Vertigo lasting days after an upper respiratory infection
- No hearing loss
- No other neurological signs or symptoms.

General Consideration

Vestibular neuronitis is the third most common cause of peripheral vestibular vertigo after BPPV and Meniere disease. Vestibular neuronitis has no gender bias and typically affects middle-aged people. Less than half the patients have an antecedent or concurrent viral illness. The presentation includes acute vertigo. Like Meniere disease, the pathogenesis is not known but most patients recover with no sequelae. The primary role of the physician is to rule out a central cause of the acute vertigo. The treatment is primarily supportive care.

Pathogenesis

The proposed etiologies for vestibular neuronitis include viral infection, vascular occlusion, and immunologic mechanisms. The most likely cause is the reactivation of a latent herpes simplex virus type 1 (HSV-1) infection. The study of the available temporal bones of patients with vestibular neuronitis shows a spectrum of injury: from normal to significant degenerative changes in the vestibular nerve, Scarpa ganglion, and vestibular neuroepithelium without evidence of vascular occlusion. The injury is often seen in the superior vestibular nerve.

Clinical Findings

A. Symptoms and Signs

The presentation of vestibular neuronitis includes the sudden onset of vertigo with nausea and vomiting. The patient has normal hearing and a normal neurological examination. The patient may have postural instability toward the injured ear but is still able to walk without falling. He or she usually does not have a headache and has spontaneous nystagmus characteristic of an acute peripheral vestibular injury. The nystagmus is usually horizontal with a torsional component and is suppressed by visual fixation. The reduction in the vestibular signal in the injured ear leads to relative vestibular excitation in the opposite ear. The result is that the slow phase of nystagmus is toward the injured ear and the fast phase is away from the injured ear. The nystagmus is intensified by looking toward the fast phase and decreased by looking toward the slow phase or toward the injured ear. This principle is Alexander's law. The direction of the nystagmus does not change with changes in the direction of gaze.

B. Imaging Studies

MRI, with emphasis on the identification of both infarction and hemorrhage in the brainstem and cerebellum, is obtained in patients with risk factors for stroke, with additional neurological abnormalities, and who do not show improvement within 48 hours. Alternately, computed tomography (CT) scanning with thin cuts to evaluate the brainstem, cerebellum, and fourth ventricle may be obtained.

C. Special Tests

In most patients, vestibular testing shows a complete or reduced caloric response in the injured ear. The caloric response eventually normalizes in 42% of patients. VEMP responses are attenuated or absent.

Differential Diagnosis

The diagnosis of vestibular neuronitis is based on the constellation of symptoms and signs described above; however, they may be mimicked by other disorders as well (see Table 57–2). The need for further evaluation is necessary only if there is

a concern for a central cause of the acute vertigo or if the acute vertigo does not substantially improve in 48 hours. The primary central cause for acute vertigo lasting days is a brainstem or cerebellar stroke. In most cases, there are other neurological findings: diplopia, dysmetria, dysarthria, motor and sensory deficits, abnormal reflexes, the inability to walk without falling, and a central nystagmus. Central nystagmus is not affected by visual fixation and may change directions with changes in gaze. A purely vertical or purely torsional nystagmus is highly suggestive of a central disorder. In the event of an isolated inferior cerebellar stroke, the presentation may be indistinguishable with vestibular neuronitis. Also, 25% of patients with risk factors for stroke who present with vertigo, nystagmus, and postural instability have had an inferior cerebellar stroke. Therefore, patients with significant risk factors for stroke should have an imaging study if they present with these symptoms.

Treatment

The primary management includes symptomatic and supportive care during the acute phase of the illness. The patients are given vestibular suppressants and antiemetics to control the vertigo, nausea, and vomiting. These medications are withdrawn as soon as possible to avoid interfering with the central vestibular compensation.

Prognosis

The natural history of vestibular neuronitis includes an acute attack of vertigo that lasts a few days with complete or at least partial recovery within a few weeks to months. Some patients (15% in one study) may have significant vestibular symptoms even after 1 year. Recurrent attacks in the same or contralateral ear have been reported but are unusual. Some patients may later develop BPPV. Vestibular rehabilitation is of benefit in patients with residual symptoms.

Strupp M, Brandt T. Vestibular neuritis. *Semin Neurol.* 2009;29(5):509–519 [PMID: 19834862]. (An excellent review of vestibular neuritis.)

SUPERIOR SEMICIRCULAR CANAL DEHISCENCE

ESSENTIALS OF DIAGNOSIS

- Vertigo or oscillopsia induced by loud sounds or pressure changes in the middle ear
- Conductive or mixed hearing loss with presence of acoustic reflexes
- Nystagmus align with the plane of the dehiscent superior semicircular canal.

General Considerations

In 1998, Lloyd Minor and colleagues described sound- and/or pressure-induced vertigo associated with the bony dehiscence of the superior semicircular canal. Patients complain of vertigo when exposed to loud noises (Tullio phenomenon), with Valsalva maneuvers, with pressure changes in the ear (Hennebert sign), or with factors that raise intracranial pressures. Auditory symptoms include sensitivity to bone-conducted sounds and autophony. Similar symptoms have also been noted with dehiscence of other semicircular canals.

Pathogenesis

The auditory and vestibular symptoms are due to exposure to external pressure along the dehiscent superior canal that is transmitted to the inner ear. Histologic and radiologic studies suggest that superior semicircular canal dehiscence is either congenital or developmental. Approximately 1% of temporal bone CT scans demonstrated significant thinning (≤0.1 mm) or dehiscence of the superior canal in the floor of the middle cranial fossa; this finding is usually bilateral. Over time, this thin bone may be further eroded by pressure transmitted by dura-encased temporal lobe.

Clinical Findings

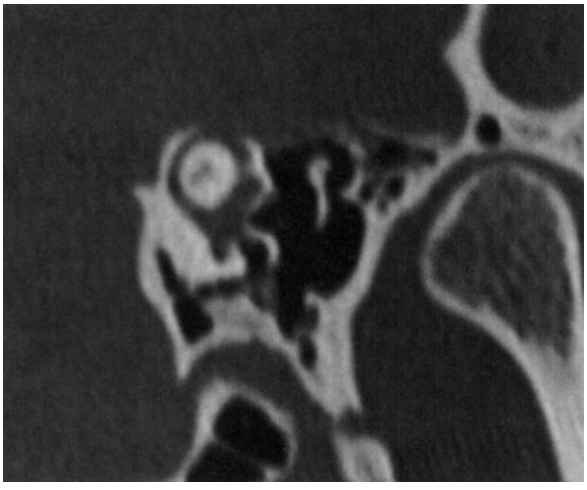
A. Symptoms and Signs

Although dehiscence of the superior canal may be congenital, symptoms and signs usually do not present early in life; the youngest patients have been in their teens. Patients may complain of vestibular symptoms only, auditory and vestibular symptoms, or, less commonly, isolated auditory symptoms. Typically, loud noises, pressure on the external auditory canal, and factors that change intracranial pressure (Valsalva maneuver, jogging, jugular venous compression) lead to vertigo or oscillopsia. Many patients complain of chronic disequilibrium.

Patients report increased sensitivity to bone-conducted sounds, hearing their pulse sound, hearing their eye movements, and autophony. "Inner ear conductive hearing loss" is also common. The hearing loss is artifactual and mimics otosclerosis (low-frequency conductive hearing loss); in contrast to otosclerosis, the stapedius reflexes are present. The dehiscent portion of the superior canal acts as a third mobile window allowing acoustic energy to be dissipated there. The presence of stapedius reflex with low-frequency conductive hearing loss should prompt radiological imaging of the inner ear to exclude the possibility of dehiscence of the inner ear.

B. Imaging Studies

The presence of vestibular symptoms with loud noises or pressure changes, abnormally enhanced bone conduction hearing, or conductive hearing loss with normal stapedius



▲ **Figure 56–4.** Superior semicircular canal dehiscence. CT scan of the temporal bone with reformation of the images in the plane of the superior canal demonstrating dehiscence of the superior semicircular canal.

reflexes should prompt radiological imaging with high-resolution CT of the temporal bone. Superior semicircular canal dehiscence is best seen with 0.5-mm collimated helical CT scans with reformation of the images in the plane of the superior canal (instead of the tradition 1.0-mm collimated images in the axial and coronal plane) (Figure 56–4).

C. Audiologic Testing

Audiologic testing demonstrates low-frequency conductive hearing loss with the presence of stapedius reflex. In otosclerosis, with fixation of the stapes footplate, the reflexes are absent. Presentation of loud auditory signal may elicit typical symptoms of vertigo and eye movements.

D. Special Examinations

Eye movements, examined with the use of Frenzel glasses (to prevent visual fixation and abolition of the nystagmus) typically align with the affected superior canal and follow Ewald law. The nystagmus is in the plane of the canal, and the fast phase is toward the stimulated canal. Loud noises, positive pressure in the ear canal, and the Valsalva maneuver against pinched nostril lead to excitation of the superior canal. The eye movements associated with the ampullifugal deflection of the cupula have the slow phase that is directed upward and torsion of the superior pole of the eye away from the affected ear. With inhibition of the superior canal due to negative pressure in the ear canal, Valsalva against closed glottis, and jugular vein compression, the eye moves downward and torsions toward the affected ear.

VEMP testing is also useful in the evaluation of patients with SSCCD. Patients with superior semicircular canal dehiscence have lower than normal threshold for eliciting the VEMP response (81 dB NHL vs 99 dB NHL).

Treatment

A. Nonsurgical Measures

Avoidance of symptom-provoking stimuli such as loud noises, jogging, or singing may be sufficient therapy for patients with mild symptoms. Correct diagnosis of superior semicircular canal dehiscence as the cause of low-frequency conductive hearing loss prevents unnecessary otosclerosis surgery.

B. Surgical Measures

Patients in whom the symptoms are associated with pressure in the ear canal can be treated with a tympanostomy tube. Patients with debilitating symptoms may require surgical repair of the dehiscence of the superior canal either through the middle cranial fossa approach or the transmastoid approach. The dehiscent area of the canal may be repaired with canal plugging or resurfacing procedure. Hearing loss following surgical repair is more common in revision surgery. The symptoms can recur following surgical repair.

Prognosis

Correct diagnosis of superior semicircular canal dehiscence is a critical first step in the management of patients with this clinical syndrome. Most patients can be helped by avoiding provoking stimuli. Surgery is reserved for the debilitated patient and is often curative.

Minor LB. Clinical manifestation of superior semicircular canal dehiscence. *Laryngoscope.* 2005;115:1717 [PMID: 16222184]. (A comprehensive review of clinical manifestations of SSCD syndrome and therapeutic outcome.)

Pfammatter A, Darrouzet V, Gärtner M et al. A superior semicircular canal dehiscence syndrome multicenter study: Is there an association between size and symptoms? *Otol Neurotol.* 2010 Jan 28. [Epub ahead of print] [PMID: 20118818]. (Patients with larger superior canal dehiscences show significantly more vestibulocochlear symptoms/signs, lower VEMP thresholds, and objective vestibular findings compared with smaller ones.)

Diving Medicine

57

Allen M. Dekelboum, MD

Constantly increasing in number, the recreational and commercial diving community frequently presents with problems poorly understood by the average physician and otolaryngologist unless they have had some training in diving medicine. The consequences of breathing compressed gas mixtures under increasing barometric pressure and subsequent decreasing barometric pressure are confusing unless one understands the physics and physiology of the pressure environment. A well-trained otolaryngologist can be better prepared to treat the conditions that divers encounter by understanding the cause of these conditions.

DIVING PHYSICS

Living at the sea level, our bodies are surrounded by one atmosphere of pressure (eg, 14.7 psi, 760 mm Hg, and 1 bar). The entire earth's atmosphere exerts this pressure, and it is exerted uniformly against our bodies. Pascal's principle states that any change in pressure in an enclosed fluid is transmitted equally throughout that fluid. The human body, being to a large extent fluid, pushes out against the ambient pressure with the same force as the surrounding media. For this reason, divers can descend in the water to extreme depths with ease. It is only the air-filled spaces in our bodies that are affected by the changes in pressure. For each 33 ft of seawater (ie, 34 ft of fresh water, or 10 m) through which we descend, we add an additional atmosphere of pressure. The pressure is doubled going from sea level to 33 ft of seawater, but is not doubled again until 99 ft of seawater is reached (Figure 57–1).

Conversely, as one ascends from depth, the pressure is decreased at the same rate. Boyle's law states that if the absolute temperature remains constant, the volume of a gas varies inversely as the absolute pressure. Because water temperature remains within a small absolute range, as a diver descends in the water, the air-filled spaces decrease in volume proportionately. As the diver ascends, the air-filled spaces increase in volume proportionately. Since we double the pressure from the surface to 33 ft of seawater and not again until 99 ft of seawater, the greatest pressure and volume changes occur closest to the surface. With the exception of decompression sickness, most divers' problems occur in the shallow depths, even as shallow as 4 ft of seawater.

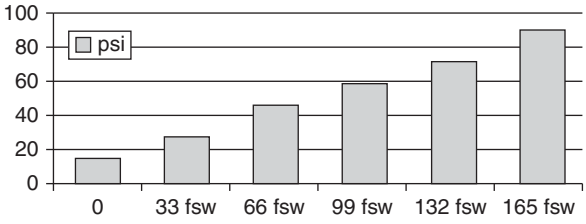
Dalton's law of partial pressure states that in a mixture of gases (eg, air), the total pressure exerted by that mixture is equal to the sum of the partial pressures of each gas in the mixture. Both nitrogen and oxygen, composing most of the air we breathe, increase in partial pressure as the ambient pressure increases. Henry's law of solubility of gases states that as the partial pressure of a gas increases, more of that gas is dissolved in the surrounding liquid until saturation occurs. Since oxygen is utilized in metabolism, nitrogen, which is metabolically inert, is driven into solution in the circulating fluids of the body (eg, blood and lymph) in increasing amounts with increasing ambient pressure. Conversely, as ambient pressure is decreased, the dissolved gas becomes supersaturated and is released as gas bubbles. The latter two laws account for the indirect effects of pressure and are responsible for decompression sickness, or the bends, to be discussed later.

EXTERNAL EAR DISORDERS

Because divers spend much of their time in the water, they are subject to the same cutaneous problems of the external ear as are swimmers.

1. External Otitis

External otitis is very common and needs to be treated in the same fashion as external otitis that does not result as a complication of diving. In mild cases of pruritus, which are indicative of atopic external otitis, treatment can be limited to steroid drops both prophylactically and therapeutically. This is more of a chronic problem and treatment can be administered as needed. The more severe forms may



▲ **Figure 57–1.** Ambient Pressure Relative to Depth.

require steroid–antibiotic drops with a wick being placed if the ear canal is completely closed. For severe infections, broad-spectrum antibiotics may be added. The prognosis is excellent and prophylaxis may prevent further infections. The use of acid–alcohol drops before diving and after leaving the water may prevent infection. One should wait until all the symptoms have resolved, the ear canal has returned to normal diameter, and hearing is restored. Prophylactic antibiotic drops may be needed for several weeks after the infection has cleared.

2. Foreign Bodies

Foreign bodies in the external ear canal, including cerumen, can be driven into the ear canal by the increasing water pressure and can either be lodged at the narrow portion of the canal or driven against the tympanic membrane. If they are lodged at the narrow portion of the ear canal and there is an air-filled space between the foreign body and the tympanic membrane, this air space is subject to Boyle's law, as stated above. The volume of the air space decreases with increasing ambient pressure, producing pain, and hearing loss. There may be hemorrhage in the canal and on the outer surface of the tympanic membrane, and blebs, and edema may be found after the foreign body is removed. Earplugs should never be used while diving unless they have a small vent hole. Treatment is removal of the foreign body and topical antibiotic eardrops.

Although exostoses can occur in divers who are also surfers; those who dive in cold water usually wear a thermal protective hood, which can prevent the formation of exostoses. If they are obstructive, they can be removed surgically.

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004. (This text includes a very complete discourse on all aspects of diving medicine. The reader can consult it for much greater detail on the subjects included in this chapter.)

Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002. (The fourth edition of one of the primary references in diving medicine, it includes detailed coverage of every subject and additional references at the end of each chapter.)

MIDDLE EAR DISORDERS

Etiology

As the diver descends in the water column, the air-filled space of the middle ear is subject to the effects of Boyle's law. With increasing pressure, the volume of the gas in the middle ear reduces proportionately and must be equalized by some technique (see equalizing techniques later in the chapter). Frequent equalization is required near the surface as one descends and less so as the diver achieves greater depth. If equalization is not performed, the volume of the middle ear gas is reduced to the point that the tympanic membrane is retracted severely and fluid or blood (or both) is secreted into the middle ear, reducing the volume and equalizing the pressure. Alternately, the tympanic membrane may rupture.

Because of the unique etiology of diving disorders, the treating physician will see the entire spectrum of middle ear disease from eustachian tube obstruction, occurring rapidly, rather than over an extended period. Because this spectrum is caused by pressure changes, and usually on descent, it is referred to as barotrauma.

Occasionally, middle ear barotrauma can occur with ascent. In this case, the middle ear is equalized at depth, or partially so, and the diver ascends with an obstructed eustachian tube due to rebound rhinitis. The air in the middle ear space increases in volume with a decrease in ambient pressure, and if the middle ear is not vented via the eustachian tube, there will be pain and possible rupture of the tympanic membrane into the external ear canal. Descending to a deeper depth can relieve these symptoms; however, the diver is usually ascending because his/her breathing gas supply is low. Swallowing continually and ascending very slowly may partially relieve the symptoms, but if the gas supply is low, returning to the surface is mandatory. The symptoms, findings, and treatment are the same as for barotrauma of descent.

Prevention

Middle ear barotrauma can be prevented by not diving when there is any condition that might lead to eustachian tube obstruction (including upper respiratory infection or allergy). The diver should be able to easily equalize the middle ear. Prophylactic oral decongestants, short courses of nasal decongestants (no longer than 3 days because of possible rebound rhinitis), and steroid nasal sprays can assist in preventing obstruction.

Clinical Findings

Symptoms of middle ear barotrauma range from a dull feeling in the ear to pain and hearing loss. If a perforation of the tympanic membrane occurs, there will be vertigo with nausea and vomiting caused by the passage of water that is colder

than body temperature into the middle ear; this water stimulates the lateral semicircular canal (a caloric stimulation).

Physical findings can be as simple as retraction, erythema and injection, or hemorrhage in the tympanic membrane. More severe findings include serous otitis, hemotympanum, and perforation of the tympanic membrane. Tuning fork tests and audiograms reveal a conductive hearing loss.

Treatment

Treatment of middle ear barotraumas consists of oral decongestants, short-term decongestant nasal sprays, and appropriate antibiotics if secondary infection is present. The diver should stay out of the water until the middle ear is healed and the diver can easily equalize the middle ear. If a perforation occurs, one must wait until the perforation heals and the tympanic membrane is intact again. If surgery is required for a nonhealing perforation, the above requirements must be met, usually requiring 3–4 months after surgery.

Divers should not return to diving until all the symptoms and findings have cleared. There should be ease of equalization of both middle ears confirmed by physical examination, tympanometry with a Valsalva maneuver, or both.

There remains controversy among otologists as to if or when divers who have had middle ear surgery can return to diving. The conditions that usually require myringoplasty or tympanoplasty are caused by eustachian tube obstruction. The surgical site and procedure should be completely healed with no evidence of difficulty in equalizing the middle ear. If ancillary conditions (eg, allergy or sinus disease) contributed to the need for middle ear surgery, they should be completely cleared, and if they recur, diving should be avoided.

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004. (This text includes a very complete discourse on all aspects of diving medicine. The reader can consult it for much greater detail on the subjects included in this chapter.)

Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002. (The fourth edition of one of the primary references in diving medicine, it includes detailed coverage of every subject and additional references at the end of each chapter.)

INNER EAR DISORDERS

1. Inner Ear Barotrauma

Etiology

Two mechanisms have been postulated as causing inner ear barotrauma. As the diver descends with difficulty in equalizing the middle ear space and continues to descend, attempting to forcefully equalize the middle ear, there can be a sudden opening of an obstructed eustachian tube with a rush of air into the middle ear space. This can rupture one of the windows between the middle ear and the inner ear—either the fenestra rotundum (ie, round window) or the fenestra ovalis (ie, oval window)—into the inner ear.

Conversely, if the diver descends with difficulty in equalizing the middle ear space and continues to descend, attempting to forcefully equalize the middle ear, and the eustachian tube does not open, the force is transmitted (as in a Valsalva maneuver) via the spinal fluid, through the cochlear aqueduct to the perilymphatic space of the inner ear. The round or oval windows can rupture into the middle ear.

Prevention

Prevention consists of avoiding situations that require forceful autoinflation of the middle ear, straining, or both.

Clinical Findings

Both mechanisms that cause inner ear barotrauma produce a perilymphatic fistula. The round window is more commonly affected than the oval window, but occasionally both windows rupture.

Symptoms include tinnitus, vertigo with nausea and vomiting, and hearing loss, which occur usually while descending. There may be pain due to a concomitant middle ear barotrauma. There is usually evidence of middle ear barotrauma, but the tympanic membrane may look perfectly normal. The hearing loss is sensorineural, accompanied by nystagmus and a positive fistula test.

Treatment

Treatment includes bed rest with the head of the bed elevated, antivertiginous medication, steroids (60–80 mg of prednisone or similar drugs initially, reducing the dosage over several days), and avoiding coughing, sneezing, and straining. Audiograms should be performed daily, and if there is improvement, continuation of nonsurgical treatment. Most patients recover spontaneously, but if the hearing loss and vertigo persist or worsen after 4–5 days, surgical exploration with repair of the fistula is recommended.

Many otologists trained in diving medicine recommend that the patient does not return to diving, and many divers do return to diving in spite of the physician's recommendation. In addition, there have been no, or limited, recurrences. The diver should have no significant residual hearing loss (especially in speech frequencies), no significant defects in vestibular function, and no abnormalities of the eustachian tube function with ease of equalization; however, he or she should not dive for at least 2 months after complete recovery. Divers should abort any dive in which there is difficulty in equalizing the middle ear. They should be advised that they might be at risk for further damage to the ear if they continue to dive.

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004.
Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002.
Pullen FW II, Rosenberg GJ, Cabeza CH. Sudden hearing loss in divers and fliers. *Laryngoscope.* 1979;89(9):1373. [PMID: 481042] (One of the original articles defining inner ear barotrauma and its treatment, a less conservative approach to management.)
Roydhouse N. Round window rupture. *South Pacific Underwater Med Soc J.* 1995;23(1):34. (This article supports the recommendations that divers may return to diving after suffering inner ear barotrauma. The late Dr. Roydhouse reported on a large series of divers with this problem.)

2. Inner Ear Decompression Sickness

Etiology

Decompression sickness follows Dalton's and Henry's laws. As one descends beneath the surface, the metabolically inert gas in the breathing mixture is dissolved in the fluids of the body with increasing pressure until that gas is saturated in solution. As one ascends, the dissolved gas comes out of solution as bubbles and is usually evacuated via the lungs. All divers ascend in a much shorter time than they spend under water; consequently, there is dissolved gas that now becomes supersaturated with decreasing pressure and is released as bubbles. Dive protocols have been created to allow the diver to ascend without the critical amounts of bubbles that produce symptoms of decompression sickness (or the bends).

Clinical Findings

If the diver violates protocols for ascending, or even when they are not violated, the bubbles can produce symptoms. The symptoms vary depending on the location of the bubbles. They can include cutaneous eruptions, pain, neurologic symptoms (including paralysis), and, rarely, death. If the bubbles lodge in the inner ear fluids, symptoms similar to inner ear barotrauma can occur and must be differentiated from that condition.

Inner ear decompression sickness is not a common problem with recreational divers who breathe gas mixtures principally containing nitrogen and oxygen (air and some mixtures with a higher content of oxygen and less nitrogen). It occurs more frequently in technical, commercial, and military divers who breathe gases that contain helium as one of the inert components. It is caused by gas bubbles being lodged in the fluids of the inner ear; these bubbles occur and enlarge on ascent.

Symptoms of tinnitus, hearing loss, severe vertigo with nausea and vomiting, ataxia, and syncope usually occur 10 minutes or longer after ascent from the dive. There is the absence of tympanic membrane and middle ear barotrauma; however, the hearing loss is sensorineural and nystagmus is present.

Table 57–1. Signs and Symptoms of Inner Ear Barotrauma and Inner Ear Decompression Sickness[a]

Inner Ear Barotrauma	Inner Ear Decompression Sickness
Can occur on any dive	The dive usually exceeds the recommended depth and time
Usually presents with evidence of middle ear barotrauma	Normal tympanic membrane and middle ear
Sensorineural hearing loss	Sensorineural hearing loss
Usually occurs on descent, but can occur on ascent	Usually occurs shortly after ascending
Can result from any gas mixture	Usually occurs with gas mixes containing helium

[a]These Symptoms and Signs can Help in the Differential Diagnosis of these Two Conditions.

Differential Diagnosis

Differentiating inner ear barotrauma and inner ear decompression sickness can usually be made by the history of the dive (Table 57–1). If there is doubt as to the differential diagnosis, patients should be treated for inner ear decompression sickness because it is the more severe condition and patients can be left with persistent vertigo and ataxia if this condition remains untreated.

Treatment

Treatment is recompression in a chamber, breathing 100% oxygen. Careful adherence to decompression schedules and ascent rates is the only prevention, but, as stated above, this condition can occur even if proper adherence to decompression schedules is followed.

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004.
Edmonds C, Lowry C, Pennefather J et al. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002.
Farmer JC. Diving injuries to the inner ear. *Ann Otol.* 1977;36:86. [PMID: 402882] (This letter to the editor offers the writer's lengthy experience to support divers returning to diving after suffering inner ear barotrauma. The late Dr. Roydhouse previously reported on a large series of divers with this problem.)
Nachum Z, Shupak A, Spitzer O et al. Inner ear decompression sickness in sport compressed air divers. *Laryngoscope.* 2001;111(5):851. [PMID: 11359165] (One of the original reports of inner ear decompression sickness in sport divers.)
Parrell GJ, Becker GD. Inner ear barotrauma in scuba diving: a long-term follow-up after continuing diving. *Arch Otol.* 1993;119:455. [PMID: 8457309] (The first retrospective report of divers having no further problems returning to diving after suffering inner ear barotrauma.)

Table 57–2. Vertigo Due to Unequal Vestibular Stimulation.

Caloric
Unilateral external auditory canal obstruction
Cerumen
External otitis
Exostoses
Foreign body
Tympanic membrane perforation
Middle ear barotrauma
Shock wave
Middle ear barotrauma
Reverse block on ascent
Middle ear barotrauma of descent
Alternobaric vertigo—a condition in which one eustachian tube only opens on ascent. Usually self-limited, but can persist for several days.
Inner ear barotrauma
Inner ear decompression sickness
Tulio phenomenon—caused by loud sounds
Seasickness
Temporomandibular joint syndrome

CAUSES OF VERTIGO WITH DIVING

Vertigo is a common symptom of diving injuries and has many causes common to the diving environment, including unequal vestibular stimulation (Table 57–2), unequal vestibular responses (Table 57–3), and central causes (Table 57–4).

Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002.

Table 57–3. Vertigo Due to Unequal Vestibular Responses.

Barotrauma
Gas toxicity
Inert gas narcosis—caused by increasing partial pressure of nitrogen with descent. Equivalent to one martini for every 30–50 ft dived. Immediately reversed on ascending to shallower depths.
High-pressure nervous syndrome—caused by very deep diving using helium and oxygen mixtures. Can be prevented by slow ascent and by adding small amounts of nitrogen to the breathing mix.
CNS oxygen toxicity.
Carbon dioxide toxicity.
Hypoxia, hypocarbia, carbon monoxide intoxication.
Sensory deprivation—diving in low-visibility situations with significant water movement.

Table 57–4. Vertigo Due to Central Causes.

CNS decompression sickness—bubbles produced in the central nervous system.
Arterial gas embolus—bubbles in the arterial system produced by lung overpressure syndromes.
Drug intoxication.

OTHER CAUSES OF BAROTRAUMA

1. Barodontalgia

Barodontalgia is a condition producing dental pain on descent or ascent. It is caused by poor fillings, air pockets beneath the fillings, dental abscesses, or pressure-induced fluid leakage around the dentin of the tooth. It may be implosive on descent or explosive on ascent, occasionally forcing a filling, inlay, or crown to be extruded. This condition is rare and if dental pain in the upper teeth is a presenting symptom, one must first consider maxillary sinus barotrauma.

2. Facial Nerve Baroparesis

Facial nerve baroparesis can occur. The facial nerve can be dehiscent of bone as it passes through the middle ear space. If there is extreme pressure due to inadequate equalization of the middle ear, temporary ischemia of the exposed portion may lead to palsy. It is usually selflimited, but can be repetitive.

TMJ Symptoms

Although not a true barotrauma condition, temporomandibular joint (TMJ) symptoms may occur. Novice divers have a tendency to bite down hard on their scuba mouthpieces, occasionally biting through the mouthpiece. The pain produced can mimic otologic conditions unless recognized. The ear examination is usually normal, and there is tenderness in the TMJ just in front of the tragus of the external ear. There may be teeth marks on the scuba mouthpiece.

Becker GD. Recurrent alternobaric facial paralysis resulting from scuba diving. *Laryngoscope.* 1983;93:596. [PMID: 684351] (The first description of recurrent facial palsy after scuba diving.)

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004.

Edmonds C, Lowry C, Pennefather J et al.. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002.

PARANASAL SINUS DISORDERS

The ostia of the paranasal sinuses are normally open unless obstructed by disease or anatomic deformities. Air freely exchanges between the nose and the sinus cavities. As long as this occurs, barotrauma of the paranasal sinuses does not occur. However, sinus barotrauma is very common, as are acute and chronic diseases of the sinuses. Pre-existing allergy, acute infections, obstruction by polyps, or a deviated nasal septum can contribute to the inability of the sinuses to adequately aerate. The frontal sinuses are the most commonly involved, followed by the maxillary sinuses, the ethmoid sinuses, and, rarely, the sphenoid sinuses.

The symptoms, findings, and treatment are the same as for sinusitis. Pain, increasing with depth while descending, is the most significant symptom. Barodontalgia is a very rare condition. Maxillary sinus pain can mimic dental pain, and one must consider maxillary sinus barotrauma if the diver complains of upper dental pain.

The diagnosis is confirmed by radiographic examination, and diving should be withheld until there is complete clearing of the sinuses. The treatment of chronic nasal conditions is essential and the correction of anatomic abnormalities is sometimes necessary.

Bartley J. Functional endoscopic sinus surgery in divers with recurrent sinus barotrauma. *South Pacific Underwater Med Soc J.* 1995;25(2):64. (A review of endoscopic sinus surgery and criteria for returning to diving after this surgery.)

Edmonds C, Lowry C, Pennefather J, Walker R. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002

CAUSES OF HEARING LOSS IN DIVING

Hearing loss is a common symptom in diving. At the scene of the diving accident, the examiner can frequently determine, with the use of tuning forks, whether the hearing loss was due to some interference with the conductive mechanism or to some damage to the sensory or neural pathway. Table 57–5 lists some of the causes of hearing loss that might occur in divers.

Table 57–5. Conditions that Produce Hearing Loss in Divers.

Conductive Hearing Loss
Negative pressure in the middle ear
Cerumen
Foreign body
External otitis
Exostoses
Tympanic membrane hemorrhage
Serous otitis media
Hemotympanum
Tympanic membrane perforation
Increased gas density—at extreme depths
Sensorineural Hearing
Loss Inner ear barotrauma
Inner ear decompression sickness
Noise-induced
Presbycusis

CONTRAINDICATIONS TO DIVING

Any condition that either prevents a diver from adequately equalizing the middle ear spaces and sinuses or puts the diver at risk if the condition was to occur under water must be recognized. Some conditions are controversial, and new evidence is helping to resolve the controversies. Several otolaryngologic conditions should preclude returning to diving. These include (1) a tympanic membrane perforation, (2) the presence of pressure-equalizing tubes in the tympanic membrane, (3) a radical or modified radical mastoidectomy (the lateral semicircular canal is exposed to water in the mastoid cavity, producing a caloric response), (4) any vertiginous condition that might occur under water, (5) the inability to inflate the middle ear, (6) chronic refractory sinusitis, (7) tracheotomy or tracheostoma, and (8) any condition that makes it impossible to hold a scuba regulator in the mouth. As noted previously, there is controversy with regard to inner ear barotrauma. Patients who have undergone stapes surgery have been advised not to return to diving. However, there is an increasing body of evidence that allows these individuals to dive safely (see references).

Temporary contraindications include (1) any acute or chronic otolaryngologic infection until resolved, (2) healed tympanic membrane perforations until they meet the criteria noted previously, (3) external otitis until cleared, (4) impacted cerumen, (5) middle ear barotrauma until resolved, (6) chronic nasal obstruction, (7) any acute sinus trauma until healed with no dehiscence of bone, (8) orthodontic appliances, and (9) current major dental therapy until completed.

Antonelli PJ, Adamcyzk M, Appleton CM et al. Inner ear barotrauma after stapedectomy in the guinea pig. *Laryngoscope.* 1999;109(12):1991. [PMID: 10591361] (A basic research article supporting returning to diving after stapedectomy.)

Bove AA. *Bove & Davis' Diving Medicine,* 4th ed. Saunders, 2004.

Edmonds C, Lowry C, Pennefather J. *Diving and Subaquatic Medicine,* 4th ed. Arnold/Hodder Headline Group, 2002.

House JW, Toh EH, Perez A. Diving after stapedectomy: clinical experience and recommendations. *Otolaryngol Head Neck Surg* 2001;1254:356. [PMID: 1159317] (A large clinical experience justifies allowing divers to return to diving after stapedectomy.)

EQUALIZING TECHNIQUES

Middle ear and sinus barotrauma are the most common injuries associated with exposure to increasing and decreasing pressure. Descent in the water adds approximately

one-half pound of pressure for each foot of descent and diminishes a similar amount on ascent. According to Boyle's law, as the pressure increases on descent, the volume of a gas in an enclosed space decreases proportionately. As the pressure decreases on ascent, the volume of the gas increases proportionately. On descent, it is imperative that all enclosed air-filled spaces be equalized actively or passively. On ascent, the increasing gas volume usually vents itself naturally. As noted previously, the greatest pressure and volume changes occur closest to the surface.

For equalization to be effective, the diver should be free of nasal or sinus infections or allergic reactions. The lining of the nose, throat, and eustachian tubes should be as normal as possible. If this is the case, the following techniques are effective in reducing middle ear and sinus squeeze.

1. *Before descent and neutrally buoyant, with no air in the buoyancy compensator, the diver's ears should be gently inflated with one of the methods listed below. This gives the diver a little extra air in the middle ear and sinuses as he or she descends.*
2. *The diver's descent should be feet first, if possible. This allows air to travel upward into the eustachian tube and middle ear, a more natural direction. A descent or anchor line should be used.*
3. *The diver should inflate gently every 2 ft for the first 10–15* ft *and less frequently as he or she descends more deeply.*
4. *Pain is not acceptable. If there is pain, the diver has descended without adequately equalizing.*
5. *If the diver does not feel the ears opening, he or she should stop, try again, and perhaps ascend a few feet to diminish the surrounding pressure.* The diver should not bounce up and down, but *should try to tilt the ear that is not opening upward.*
6. *If the diver is unable to equalize, the dive should be aborted. The consequences of descending without equalizing could ruin an entire dive trip and, more important, produce permanent damage and hearing loss.*
7. *If the diver's physician agrees, decongestants and nasal sprays may be used before diving to reduce swelling in the nasal and sinus passages, as well as in the eustachian tube.*

Decongestants should be taken 1–2 hours before descent; they generally last from 8 to 12 hours. Nasal sprays should be taken 30 minutes before descent and usually last about 12 hours. Caution should be taken when using over-the-counter nasal sprays, since repeated use can cause a rebound reaction with a worsening of congestion and a possible reverse block on ascent.

8. *If at any time during the dive the diver feels pain, has vertigo (the "whirlies"), or notes sudden hearing loss, the dive should be aborted. If these symptoms persist, the diver should not dive again until consulting a physician.*
9. *Equalizing techniques may be used.*

The following techniques can be used by the diver to equalize the volume of gas in the middle ear.

a. Passive: *This technique requires no effort.*
b. Valsalva: *The diver can increase nasopharynx pressure by holding the nose and breathing against a closed glottis (throat).*
c. Toynbee: *The diver swallows with mouth and nose closed. This technique is especially good for ascent.*
d. Frenzel: *This technique involves the diver's using the Valsalva technique while contracting the throat muscles with a closed glottis.*
e. Lowry (Valsalva plus Toynbee): *The diver holds the nose closed, gently trying to blow air out of the nose while swallowing. This technique is the easiest and best method to use after it is practiced.*
f. Edmonds: *The diver juts the jaw forward and then performs the Valsalva technique, the Frenzel technique, or both. This method is very effective.*
g. Miscellaneous: *Miscellaneous techniques include swallowing and wiggling the jaw. These techniques are especially good for ascent.*

Antonelli PJ, Adamcyzk M, Appleton CM et al. Inner ear barotrauma after stapedectomy in the guinea pig. *Laryngoscope.* 1999;109(12):1991. [PMID: 10591361] (A basic research article supporting returning to diving after stapedectomy.)

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Farmer JC. Diving injuries to the inner ear. *Ann Otol.* 1977;36:86. [PMID: 402882] (This letter to the editor offers the writer's lengthy experience to support divers returning to diving after suffering inner ear barotrauma. The late Dr. Roydhouse previously reported on a large series of divers with this problem.)

House JW, Toh EH, Perez A. Diving after stapedectomy: clinical experience and recommendations. *Otolaryngol Head Neck Surg.* 2001;1254:356. [PMID: 1159317] (A large clinical experience justifies allowing divers to return to diving after stapedectomy.)

Nachum Z, Shupak A, Spitzer O et al. Inner ear decompression sickness in sport compressed air divers. *Laryngoscope.* 2001;111(5):851. [PMID: 11359165] (One of the original reports of inner ear decompression sickness in sport divers.)

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Roydhouse N. Round window rupture. *South Pacific Underwater Med Soc J.* 1995;23(1):34. (This article supports the recommendations that divers may return to diving after suffering inner ear barotrauma. The late Dr. reported on a large series of divers with this problem.)

WEB SITES

[Diving Medicine Online]
http://www.scuba-doc.com/

ADDITIONAL RESOURCES

The Divers Alert Network, maintained at Duke University, has a 24 hour number with trained medical personnel available to deal with diving accident problems: (800) 446–2671. They can refer you to the nearest recompression chamber and to the nearest physician trained in diving medicine who can handle your questions.

Occupational Hearing Loss

58

George A. Gates, MD & William W. Clark, PhD

The hearing mechanism, being very sensitive to sound stimuli, is also very susceptible to injury. Many workplaces are hazardous to hearing health due to exposure to (1) noise, (2) physical trauma, and/or (3) toxic materials. Each of these elements comprises a separate subchapter in this review. The majority of the review is focused on noise damage as it is far and away the most prevalent type of occupational auditory injury. The final section discusses some medicolegal aspects of occupational hearing loss.

HEARING LOSS DUE TO NOISE

Occupational hearing loss is noise-induced hearing loss (NIHL) due to chronic overexposure to hazardous levels of noise in the workplace. NIHL may also occur from non-workplace (eg, recreational) noise overexposure. Because the pattern of hearing loss is essentially the same, allocating occupational versus recreational noise damage remains a challenge. NIHL represents about 15% of the total societal burden of hearing loss among American adults. People with occupational NIHL represent approximately half that total, or about 2.5 million adults; another 2 million suffer NIHLs from nonoccupational or leisure activities such as hunting and target shooting, listening to loud music, or engaging in noisy hobbies or recreational activities.

In spite of considerable attention aimed at limiting noise overexposure—through wearing of personal hearing protection, engineered reductions in noise levels, and industrial hygiene measures—loss of hearing still occurs. The additive effect of aging upon the auditory system complicates the evaluative process even if serial examinations are available. Traumatic hearing loss in the military—both NIHL and acoustic trauma—is an increasing source of disability and compensation in the Veteran's administration.

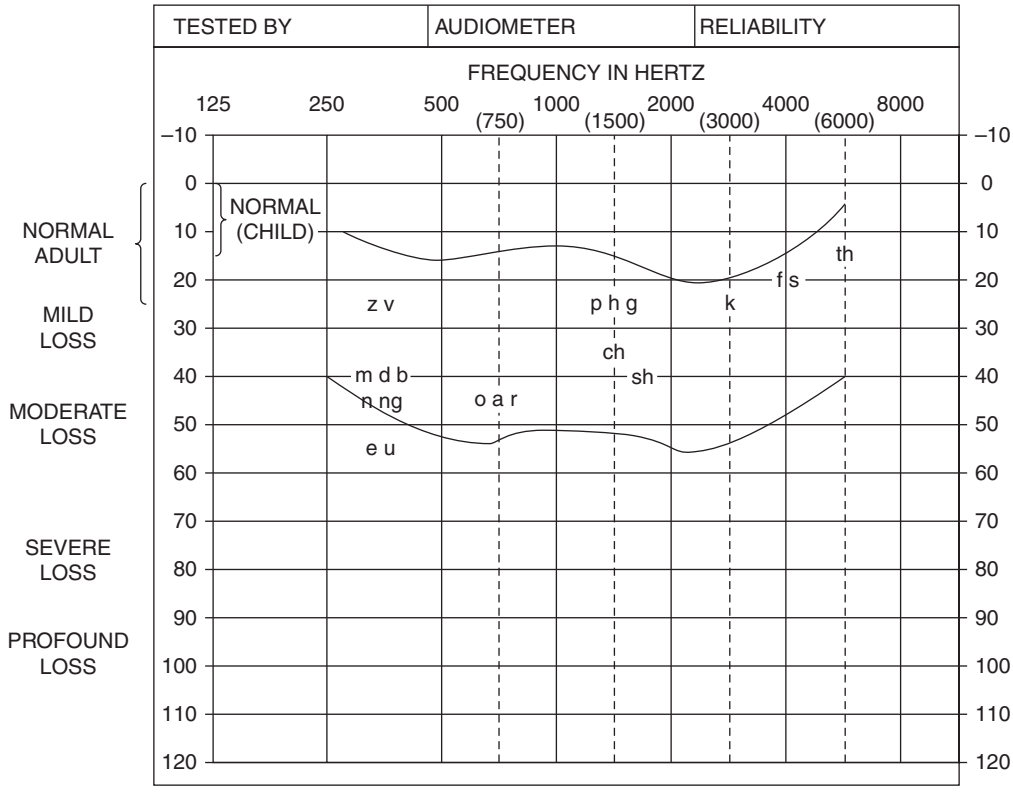
The goal of this review is to provide guidance for physicians who evaluate and treat people with suspected NIHL. We will focus primarily on diagnosis and evaluation, with updated information on prevention and remediation.

Background

Noise may be defined as unwanted, undesirable, or excessively loud sounds as experienced by an individual. The effects of chronic noise exposure vary with the characteristics of the sound: damage is related to intensity, exposure duration, and exposure pattern (continuous exposures are more damaging than interrupted exposures for the same overall duration and intensity). Daily exposure to hazardous noise over years produces the characteristic loss of high-frequency sensitivity in the 4–6 kHz range (Noise notch—See Figure 58–1).

A less common but potentially more devastating form of occupational hearing loss results from acoustic trauma, wherein high-intensity impulse noises (eg, explosions) physically disrupt any or all parts of the ear resulting in immediate and irreversible hearing loss. Blast damage generally follows energy levels of >140 dB on the A scale (dBA), and increases as the intensity increases. The damage from the improvised explosive devices (IED) being used in the current military conflicts is often total owing to the confinement of the explosive energy within the armored vehicle. IED trauma in the military is often associated with brain injury as well.

The stapedius muscle contracts reflexively (acoustic reflex) in response to noise >90 dB. Although the acoustic reflex dampens sound transmission, it is most effective against low frequency noise. The delay between the noise exposure to onset of the reflex is 25 to 150 ms, which renders it less effective against impulse noise as opposed to continuous noise. People without a stapedius reflex (about 1–2 % of the population) are more vulnerable to noise damage than those with the reflex. There are few if any ways to use the acoustic reflex in NIHL abatement plans. One potential example might be to trigger the reflex by providing background sound during magnetic resonance imaging as an attempt to attenuate the noise exposure from energizing the magnets.



▲ **Figure 58–1.** Relative consonant and vowels sounds on an audiogram are a function of frequency.

Pathology

NIHL is thought to result from metabolic depletion of the sensory epithelium of the cochlea, mainly the outer hair cells and associated neurons. The damage begins first in the 4–6 kHz region of the cochlea depending more on the resonance characteristics of the ear canal than on the frequency of the noise. NIHL has two aspects: temporary threshold shift (TTS) and permanent threshold shift (PTS). TTS is commonly experienced after intense short-term exposures (such as a rock concert) wherein the hearing loss recovers in a few days. Repeated TTS exposures may result in PTS over time.

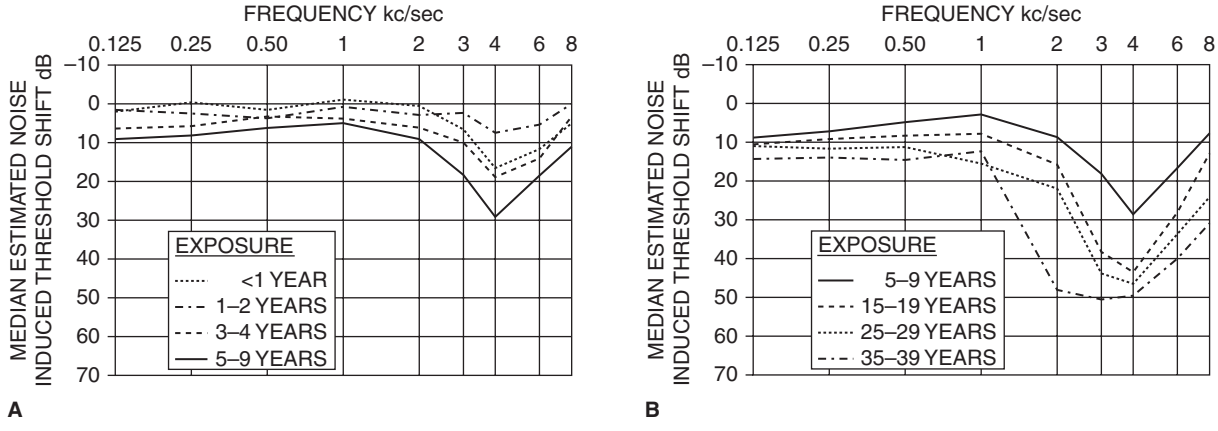
Early studies of TTS were directed toward determining whether TTS might predict susceptibility for PTS (which it does not) and the mechanism of effect. Pujol and Puel described the changes in spiral ganglion neurons wherein the synaptic face of the neuron physically withdraws from the inner hair cell and reattaches in a few days. This process coincides with the time course of TTS and is thought to result from glutamate toxicity secondary to overstimulation.

In classic PTS, the changes become irreversible and include loss of outer hair cells, degeneration of cochlear nerve fibers, and scar formation (dead zones) in the Organ of Corti. However, Kujawa and Liberman have shown that irreversible noise-induced neural degeneration may occur in the absence of changes in auditory thresholds, and, further, without loss of outer hair cells in some cases.

In contrast to NIHL, acoustic trauma causes immediate physical damage to the ear in proportion to the intensity of the overpressure. High-intensity impulse noises can physically damage tympanic membrane, ossicles, inner ear membranes and the Organ of Corti. Indeed, rupture of the TM may absorb some of the energy that would have otherwise been transferred to the inner ear. These types of blast injury are increasingly common in war injuries secondary to IED used widely in the current Mideast conflicts. There is evidence from animal studies that such damage initiates apoptotic cell death and the otoprotectants may theoretically limit the damage somewhat. Human studies to evaluate these possibilities are underway.

Clinical Characteristics of Occupational Noise-Induced Hearing Loss

According to the 1987 report of the Hearing Conservation Committee of the American College of Occupational



▲ **Figure 58–2.** Median noise-induced threshold shift as a function of frequency, for various durations of exposure compared with nonexposed controls.

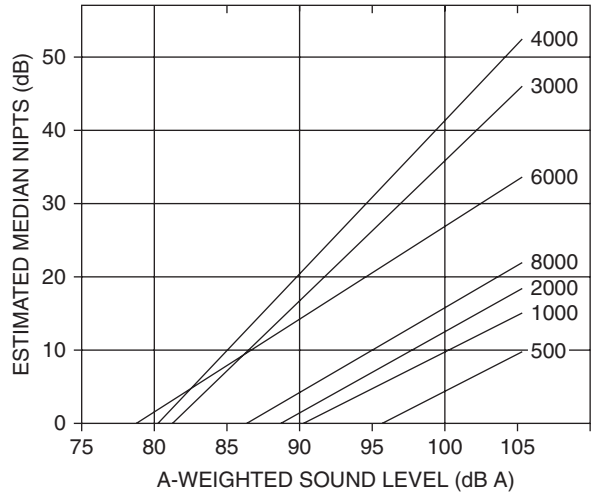
Medicine (ACOM), the considerations that a physician should use in establishing a diagnosis of occupational NIHL are as follows: (1) significant exposure to hazardous occupational noise (time weighted average of 90 dB on the A scale (dBA); (2) gradual onset of hearing loss; (3) a symmetrical, or nearly symmetrical, loss in both ears; (4) a hearing loss at approximately 4000 Hz, commonly referred to as a hearing loss "notch"; (5) occupational hearing loss is not progressive after a maximum loss is incurred approximately 10 to 12 years after initial exposure; (6) normal or near normal speech discrimination scores ; (7) the maximum amount of hearing loss caused by occupational noise exposure to the loudest noises is 40 dB in the speech frequencies and 75 dB in the higher frequencies; (8) occupational hearing loss does not progress once the subject is removed from the noisy environment.

The presence of these elements does not necessarily lead to a conclusive diagnosis of occupational hearing loss since other causes may have similar characteristics. On the other hand, the absence of one, or more, of these factors is generally evidence of a cause other than occupational noise exposure. Not addressed by the ACOM report are: (1) the confounding issue of recreational noise exposure, which frequently co-occurs with occupational noise exposure and (2) the interaction of age changes superimposed on NIHL.

The profile of typical audiometric noise notches was compiled by Cooper and Owens (Figure 58–2) as the mean pure-tone thresholds from 450 ears of men with clear-cut histories of noise exposure. Note that the threshold at 8 kHz is better than at 4–6 kHz. With time (age), the depth of the notch is decreased by worsening of the 8 kHz threshold but is still discernable in the vast majority of cases. Figure 58–3 displays the net change in audiometric profile with time for women employed in jute manufacturing (as compared to age-matched controls). This classic epidemiologic study by Taylor et al. has yet to be surpassed.

In evaluating a patient claiming occupational hearing loss, the following conditions and factors must be considered either as alternative diagnosis or coexistent disorders:

1. presbycusis (ie, age-related hearing loss);
2. hereditary hearing impairment causing progressive degeneration;
3. metabolic disorders (eg, hypertension, diabetes mellitus, hypothyroidism, renal failure, autoimmune disease, hyperlipidemia, and hypercholesterolemia);



▲ **Figure 58–3.** Estimated permanent threshold shifts at various frequencies produced by noise exposure of more than 10 years duration.

4. smoking;
5. hearing loss resulting from infectious origins (ie, bacterial or viral infections, including meningitis and encephalitis);
6. hearing loss resulting from central nervous system dysfunction;
7. nonorganic hearing loss (ie, functional hearing loss);
8. nonoccupational NIHL.

The following common otologic problems should be excluded in the differential diagnosis of NIHL even though they are predominately unilateral conditions: sudden sensorineural hearing loss, Meniere's disease, and cerebellopontine angle tumor. In general an accurate history will reasonably exclude the majority of these considerations but special testing may be necessary.

EVALUATION OF HEARING

In all cases of suspected occupational hearing loss, a complete pure-tone audiogram with speech reception thresholds (SRT) and word recognition scores (WRS) must be done. The audiometric equipment should have been calibrated annually to conform to American National Standards Institute standards. The testing should be done 48 hours or more after the last day at work.

Functional hearing loss should always be considered as an element in the evaluation of people seeking compensation for NIHL. Although the following tests may be used to help differentiate this from a genuine occupational hearing loss, the situation more often than not is not a clear choice between either functional or organic but, rather, a functional overlay on an organic loss. As such, the examiner has a challenge in separating the components.

If SRT scores diverge more than 10 dB from the pure-tone average (PTA) for speech frequency, additional testing should be done to exclude the possibility of a nonorganic component. Auditory brainstem response and otoacoustic emissions will be normal in pure functional hearing loss cases. The Stenger test is the classic behavioral test for estimating a functional unilateral hearing loss. It is based on the principle that if tones of the same frequency are presented to both ears, the patient can only perceive the louder tone.

Diagnostic Considerations

Patients with NIHL frequently complain of a gradual deterioration in hearing, in particular speech in the presence of competing background noise, and almost all note the presence of tinnitus. Background noise masks the better-preserved portion of the hearing spectrum and further exacerbates problems with speech comprehension. Because patients with NIHL have predominately high-frequency loss, they experience a decrease in high-frequency speech sounds (primarily the consonants) Figure 58–1 and when listening to people with particularly high-pitched voices (eg, women and children).

NIHL is frequently accompanied by tinnitus. Most often patients describe a high-frequency tonal sound (eg, ringing), but the sound is sometimes lower in tone (eg, buzzing, blowing, or hissing). Often, the tinnitus frequency matches the frequency of the hearing loss seen on the audiogram and is approximately 5 dB above that threshold in loudness. Tinnitus in the absence of threshold elevation in the 3–6 kHz region of the audiogram is unlikely to be related to noise exposure.

The clinical attributes of occupational NIHL were summarized in an evidence-based policy statement by the American College of Occupational and Environmental Medicine (2002) as follows.

1. It is always sensorineural, affecting hair cells in the inner ear.
2. Since most noise exposures are symmetric, the hearing loss is typically bilateral.
3. Typically, the first sign of hearing loss due to noise exposure is a "notching" of the audiogram at 3000, 4000, or 6000 Hz, with recovery at 8000 Hz. The exact location of the notch depends on multiple factors including the frequency of the damaging noise and the length of the ear canal. Therefore, in early noise-induced hearing loss, the average hearing thresholds at 500, 1000, and 2000 Hz are better than the average at 3000, 4000, and 6000 Hz, and the hearing level at 8000 Hz is usually better than the deepest part of the "notch." This "notching" is in contrast to age-related hearing loss, which also produces high frequency hearing loss, but in a down-sloping pattern without recovery at 8000 Hz.
4. Noise exposure alone usually does not produce a loss greater than 75 dB in high frequencies, and 40 dB in lower frequencies. However, individuals with superimposed age-related losses may have hearing threshold levels in excess of these values.
5. The rate of hearing loss due to chronic noise exposure is greatest during the first 10–15 years of exposure, and decreases as the hearing threshold increases. This is in contrast to age-related loss, which accelerates over time.
6. Most studies suggest that previously noise-exposed ears are not more sensitive to future noise exposure and that hearing loss due to noise does not progress (in excess of what would be expected from the addition of age-related threshold shifts) once the exposure to noise is discontinued.
7. In obtaining a history of noise exposure, the clinician should keep in mind that the risk of NIHL is considered to increase significantly with chronic exposures above 85 dBA for an 8 hour time-weighted average (TWA). In general, continuous noise exposure over the years is more damaging than interrupted exposure to noise which permits the ear to have a rest period. However, short

exposures to very high levels of noise in occupations such as construction or firefighting may produce significant loss and measures to estimate the health effects of such intermittent noise are lacking. When the noise exposure history indicates the use of hearing protective devices, the clinician should also keep in mind that the real world attenuation provided by hearing protectors may vary widely between individuals.

The typical "4000 Hz notch" (Figure 58–1) is thought to occur primarily as a result of the position of the stapes footplate over the high-frequency end of the basilar membrane and the resonance frequency of the ear canal, which amplifies high frequency sounds. Lower and higher frequencies become affected after many years of noise exposure and a significant decrease in WRS does not begin until frequencies <3000 Hz are affected (Figure 58–1). Mild asymmetry can exist in the audiogram, particularly when the source of the noise is lateralized (eg, a rifle or shotgun firing, driving with the window open). Typically, the left ear has poorer thresholds in right-handed people.

The ACOEM statement warrants re-examination as newer evidence calls attention to the issue of progression on NIHL after noise exposure ceases. Whether the progression is viewed as continuing "injury" or "accelerated aging" is not resolved. It is clear that noise damage does not recover and that effects of the damage are exacerbated over time. Further, the importance of primary neuronal injury is not addressed by this statement.

ESSENTIALS OF DIAGNOSIS OF OCCUPATIONAL NIHL

- High-frequency notch in 4–6 kHz area in one or both ears
- Plausible history of hazardous noise exposure
- Rate of loss over time fits NIHL pattern
- Exclusion of other causes of high-frequency loss.

Predisposing Factors

A. Susceptibility

There appears to be variable tolerance to high noise levels. The genetic basis of this variability has been studied in animal models with conflicting results. While the risk is likely an interaction between genetic susceptibility and the duration and intensity of the noise exposure, the parameters of this risk have not been fully determined.

B. Presbycusis

NIHL and presbycusis often coexist in our aging population. Although studies have shown that the combined effect is additive over time, it appears that the effect is not linear and animal models suggest that genetic variability is an important factor in determining whether aging makes the ear more or less susceptible to noise damage.

C. Ototoxicity

Concurrent exposure to noise and ototoxic medications may potentiate hearing loss. These effects have been shown for both cisplatin and aminoglycosides. Loop diuretics and salicylates, however, have not been definitively been shown to potentiate noise-induced hearing loss.

4. Vibration

There is recent evidence that vibration can interact with noise to cause both TTS and PTS. The mechanism of this effect is not well understood.

ACOEM Noise and Hearing Conservation Committee Evidence-Based Statement: Noise Induced Hearing Loss. American College of Occupational and Environmental Medicine, 2002. (Lists essential elements in NIHL; widely quoted.)

Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *J Neurosci*. 2009;29:14077–14085. (Provides new insights into the relation of hair cell and neuronal loss secondary to noise exposure.)

Pujol R, Puel JL. Excitotoxicity, synaptic repair, and functional recovery in the mammalian cochlea: a review of recent findings. *Ann NY Acad Sci*. 1999;884:249–254. (Demonstrates physiologic basis for TTS.)

Taylor W, Pearson JC, Kell R et al. A pilot study of hearing loss and social handicap in female jute weavers. *Proc R Soc Med*. 1967;60:1117–1121. (Classic study of NIHL in Scottish women that displays the rate of loss over time from constant occupational noise levels.)

Treatment

As there are no medical or surgical treatments available to reverse the effects of NIHL, prevention is key. This may require a collaborative approach involving persons with backgrounds in acoustic engineering, industrial hygiene, otolaryngology, and audiology to examine ambient noise levels in the various work environments and design educational and monitoring programs for personal hearing protection. After the diagnosis has been established by otologic examination and the administration of an audiometric test battery, the physician should counsel the patient on the likely consequences of continued noise exposure.

Use of amplification is the customary recommendation for people who note difficulty in hearing. Individual needs and acoustic environments influence decisions for selecting the specific type of aid. In bilateral hearing losses, bilateral amplification usually provides more satisfactory rehabilitation, unless there is evidence of central auditory dysfunction,

where a unilateral aid often gives better results. A reasonable criterion for referral for hearing aid evaluation is a SRT of greater than 25 dB or a WRS of less than 80% at presentation levels of 50 dB above threshold. There are some instances in which hearing aids may be recommended to assist the patient to hear in special circumstances, such as lectures or group situations. In patients with high-frequency hearing loss and relatively normal low-frequency hearing, hearing aids are generally the most helpful to those who have a significant loss at 2000 Hz.

The basic hearing aid today is a digital programmable device with squeal suppression and an open ear mold. A hearing aid evaluation should be done to select from the variety of possible fittings and a trial usage period, with the patient wearing the aids in various circumstances, is recommended. Numerous assistive listening devices are available (FM and infrared) to enhance comprehension in specific situations. Aural rehabilitation classes designed to enhance the patient's ability to comprehend speech may also be helpful and are usually available in some urban areas.

There is no cure for tinnitus associated with NIHL although numerous ameliorative measures are available. In the absence of further inner ear injury, tinnitus usually diminishes with time. A variable degree of tinnitus often persists and is especially obvious in quiet. For the few patients who find this to be extremely troublesome, masking the tinnitus with music or some other pleasant sound is often helpful. In those with significant hearing loss, appropriate amplification is helpful. Modified hearing aids (tinnitus maskers) designed to produce masking noises have generally been of limited success. Tinnitus retraining therapy is now widely available to help people cope with their tinnitus trouble. Psychiatric referral may be necessary to manage associated depression and anxiety that is common in those "bothered" by their tinnitus.

Prognosis

The trajectory of NIHL shows the greatest change in the first 10 years of exposure with less and less additional loss as exposure continues. In contrast, age-related hearing loss has an increasing trajectory with time. The superimposition of age effects on prior noise damage effects remains as a controversial matter in compensation evaluations. The pattern of hearing loss in the Scottish jute weavers (See Fig 58-3) is the classic demonstration of NIHL over time.

The standard teaching is that NIHL does not progress after hazardous noise exposure ceases. The worsening of hearing after, say, retirement is usually attributed to aging (presbycusis), although other conditions may contribute to the change. Presbycusis can add to NIHL as the patient grows older. However, the effect is uneven. Since cells lost from one cause (eg, noise) cannot be "relost" (eg, aging), there is less change with time in the "notch" frequencies but slightly greater loss with time in the adjacent frequencies, in particular, 3 kHz. (Gates and Kujawa). Whether such loss should be attributed to the consequence of prior noise-damage or to accelerated aging is moot at present.

Prevention of NIHL

NIHL can be prevented by reducing noise at the source through engineering controls, limiting exposure by administrative controls, and employing effective hearing protection practices for exposures that cannot or are not avoided. The key component to all prevention efforts is education. Workers exposed to hazardous workplace noise need to understand that hearing can only be protected and preserved if efforts to reduce all hazardous exposures, not just those in the workplace, are undertaken.

A. Regulation of Occupational Noise Exposure

Noise exposure associated with the workplace has been known for centuries to produce hearing loss. In fact, "boilermakers' deafness" was the term coined to describe the now-familiar bilateral sensorineural hearing loss associated with excessive exposure to occupational noise. Largely on the basis of knowledge gained through field studies of hearing loss in industrial workers and military personnel, the U.S. Department of Labor promulgated regulations in the 1970s and 1980s designed to protect the hearing of employees who work in noisy environments. The principal regulation is the Occupational Noise Standard, promulgated by the Occupational Health and Safety Administration in 1972 and amended in 1983. This regulation covers workers in industry governed by the Department of Labor; other federal agencies (Federal Railroad Administration, Mine Safety and Health Administration, etc) have regulations that share key features with the OSHA rule.

The maximum exposure levels permitted by OSHA for various durations are shown in Table 58–1. The levels stated in the table represent the maximum allowable daily noise exposure, or the "permissible exposure limit" (PEL), as specified by OSHA and other federal agencies. The PEL for an 8 hours exposure is referred to as the "criterion;" it reflects the sound level in dBA (decibels measured with the A-weighting filter network in place, which reaches the PEL after 8 hours of exposure. Note that for exposures that differ from 8 hours the allowable daily exposure level is increased or decreased by 5 dB for each halving or doubling of exposure duration: ninety decibels are allowed for 8 hours daily, 95 dB for 4 hours daily, etc. Each of the exposures listed in the table represents an equivalent TWA exposure of 90 dBA for 8 hours. By definition an 8 hours TWA of 90 dB represents 100% of the allowable "dose."

When the daily noise exposure is composed of two or more periods of exposure at different levels, their effects are combined by the following rule:

$$C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n$$

Table 58–1. OSHA Noise Standard Permissible Noise Exposure.

Daily Duration (h)	Sound Level (dBA)
32	80
16	85
8	90
4	95
2	100
1	105
0.5	110
0.25 or less	115

Source: OSHA, 1983

where C is the exposure duration at a given level; and T the allowable duration at that level.

"Percent allowable dose" is then calculated by multiplying the result by 100%. That is,

$$D = 100(C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n)$$

All exposures between 80 and 130 dBA are required to be integrated into the dose calculation. Exposures below the so-called threshold are not counted in the calculation of daily exposure; threshold values range from 80 to 90 dBA among various regulations. For example, consider the following daily noise exposure for a sheet metal worker:

Activity	Level (dBA)	Duration (h)
Grinding	90	2.0
Buffing	85	1.0
Cutting	100	0.5
Packaging	75	2.0
Lunch, breaks	79	1.5

Calculation of Daily Dose is Made as Follows.

Activity	C/T	Dose (%)
Grinding	2/8	25
Buffing	1/16	6.25
Cutting	0.5/2	25
Packaging	2/ infinity	0
Lunch, breaks	1/ infinity	0
Total	0.74	56.25

Therefore, this employee's exposure would not exceed OSHA's PEL. The dose could also be expressed as a TWA level in decibels by calculating the 8 hours exposure level that would result in the same dose:

$$\text{TWA} = 16.61\log_{10}(\text{dose}/100) + 90$$
$$= 16.61 \text{ Xlog } (56.25/100) + 90 = 85.9\text{dBA}$$

It is important to remember that "dose" and "TWA" really refer to the same measurement: the 8-hours equivalent exposure for any measured duration or combination of levels and durations, expressed as percent or decibels.

As amended in 1983, the current U.S. occupational noise exposure standard identifies a TWA of 85 dBA, or 50% dose, as an "action level." Workers covered by the standard who are exposed above the action level must be provided an effective hearing conservation program, including annual audiometric evaluations, personal hearing protection if desired, and education programs. With a daily noise exposure of 56.25%, or a TWA above 85 dBA, the sheet metal worker described should be in a company hearing conservation program.

The exposure limits set by OSHA were empirically determined from epidemiological and laboratory data concerning hearing damage from noise exposure and were designed to protect employees against sustaining a material impairment in hearing after a working lifetime. They were derived by subtracting the percent of workers sustaining a material impairment in hearing as a function of exposure level from a control population without occupational exposure. The resultant percentage is the "percent risk" or "percent additional risk" of a material impairment in hearing after, say, 40 year of exposure, above that expected from presbycusis alone. Estimates of percent risk vary depending upon which criteria and databases are used; the estimates provided in the original standard have been revised downward on the basis or more modern statistical fitting methods by the National Institute for Occupational Safety and Health (NIOSH) and support a conclusion that that the PEL of 90 dBA, with the 85 dBA action level, if enforced, would protect 93–96% of the working population from sustaining occupational noise-induced hearing loss.

In 1998 NIOSH revised its original 1972 recommendation that the permissible exposure limit for occupational noise be set to a time-weighted exposure of 85 dBA, and added, further, that the exposures be calculated with a 3 dB exchange rate. In other words, daily exposure at 85 dBA represents a 100% dose and the dose is doubled or halved for every 3 dB increase or decrease (ie, 88 dBA= 200%, 82 dBA= 50%, etc). NIOSH's recommended exposure limit (REL) is much more conservative than the OSHA standard, particularly for workers exposed at high levels for relatively short durations. For instance, the sheet metal worker's OSHA PEL 56% exposure (TWA = 85.8 dBA) described above would be 292% of the REL (TWA = 89.7 dBA) using the NIOSH limits. Although various groups have recommended the NIOSH REL as the appropriate federal standard for many years, it has not been adopted by any federal agency as a national standard.

Table 58–2. Permissible Noise Exposure in the Workplace.

Hours Per Day	Sound Levels dBA (Slow Response)
16	85
8	90
6	92
4	95
2	100
1	105
0.5	110
0.25	115

The American Conference of Government Industrial Hygienists has also listed guidelines for occupational exposure to noise. These limits are specified as "threshold limit values" (TLVs), and they use the same metrics as the NIOSH REL (85 dBA criterion; 3 dB exchange rate). However, the TLV is specified by ACGIH as the *minimum* exposure at which one should *consider* implementing a hearing conservation program; it does not imply an upper limit of tolerable exposure, as does the OSHA PEL. Viewed in this way, there is no conflict between the ACGIH TLV and the OSHA PEL; hearing conservation programs should be implemented if the exposure exceeds the ACGIH TLV, and workers should not be exposed above the OSHA PEL.

The OSHA noise standards are useful to the physician in arriving at a diagnosis, and in determining whether a recommendation about hearing protection should be made. First, because workers exposed to excessive occupational noise should be in a hearing conservation program, evidence of exposure history and prior company-obtained audiograms may be available for consideration (Table 58-2). If the worker is not in a hearing conservation program, he or she may not work in significant occupational noise. Unfortunately, because not all workers are covered by OSHA standards and because enforcement has been weak, lack of participation in a hearing conservation program by a worker does not guarantee he or she has not been exposed to excessive occupational noise. However, in evaluating a patient, if it is determined that exposure to occupational noise did not exceed a TWA of 85 dBA, or a dose of 50%, then exposure to occupational noise should be ruled out of the etiology.

B. Hearing Conservation Program

OSHA requires workers exposed above the action level (8 hours TWA of 85 dBA, or 50% dose) to be enrolled in a continuing, effective hearing conservation program. The major components of the program are summarized below.

1. Noise Monitoring—Two general types of exposure assessment are commonly used in industry: area noise surveys and personal noise dosimetry. Area surveys are used to identify job locations where the TWA exposure may exceed 85 dBA; they are conducted by placing a sound level meter in a specific location and sampling the noise field. Exposures are then calculated based upon the amount of time an employee works in that specific location. Area surveys are also useful in determining the sources of exposure in an industrial environment and for planning noise control engineering strategies for reducing exposure (Table 58-3).

Occupational exposures can also be measured directly by using personal noise dosimeters. These devices are small, computerized integrating sound level meters that can record the minute-by-minute sound exposure throughout the workday. They are worn on a belt or in a pocket, and the microphone is positioned on the shoulder, approximately 5 in. lateral to the ear. Technological advances in microprocessor design, incorporating low power consumption and component miniaturization, have led to sophisticated, small, lightweight dosimeters that can be worn unobtrusively. A distinct

Table 58–3. Examples of Noise in Industry and Noise in the Environment.

Jet Engines-Flight Line	
FA-18E engine at 80% (rear) < 50 ft	130 dBA
FA-18E engine at idle (rear) < 50 ft	105 dBA
FA-18 after burner test (rear) < 50 ft	139 dBA
F104 Engine at idle from 200 ft	91 dBA
Diesel hydraulic jenny	107 dBA
Heavy Mobile Equipment	
Scrapers-Loaders	117 dBA
Road graders	95 dBA
Tool Operations (Metal)	
Pneumatic grinders aluminum	100–102 dBA
Chipping weld on large aluminum structure	120 dBA
Cut-off grinder cutting aluminum pipe	100 dBA
Cut-off grinder cutting galvanized pipe	96–98 dBA
Needle gun on ¼-in.steel plate	108 dBA
Punch Press 3/8-in. flat bar steel	118 dBA
Tool Operations (Woodworking)	
Cut-off saw	112 dBA
Radial arm saw	98 dBA
Router	93 dBA
Planner	106 dBA
Socioacusis	
Normal conversation	50–60 dBA
Motorboats	74–114 dBA
Motorcycles	up to 110 dBA
Snowmobile	85–109 dBA
Lawnmower	up to 96 dBA
Hunting weapons	143–173 dBA

advantage to using dosimetry over other methods is that the measurement instrument travels with the worker and can therefore provide a more accurate assessment of exposure as he or she moves among different noise environments during the work day. Exposure assessment using dosimetry does have some disadvantages. Because the instrument is mounted on the shoulder, reflection of sound off the body adds about 2 dB to the exposure assessment. In addition, it is nearly impossible to prevent bumping or touching the surface of the microphone during a normal workday. Contact with the microphone, even with a windscreen in place, will always increase the dose measure, and for short-duration, high-level impacts, the exposure can be inflated dramatically. Finally, because the dosimeter travels with the worker rather than staying under the control of the professional assessing the exposure, errors of commission and omission can occur. For example, a dosimeter attached to a jacket, which is then deposited in a locker before the workshift begins, will record the exposure of the jacket, rather than that of the worker.

2. Engineering controls—Can be implemented to reduce employee exposure in many cases. Designers' conceptualize possible engineering solutions in terms of (1) the source (what is generating the noise), (2) the path (the routes the generated noise may travel, and (3) the receivers (the noise-exposed workers). To reduce noise exposure to workers such controls may involve (1) enclosures to isolate the sources or receivers, (2) barriers to reduce energy transmission along the path, and (3) distance to increase the path and ultimately to reduce acoustic energy at the receiver. Additional important engineering controls include the design of quieter manufacturing processing (low-acoustic emission saw blades).

3. Administrative controls—Include (1) reducing the amount of time a given worker might be exposed to a noise source to prevent a TWA of noise exposure from reaching 85 dBA and (2) establishing purchasing guidelines to prevent the introduction of equipment that would increase the dose of noise to which workers are subjected. Though simple in principle, the implementation of administrative control requires management commitment and constant supervision, particularly in the absence of engineering or personal protection controls. In general, administrative controls are used as an adjunct to existing noise control strategies within a hearing conservation program rather than as an exclusive approach for controlling noise exposure.

4. Worker education—Workers and management must understand the potentially harmful effects of noise in order to satisfy OSHA requirements and—most important—to ensure that the hearing conservation program is successful in preventing NIHL. A good worker education program describes (1) program objectives, (2) existing noise hazards, (3) how hearing loss occurs, (4) the purpose of audiometric testing, and (5) how workers can protect themselves. In addition, the roles and responsibilities of the employer and the workers should be clearly stated. Training is required to be provided annually to all workers included in the hearing conservation program. Opportunities for maintaining awareness occur during periodic safety meetings, as well as during audiometric testing appointments, when testing results are explained.

5. Hearing protection—Workers in environments that exceed the OSHA PEL must wear hearing protectors that will reduce exposures to below the action level (85 dBA TWA). Hearing protectors must be offered to employees exposed at or above the action level but below the PEL, and hearing protector use is mandated if the employee exhibits a standard threshold shift (defined below). It is important that workers not be forced to wear hearing protectors with attenuation values significantly exceeding the attenuation needed to reduce the exposure to safe levels (ie, below the action level). There is no need to reduce exposures below the safe limit; doing so decreases workers compliance and decreases the ability of workers to communicate and hear warning sounds, which increases the probability of injury from accidental causes.

For many years OSHA has required employers to use the "noise reduction rating" (NRR), a method for rating hearing protectors approved by the Environmental Protection Agency in 1979. Because the NRR was developed as a laboratory standard to provide a benchmark comparison value among earplugs, it has long been recognized as an inadequate method for determining the real-world attenuation values that can be expected for a worker in a real-world environment. Recognizing the problems with the original NRR, OSHA provides, in a complicated appendix to the noise standard, three methods for derating the NRR values in order to arrive at a more "realistic" estimate of the actual attenuation that might be expected for a worker using the earplug. Discussion has been ongoing about a possible new rule, and a new one appears to be around the corner at the writing of this chapter.

The new rule, *EPA Noise Labeling Standards for Hearing Protection Devices* (40CFR 211 subpart B), is expected to be issued early in 2010. The rule provides a new method that gives NRRs determined by subjects who fit themselves without assistance. Further, a range of NRRs is provided rather than a single number. The range is designed to account for differences in individual subject fitting and also will address inherent differences in hearing protector type, as well as addressing modern hearing protectors that include active noise reduction circuitry. The low number in the range is the attenuation achieved by 80% of the subjects; the higher number reflects the attenuation achieved by 20% of the subjects. (Note in editing: there is considerable sentiment that the upper number should be 10%.) The new rule, when enacted, will form the basis of OSHAs hearing protector fitting methods.

6. Audiometric evaluation—Provides the only quantitative means of assessing the overall effectiveness of a hearing

conservation program. A properly managed audiometric testing program supervised by either a certified audiologist, physician, or other personnel trained and experienced in occupational hearing conservation can detect changes in hearing over time that might otherwise be overlooked. The results of audiometric testing must be shared with employees to ensure effectiveness. The overall results or trends noted in an audiometric testing program can be used to fine-tune the hearing conservation program, including determining what types of hearing protection devices to offer to employees and the location where additional employee training is needed.

Employers are required to obtain an initial audiogram, usually obtained within the first 6 months of employment to be used as a baseline to which subsequent audiograms are compared. If a "standard threshold shift" defined as a change in hearing averaging 10 dB or more at the audiometric test frequencies of 2, 3, and 4 kHz occurs in either ear, the individual employee is notified and further action is required that may necessitate both modifying the hearing conservation program and notifying the appropriate authorities (eg, the employer or the appropriate government agency). In some cases, a referral to an otologist is indicated to determine the work-relatedness of the shift and to evaluate other potential medical causes.

American Conference of Governmental Industrial Hygienists (2006). *Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs)*. Cincinnati, OH. (Reference source for toxic exposures.)

American National Standards Institute, Inc. [ANSI]. (1996). *American National Standard: Determination of occupational noise exposure and estimation of noise-induced hearing impairment* (ANSI S3.44-1996). New York: American National Standards Institute, Inc.

National Aeronautics and Space Administration. National Auditory Demonstration Laboratory TWA Calculator. Website: http://adl.grc.nasa.gov/340/twa-calculator. Accessed March 31, 2010. (Resource for determination of noise exposure parameters.)

National Institute for Occupational Safety and Health [NIOSH]. (1998). *Criteria for a recommended standard. Occupational exposure to noise. Revised criteria.* U. S. (DHHS Publication No. 98–126). Cincinnati, OH: NIOSH. (Proposal for new standard for noise exposure.)

Occupational Safety and Health Administration [OSHA]. (1983). *Occupational noise exposure: Hearing conservation amendment; final rule.* Occupational Safety and Health Administration, 29 C.F.R. 1910.95; 48 Fed. Reg. 9738–9785. (Federal rule for occupational noise exposure.)

HEARING LOSS DUE TO PHYSICAL TRAUMA

Blunt head injury is by far the most common cause of traumatic hearing loss; motor vehicle accidents account for approximately 50% of temporal bone injuries. The cochlear injury observed following blunt head trauma closely resembles, both histologically and from an audiologic perspective, the trauma induced by high-intensity acoustic trauma. Such injury may be ameliorated if the middle ear structures absorb some of the energy and rupture.

Penetrating injuries of the temporal bone are relatively rare. Other occupational causes of ear injury include falls, explosions, burns from caustic chemicals, open flames, and welder's slag injuries.

Examination & Treatment

In the conscious patient, the type of auditory injury may be suspected with a 512 Hz tuning fork. The sound will lateralize toward the damaged ear with a conductive hearing loss and away from a sensorineural one. In many cases the injury is mixed and bilateral so the tuning fork results may be ambiguous. Patients should also be checked for signs of vestibular injury (eg, nystagmus) and facial nerve trauma (eg, paralysis). Complete audiometric examinations can be performed after the patient has been stabilized.

A. Injuries Causing Conductive Hearing Loss

Blunt head trauma with or without temporal bone fracture may cause hemotympanum, a collection of blood in the middle ear. If this is the sole injury, hearing usually recovers over several weeks. Burns sustained when a piece of welder's slag may penetrate the eardrum. These often heal poorly, and chronic infection often results. A loud explosion with sound pressure levels exceeding 180 dB may cause rupture of the tympanic membrane. Traumatic membrane perforations usually heal spontaneously if secondary infection does not develop, although hearing loss may persist. Water precautions should be observed to avoid secondary infection.

A conductive hearing loss that persists for more than 3 months after injury is usually due to a tympanic membrane perforation or disruption of the ossicular chain. These lesions are generally suitable for surgical repair, which is detailed elsewhere in this book.

B. Injuries Causing Sensorineural or Mixed Hearing Loss

Trauma to the inner ear most commonly results from blunt head injury. Labyrinthine concussion frequently occurs with transient vertigo, potentially with permanent hearing loss and tinnitus. These patients may be treated with vestibular suppressants for short-term symptomatic relief of vertigo. However, vestibular rehabilitation is warranted for severe loss.

OTOTOXIC HEARING LOSS

Chemicals in the workplace can be absorbed through the skin or inhaled, and secondarily reach inner ear fluids via the bloodstream. Industrial chemicals are thought to damage both the cochlea and central auditory structures via free-radical production.

According to Morata, the Human Field Studies Working Group has identified the following chemicals as having the highest priority for intervention in the workplace:

Solvents—toluene, styrene, xylene, *n*-hexane, ethyl benzene, white spirits/Stoddard, carbon disulfide, fuels, and perchloroethylene.

Asphyxiants—carbon monoxide and hydrogen cyanide.

Metals—lead and mercury.

Pesticides/herbicides—Paraquat and organophosphates.

Outside of the occupational setting, however, the majority of ototoxic hearing loss is secondary to medications including aminoglycosides, loop diurectics, antineoplastic agents, and salicylates.

Workplace controls must be in place to limit exposure to chemical ototoxins. High-risk workers should be identified based upon ototoxic exposure, preexisting sensory hearing loss, and compromised renal or hepatic function. Audiometric evaluation is appropriate to identify and monitor ototoxic exposure, and the addition of otoacoustic emissions, evoked auditory brainstem potentials, and behavioral audiometry have been proposed to examine central effects of industrial chemicals.

Workers taking potentially ototoxic medications are at an increased risk of hearing loss when placed in noisy environments, since the combination of some ototoxic drug treatments and noise trauma can lead to a greater degree of hearing loss than either of these would produce by itself. Conversely, patients with any type of preexisting sensorineural hearing loss, including NIHL, may be more susceptible to the ototoxic effects of medications. Aspirin, however, while known to cause reversible sensorineural hearing loss, is probably not associated with an increased likelihood of NIHL.

Medicinal ototoxins should be administered in the lowest dose compatible with therapeutic efficacy. Serum peak and trough levels should be monitored to reduce the risk of excessive dosages. The simultaneous administration of multiple ototoxic drugs (eg, furosemide and an aminoglycoside antibiotic) should also be avoided, when possible, to minimize synergistic effects.

Morata TC. Chemical exposure as a risk factor for hearing loss. *J Occup Environ Med*. 2003;45:676–682. (Source data for chemical exposures in the workplace.)

MEDICAL–LEGAL ISSUES

1. Workers' Compensation

All states within the U.S. have workers' compensation programs to compensate the worker for injuries that arise from employment. Each state has developed its own method for handling the injured worker, and state statutes are not uniform across the United States. Prior to assessing a worker compensation case, it behooves the medical examiner to understand the appropriate statutes of the state in which the claim is being filed.

To make matters more complicated, cases that fall under the purview of the Federal government, such as civilian Federal employees under the Federal Employee Compensation Act (FECA) are handled differently than cases involving longshoreman under the Longshoreman and Harbor Workers' Compensation Act (LHWCA), despite the fact that both acts are adjudicated by the U.S. Department of Labor.

Cases involving maritime workers fall under the purview of the Jones Act, which covers workers such as merchant marines (seamen and ship crewmen), some divers, and pile drivers. Though Jones Act cases are under the auspices of the Federal Government, they are adjudicated differently than the Department of Labor cases.

Cases involving railroad workers involved in interstate commerce are handled by the Federal Employers Liability Act (FELA). Though the Jones Act and FELA are different from a practical point of view for the physician performing the evaluation, they are similar and are handled by medical examination and possible testimony in court rather than through a scheduled award (by a guideline that determines the percentage of hearing loss).

2. Calculation of Percentage of Hearing Loss

Several methods for calculating the percentage of hearing loss are in widespread use. The most current and frequently used method recommended by the American Academy of Otolaryngology (AAO; 1979) is as follows (Table 58–4).

1. **Thresholds** The average hearing threshold level at 500, 1000, 2000, and 3000 Hz is calculated for each ear.
2. **Monaural impairment** The percentage of the impairment for each ear is calculated by taking the PTA (500–3000 Hz), subtracting 25 dB, and multiplying the result by 1.5. The maximum 100% monaural loss is reached at 92 dB (high fence). This is based on the assumption that hearing loss only becomes a handicap beyond 25 dB and that the handicap increases at a rate of 1.5% per decibel after this point.
3. **Hearing Handicap** This is calculated by multiplying the smaller percentage (better hearing ear) by 5, adding this figure to the larger percentage (worse hearing ear), and dividing the total by 6. As unilateral deafness is only considered a mild handicap, a 5 to 1 weighting is used for the better ear.

The AAO method for calculating the percent hearing loss described above is identical to the hearing impairment guidelines developed by the American Medical Association (AMA Guidelines on Evaluation of Permanent Impairment). The AAO method is now used by the majority of states in local worker compensation programs and by the US Department of Labor (eg, FECA and LHWCA).

Table 58–4. Calculation of Hearing Handicap.

Thresholds (dB)	Left Ear	Right Ear
500 Hz	dB	dB
1000 Hz	dB	dB
2000 Hz	dB	dB
3000 Hz	dB	dB
Pure tone average (PTA)	$\frac{\Sigma Thresholds(left)}{4}$	$\frac{\Sigma Thresholds(Right)}{4}$
Monaural impairment (MI)	$= 1.5(PTA_L - 25)$	$= 1.5(PTA_R - 25)$
Hearing handicap (HH)	$\frac{5(M/b)+M/w}{4}$	

PTA_R —pure-tone average of right ear; MIb—monaural impairment of better ear; MIw—monaural impairment of worse ear

Some states use the 1959 American Academy of Ophthalmology and Otolaryngology rule. This method for calculating the percentage of hearing loss is similar to the AAO method, except that the 3000 Hz threshold is not included in the pure-tone average.

Generally, there is a statute of limitations that determines when an employee is eligible to apply for compensation. This statute varies from state to state and with the Federal government. In taking a history, the medical examiner should include a statement as to when the hearing loss occurred and when the employee may have realized that the hearing loss was related to noise.

Most states will apportion a pre-existing hearing loss; the U.S. Department of Labor does not deduct for pre-employment hearing loss. The U.S. Department of Labor, FECA, and LHWCA ask only if the hearing loss was precipitated, accelerated, aggravated, or proximately caused by the accepted conditions of employment.

3. Assessment of Impairment

The normal range of SRT is between 0 and 20 dB, with hearing losses designated according to the following measures: (1) mild (25–40 dB); (2) moderate (40–55 dB); (3) moderately severe (55–70 dB); severe (70–90 dB); (5) profound (>90 dB). Of course, the extent of the disability suffered by the patient depends on many psychological, social, and work-related factors. Disability is a relative term. The assessment of an individual's ability to do his or her job requires knowledge about the various duties performed by that individual. Some typical work-related issues for consideration include the amount of communication with coworkers and others that is required on the job, the type of communication (eg, in person or via the telephone), and the need to hear alerting signals or emergency warning alarms.

Police, firefighters, and other emergency and law enforcement personnel generally have to meet certain hearing requirements for employment. Guidelines for these occupations differ regionally; however, the guidelines for entry-level police officers and firefighters generally require a PTA at 500, 1000, 2000, and 3000 Hz of 25–30 dB. Postemployment requirements vary greatly. There is an effort in some states to quantify hearing in a noisy environment and California now conducts "hearing in noise" tests (HINT).

To meet the Social Security Administration guidelines for total disability due to hearing impairment, an individual must have either (1) an average hearing threshold of ≥90 dB for the better-hearing ear based on both air and bone conduction at 500, 1000, and 2000 Hz, or (2) a speech discrimination score of 40% or less in the better-hearing ear. In both cases, hearing must not be restorable by hearing amplification devices.

In assessing cases of tinnitus, the otologist and audiologist may attempt to match the tinnitus with the intensity of the tinnitus in decibels and the frequency of the ringing in Hertz. Tinnitus is a solely subjective finding. Some states allow an award for tinnitus while other states do not.

The examining physician should include a statement regarding the claimant's ability to perform his usual and customary occupation.

4. Compensation for Occupational Hearing Loss

An example of how occupational hearing loss is compensated is provided by the statistics of the US Department of Labor (FECA). In the fiscal year 1999–2000, there were 6745 claims. The cost to the Federal government was $8,982,139 in medical costs and $30,925,247 in compensation for a total cost of $39,907,386. The average cost per claim was $5917.

The general rise in costs per claim over the years reflects the rising costs of hearing aids. Many claimants are requesting newer digital hearing aids that cost $2500 or more each.

The relationship between NIHL and presbycusis remains incompletely understood. Many studies have tried to address the issue of workers exposed to hazardous noise for a long period of time and their "presumed" hearing losses based on their age (ie, presbycusis). The International Organization Standards (ISO) published a report that attempts to quantify that relationship. As with all large series, attempts to estimate hearing for individuals at certain ages are also based on determining the median or averages of large populations at a given age. There is much debate whether epidemiologic hearing loss data can be applied to individuals.

Dobie RA. *Medical-Legal Evaluation of Hearing Loss*. 2nd ed. Singular/Thomson Learning, 2001. (Widely respected authority on NIHL.)

International Organization for Standardization: ISO-1999. Acoustics—Determination of Occupational Noise Exposure and Estimation of Noise Induced Hearing Impairment. International Organization for Standardization, 1990. (Comprehensive attempt to understand the interaction of noise and aging in groups).

We would like to acknowledge Sumit K. Agrawal, MD, David N. Schindler, MD, Robert K. Jackler, MD, and Scott Robinson, MPH, CIH, CSP for their contribution to this chapter in the previous editions of CDT.

59 Temporal Bone Trauma

John S. Oghalai, MD

EXTERNAL & MIDDLE EAR TRAUMA

ESSENTIALS OF DIAGNOSIS

- History of trauma to ear or foreign body insertion into the ear
- Symptoms of pain and hearing loss
- Bloody otorrhea.

General Considerations

Injuries localized to the external or middle ear include auricular hematoma, external auditory canal abrasion or laceration, tympanic membrane perforation, and ossicular chain dislocation. Local trauma to the tympanic membrane and ossicles can occur by a penetrating injury with objects such as a cotton-tipped applicator, a bobby pin, a pencil, or a hot metal slag during welding. In addition, barotrauma, such as a slap to the ear or a blast injury, can cause a tympanic membrane perforation or ossicular chain dislocation.

1. Auricular Hematoma

An auricular hematoma may present after a forceful blow to the external ear. It can be recognized as a tender swelling of the pinna that is fluctuant on palpation. The hematoma arises after the perichondrium is sheared off the cartilage of the auricle. This fluid accumulation needs to be drained to prevent chondronecrosis and lead to a misshapen pinna, commonly known as a "cauliflower ear" or "wrestler's ear." After incision and drainage, a compression dressing is sutured through the pinna to bolster the skin and perichondrium against the auricular cartilage, preventing reaccumulation of the fluid.

2. External Auditory Canal Abrasion

Injuries to the external auditory canal most commonly occur when a patient is trying to remove his or her own earwax with a cotton-tipped applicator or bobby pin. The injury is usually a simple abrasion or laceration. Treatment consists of using an antimicrobial otic drop to prevent bacterial or fungal superinfection of the area. Alternately, there may be a localized area of blood collection underneath the skin of the external auditory canal, called a *bulla*. Perforating the tense bulla with a sharp pick often helps to reduce the patient's discomfort. Patients with diabetes have a high risk of developing external otitis from this type of injury because of their poor microcirculation. These patients need to be followed up closely to verify wound healing.

3. Tympanic Membrane Perforation

A tympanic membrane perforation can occur after the use of a cotton-tipped applicator, a bobby pin, a pencil, or the entry of a hot metal slag into the ear canal during welding. Finally, barotrauma, such as a slap to the ear or a blast injury, can cause a perforation. In all cases, patients usually complain of pain and hearing loss, and the perforation can be diagnosed by otoscopy. It is important to note how much of the tympanic membrane has been perforated. A central perforation does not involve the annulus of the eardrum, whereas a marginal perforation does. In addition, the Weber tuning fork test should be performed to verify that it radiates to the affected ear, and the eyes should be checked for nystagmus. If the Weber test does not radiate to the affected ear and the patient has nystagmus, it is likely that stapes subluxation with sensorineural hearing loss has occurred. This is termed a perilymphatic fistula and requires urgent treatment (see Perilymphatic Fistula, Treatment).

If no evidence of sensorineural hearing loss is found, no specific treatment is required because traumatic tympanic membrane perforations, especially central perforations, typically heal spontaneously. However, strict dry

ear precautions should be followed to prevent water from getting into the ear. Instructions to the patient include no swimming and use of a cotton ball thoroughly coated with petrolatum (eg, Vaseline) in the affected ear during bathing. An audiogram should be performed after about 3 months to verify that hearing has returned to normal and that there is no ossicular chain discontinuity. If the perforation has not healed by 3 months, a tympanoplasty will likely need to be performed.

4. Ossicular Chain Dislocation

Penetrating trauma with objects such as a cotton-tipped applicator, a bobby pin, or a pencil can injure the ossicular chain (after perforating the tympanic membrane). Barotrauma, such as a slap to the ear, a blast injury, or rapid decent in an aircraft, can cause ossicular chain dislocation without tympanic membrane perforation. Ossicular chain dislocation with an intact eardrum manifests as a maximal (60 dB) conductive hearing loss. Ossicular chain dislocation with a perforated eardrum results in lesser degrees of hearing loss. Treatment in any case is middle ear exploration and ossicular chain reconstruction, with tympanoplasty if needed.

TEMPORAL BONE FRACTURES

ESSENTIALS OF DIAGNOSIS

- History of blunt head trauma
- Symptoms of hearing loss and possibly vertigo and facial nerve palsy
- Signs include Battle sign, hemotympanum, and bloody otorrhea.

General Considerations

The skull base includes the frontal bone, the sphenoid bone, the temporal bone, and the occipital bone. A fracture in the skull base (otherwise known as a basilar skull fracture) must involve at least one of these bones and may involve all of them. Temporal bone fractures represent roughly 20% of all skull fractures. Risk factors include being male and under 21. The most common causes include motor vehicle accidents, falls, bicycle accidents, seizures, and aggravated assaults. Blunt trauma to the lateral surface of the skull (the squamous portion of the temporal bone) often results in a longitudinal fracture. A blow to the occipital skull may go through the foramen magnum and result in a transverse fracture of the temporal bone (Figure 59–1).

Pathogenesis

Longitudinal fractures involve the squamous portion of the temporal bone, follow the axis of the external auditory canal to the middle ear space, and then course anteriorly along the geniculate ganglion and eustachian tube, ending near the foramen lacerum. In a longitudinal temporal bone fracture, the otic capsule is spared. In contrast, transverse fractures course directly across the petrous pyramid, fracturing the otic capsule, and then extend anteriorly along the eustachian tube and geniculate ganglion. Longitudinal temporal bone fractures and transverse temporal bone fractures represent 80% and 20%, respectively, of temporal bone fractures.

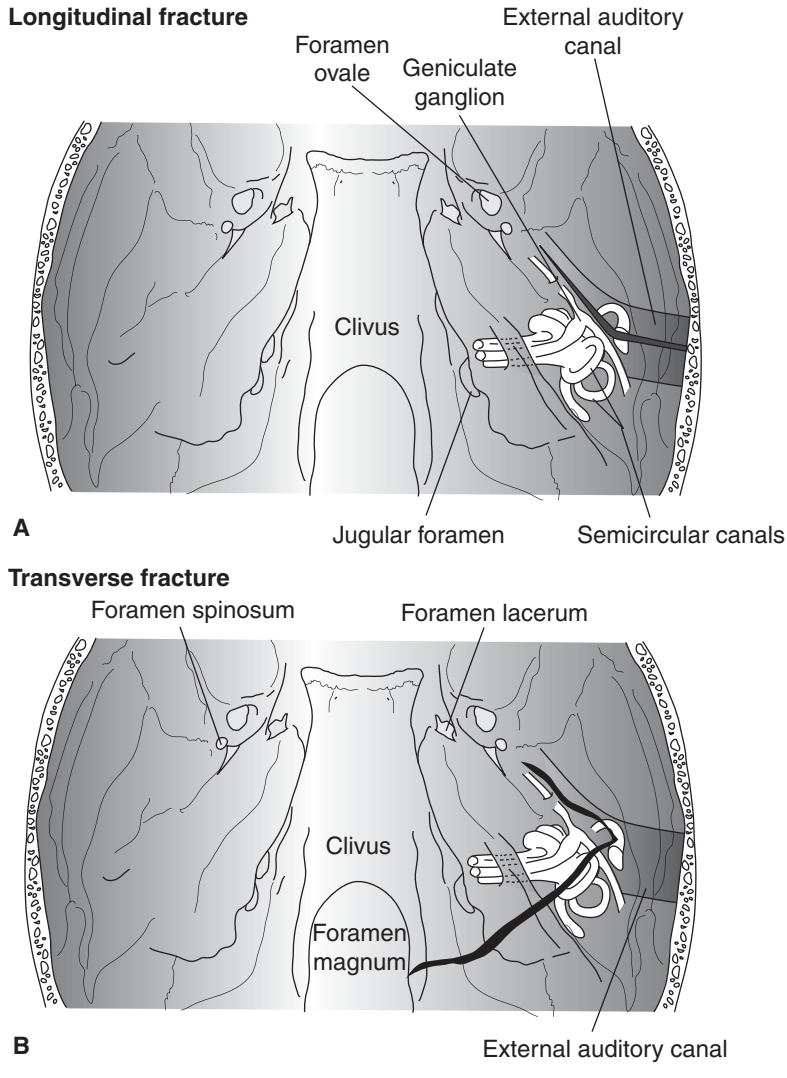
Clinical Findings

A. Symptoms and Signs

Symptoms include hearing loss, nausea and vomiting, and vertigo. Clinical signs include Battle sign, which is a postauricular ecchymosis resulting from extravasated blood from the postauricular artery or mastoid emissary vein. The "raccoon" sign (periorbital ecchymosis) is associated with basilar skull fractures that involve the middle or anterior cranial fossa. Physical examination may demonstrate an external auditory canal laceration with bony debris within the canal. A hemotympanum is almost always identified. Cerebrospinal fluid (CSF) otorrhea or rhinorrhea may be seen. Tuning fork tests should always be performed on patients with a temporal bone fracture. The Weber tuning fork test radiates to the fractured ear if conductive hearing loss is present and radiates to the contralateral ear if sensorineural hearing loss is present. The presence or absence of facial nerve paralysis should be documented in all patients with temporal bone fractures.

B. Imaging Studies

After initial resuscitation in the emergency room, computed tomography (CT) scanning of the head is usually the first study performed on patients with head trauma. It is critical to rule out an intracranial hemorrhage, which may require urgent neurosurgical treatment. It is at this point that a temporal bone fracture is usually identified. High-resolution CT scanning of the temporal bone is valuable in delineating the extent of the fracture, but it is not required unless a complication is suspected (eg, otic capsule fracture, facial nerve injury, or CSF leak). Patients with a longitudinal fracture associated with hemotympanum, without nystagmus, without evidence of CSF leak, with a Weber tuning fork test that radiates to the affected ear, and with normal facial nerve function typically do not need a CT scan of the temporal bone. Angiography may be performed if there is significant hemorrhage from the skull base to rule out vascular injury, but this is uncommon.



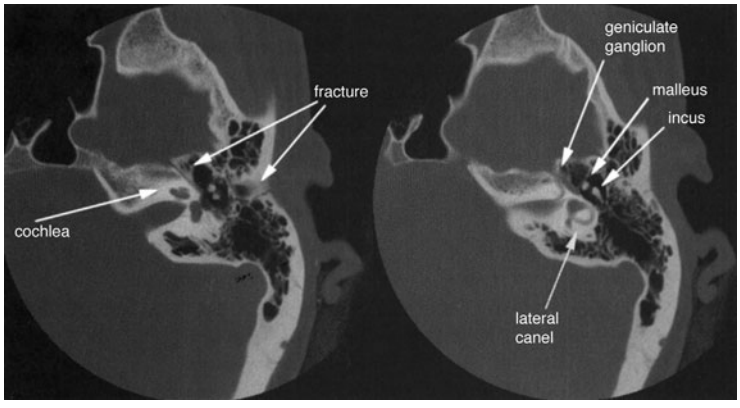
▲ **Figure 59–1.** Types of temporal bone fractures. **(A)** Longitudinal fractures begin at the squamous portion of the temporal bone, run through the external auditory canal, and then turn anteriorly toward the foramen lacerum. **(B)** Transverse fractures begin from the foramen magnum, run through the otic capsule bone that surrounds the inner ear, and then turn anteriorly toward the foramen lacerum.

C. Special Tests

1. Audiometry—Audiometry should be performed on all patients with a temporal bone fracture. However, this does not need to be done acutely in most cases. If clinical examination is consistent with conductive hearing loss and there is no evidence of otic capsule fracture, audiometric assessment can be performed several weeks after the injury, permitting time for the hemotympanum to resolve. If the otic capsule is fractured, there is a high likelihood of permanent complete sensorineural hearing loss and there is no treatment available to alter this prognosis. Urgent audiometry may be considered if stapes subluxation into the vestibule has occurred and surgery to repair a perilymph fistula is planned.

2. Facial nerve testing—Facial nerve testing should be performed if a delayed, complete facial palsy occurs. The rationale is to identify patients with >90% degeneration of the facial nerve, because these patients have poorer recovery of the function and may benefit from surgical decompression. **The nerve excitability test** is performed by placing the two probes of a Hilger nerve stimulator across the stylomastoid foramen and slowly turning up the current until a facial twitch is just barely visible. This is the stimulation threshold of the facial nerve. A 3.5-mA difference between the injured and uninjured sides correlates with a > 90% loss of neural integrity.

Alternately, **electroneuronography** can be performed by a neurophysiologist. This involves stimulating both facial nerves with equal currents while simultaneously measuring the evoked myogenic potential in the muscles of facial expression. If the amplitude of the ipsilateral evoked potential is < 10% of that from the contralateral side, >90% loss



A B

▲ **Figure 59–2.** Axial computed tomography scan of a patient who sustained a longitudinal temporal bone fracture several months previously. This patient had a 60-dB conductive hearing loss with a normal tympanic membrane on physical exam. **(A)** The inferior cut demonstrates the line of the fracture. **(B)** The superior cut shows dislocation of the malleus-incus joint. Note that the fracture runs directly along the geniculate ganglion, but the patient did not have facial nerve dysfunction.

of neural integrity has occurred. Neither of these tests is accurate within 3 days of the injury because it takes about 72 hours for nerve fibers distal to the site of the injury to degenerate. Nonetheless, surgical decompression of delayed facial paralysis remains controversial.

Complications

A. Conductive Hearing Loss

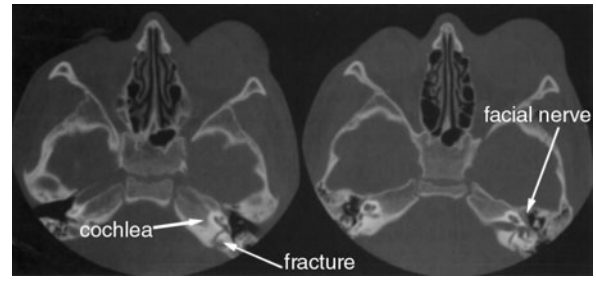
Conductive hearing loss is most commonly due to hemotympanum, but may also represent a tympanic membrane perforation or ossicular discontinuity. The most common form of ossicular discontinuity after temporal bone trauma is incudostapedial joint dislocation. The second most common is incudomalleolar joint dislocation (Figure 59–2). In addition, ossicular fixation may occur several months after the trauma if new bone formation at the line of the fracture fuses to the ossicular chain.

B. Sensorineural Hearing Loss and Vertigo

These complications are found in patients who sustain a transverse temporal bone fracture with otic capsule involvement (Figure 59–3). Pneumolabyrinth (air in the inner ear) is often noted by CT. An audiogram usually demonstrates a complete sensorineural hearing loss in the affected ear. Acutely, clinical examination also reveals nystagmus, which is consistent with a unilateral vestibular deficit. Sensorineural hearing loss can also be sustained without otic capsule fracture if a labyrinthine concussion, traumatic noise exposure, or blast injury occurs. This is thought to involve tearing of the cochlear membranes and/or trauma to the hair cell epithelium due to the rapid acceleration and deceleration forces within the inner ear. These injuries can manifest either as a high-frequency hearing loss, atemporary threshold shift in their hearing that resolves, or a permanent and complete sensorineural hearing loss.

C. Facial Nerve Injury

Facial nerve palsy occurs in 20% of longitudinal temporal bone fractures and 50% of transverse temporal bone fractures. The most important clinical feature to identify is whether the facial nerve palsy was of delayed or immediate onset. Patients with delayed-onset palsy present to the emergency room with normal facial nerve function that slowly worsens over the next several hours to days. This is thought to represent edema within the facial nerve without disruption of neural integrity. In contrast, immediate facial nerve injury is highly suggestive of facial nerve transection. Unfortunately, it is common to have an undetermined onset time of facial nerve palsy because



A B

▲ **Figure 59–3.** Axial computed tomography scan of an 8-year-old child who sustained a transverse temporal bone fracture. This patient had nystagmus and a complete sensorineural hearing loss. His facial nerve function was normal. **(A)** The inferior cut demonstrates the line of the fracture that extends through the dense, white bone of the otic capsule. **(B)** The superior cut shows that the fracture extends to the facial nerve canal.

patients with temporal bone fractures and facial nerve palsy typically have many other life-threatening issues that are being dealt with at the time of the initial evaluation. These patients are often comatose and therefore difficult to examine.

D. Cerebrospinal Fluid Leak

There is a 2% incidence of CSF leak in all skull fractures and a 20% incidence in temporal bone fractures. CSF leaks usually start within the first 48 hours of the trauma and are noted as clear fluid emanating from the ear or nose. Straining, standing up, or bending over worsens the CSF leak. If clear fluid emanating from the nose or ear is suggestive of a CSF leak, the fluid can be collected and sent for β_2 transferrin testing. β_2 transferrin is a protein found only in CSF.

E. Posttraumatic Encephalocele

Posttraumatic encephalocele can result if a large defect in the floor of the middle cranial fossa occurs. Dura and temporal lobe brain can herniate down into the middle ear and mastoid. This can sometimes be visible on otoscopic examination of the ear as a white mass with blood vessels behind the tympanic membrane. A CSF leak can occur in combination with an encephalocele.

F. Perilymphatic Fistula

A perilymphatic fistula can occur after a fracture of the otic capsule or stapes subluxation of the oval window. It manifests as fluctuating vertigo and sensorineural hearing loss. This entity is fully described later in this chapter.

Treatment

A. Conductive Hearing Loss

A hemotympanum resolves spontaneously within 34 weeks of the injury with no sequelae. Traumatic tympanic membrane perforations have an excellent chance of healing spontaneously. Within 1 month, 68% are healed; within 3 months, 94% are healed. If the perforation has not healed by 3 months, a paper-patch myringoplasty can be attempted in the office. This should be performed only if the perforation is quite small (<25%) and does not involve the margins of the eardrum and if the middle ear mucosa appears uninfected and dry. The edges of the perforation are freshened with a Rosen needle and a paper patch (cigarette paper or a Steri-Strip) is placed over the perforation.

If the perforation is large or has failed an attempt at paper-patch myringoplasty, the patient should be taken to the operating room for a standard tympanoplasty. The ossicular chain should also be explored to verify that it is intact during this procedure. A patient with a normal tympanic membrane and persistent conductive hearing loss probably has ossicular chain discontinuity. A middle ear exploration should be done through the canal by raising a tympanomeatal flap and carefully inspecting and palpating the ossicles. Ossicular chain reconstruction is based on the site of the injury.

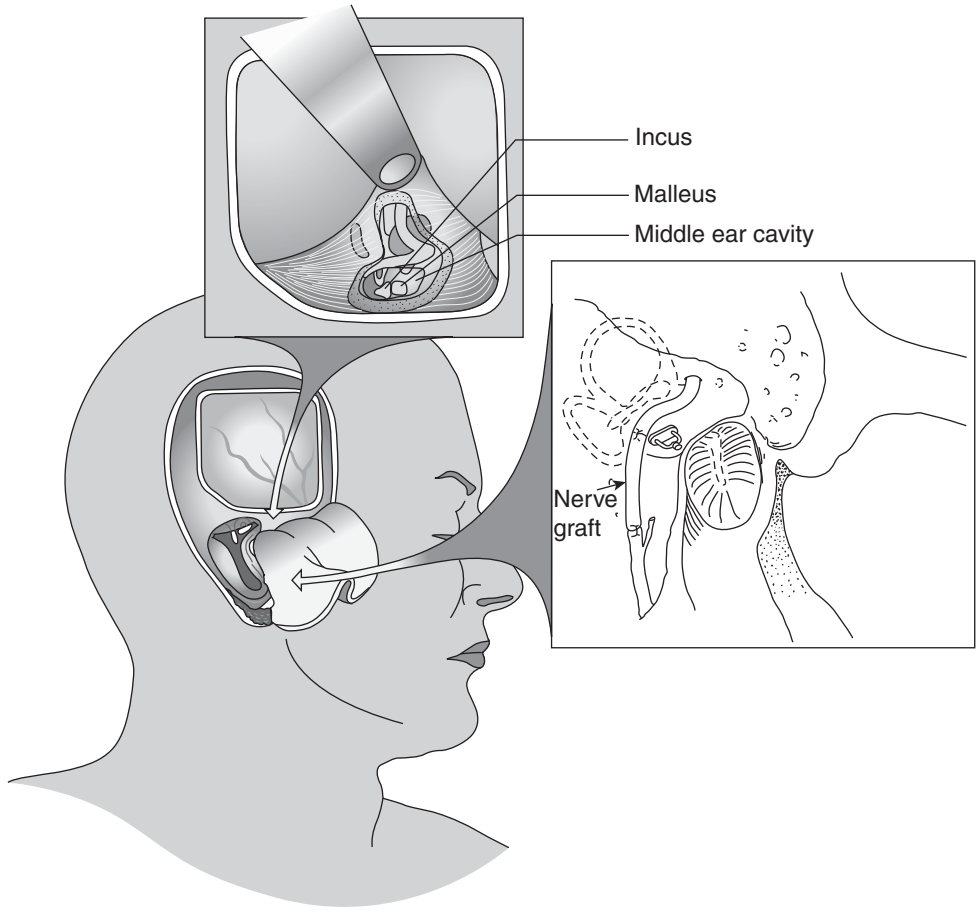
B. Facial Nerve Paralysis

The treatment of delayed-onset palsy is based on conservative, nonsurgical management. It is expected that 94% to 100% of these patients will have complete and full recovery of their facial nerve function. However, patients with > 90% degeneration of neural integrity have been shown to have poor recovery. Presumably, the nerve is swollen within the bony fallopian canal, compressing itself within this confined space and therefore causing permanent injury to the nerve fibers.

The management of patients with > 90% degeneration is controversial. Although some neurotologists recommend facial nerve exploration and decompression, others recommend watchful waiting. In contrast, there is no controversy about patients with immediate-onset facial palsy. These patients should undergo facial nerve exploration as soon as the patient is medically stabilized. Human studies have not proved that early surgery improves the long-term facial nerve outcome, but animal studies suggest that intervention within 21 days of facial nerve transection is beneficial.

The exploration of posttraumatic facial nerve palsy is based on two routes. If the patient has normal hearing, a combined middle fossa-transmastoid facial nerve exploration is performed (Figure 59–4). This includes a subtemporal craniotomy with delineation of the facial nerve within the internal auditory canal from the *porus acousticus internus* to the geniculate ganglion. A mastoidectomy is also performed to explore the facial nerve from the middle ear to the stylomastoid foramen. If the patient has a complete sensorineural hearing loss, a translabyrinthine facial nerve exploration and repair can be undertaken (Figure 59–5). This approach allows for complete exposure of the facial nerve from the porous acousticus to the stylomastoid foramen completely through the mastoid.

Injuries are most commonly located in the area of the geniculate ganglion. If an intraneural hematoma is identified, the epineurium should be carefully opened and the hematoma evacuated. If bony fragments are impinging upon the nerve, these can be carefully removed as well. If there is an obvious fracture of the facial nerve, the two ends of the facial nerve should be freshened and anastomosed. If the segment of missing nerve is too long to be easily anastomosed without tension, an interposition nerve graft should be used from the greater auricular or sural nerve. If no pathology is visualized, the act of opening the bony canal of the facial nerve should allow adequate decompression and permit swelling of the nerve without impingement. The epineurium does not need to be incised.

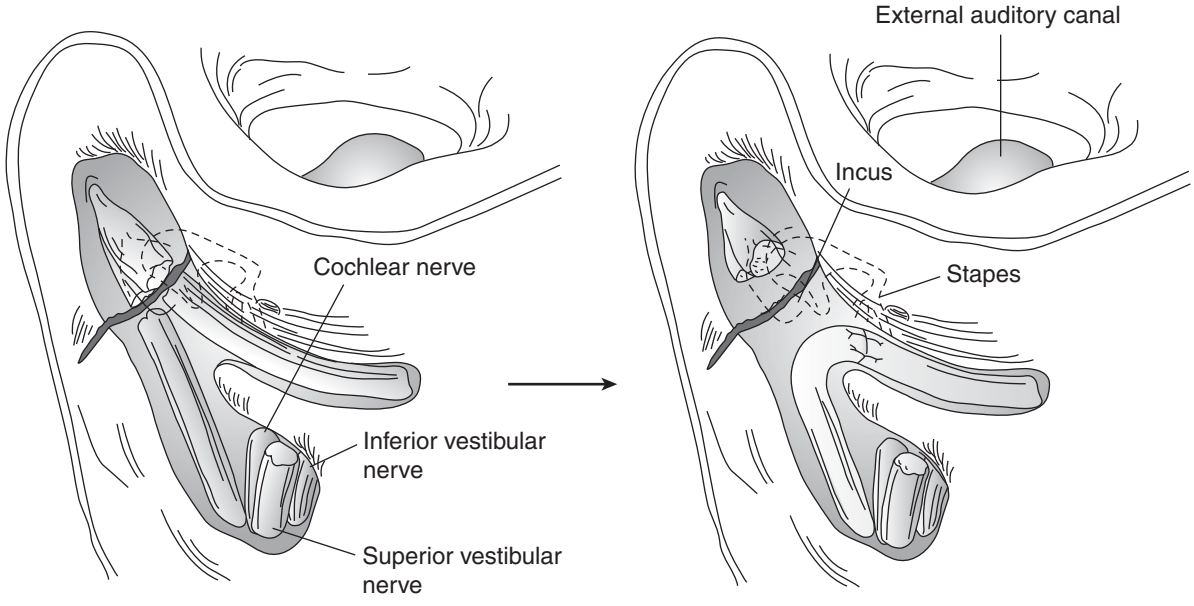


▲ **Figure 59–4.** The combined middle fossa-transmastoid approach. This approach is used for facial nerve exploration in patients with normal hearing. The middle fossa exposure permits visualization of the nerve from the brainstem to the geniculate ganglion, whereas the transmastoid route exposes the nerve from the geniculate ganglion to the stylomastoid foramen. In this example, an interpositional facial nerve graft has been placed within the vertical segment of the facial nerve.

C. Cerebrospinal Fluid Leak and Encephalocele

Eighty percent of posttraumatic CSF leaks close spontaneously after 7 days, and the risk of meningitis is quite low (3%) within this time period. Thus, medical treatment is attempted initially. This includes head elevation, stool softeners, acetazolamide (to decrease CSF production), and the placement of a lumbar drain. Patients with intracranial hemorrhage who have undergone craniotomy often already have an intraventricular drain in place, in which case a lumbar drain is not needed. Short-term antibiotics have been shown to be useful in preventing meningitis. The most common organisms that cause meningitis in this situation are *Pneumococcus, Staphylococcus, Streptococcus*, and *Haemophilus influenzae*. If the CSF leak persists for more than 7–10 days, the risk of meningitis increases dramatically (>20%) and surgical repair of the CSF leak should be performed. This situation is most common in patients who sustain a transverse temporal bone fracture with CSF leaking through the otic capsule. Otic capsule bone does not heal with new bone formation but by fibrous union, and this is often not strong enough to contain CSF.

An encephalocele should always be surgically repaired. If the patient has normal hearing, the repair of either a persistent CSF leak or an encephalocele is via a combined middle fossa craniotomy-transmastoid approach with dural repair and skull base reconstruction. In a patient with no useful hearing, obliteration of the ear with an abdominal fat graft, plugging of the eustachian tube, and closure of the ear canal can be performed through the mastoid alone.



▲ **Figure 59–5.** The translabyrinthine approach. This approach is used for facial nerve exploration in patients with complete sensorineural hearing loss and allows complete exposure of the nerve through one opening. In this example, a primary facial nerve anastomosis has been performed.

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PENETRATING TRAUMA TO THE TEMPORAL BONE

ESSENTIALS OF DIAGNOSIS

- Usually caused by a gunshot wound
- Significant soft-tissue deficit
- High likelihood of facial nerve palsy and vascular injury.

General Considerations

Penetrating trauma, predominantly from gunshot wounds, is much more damaging to the temporal bone than is blunt trauma. There is often significant injury to the external auditory canal, which requires local debridement of bone fragments and soft tissue, as well as stenting with Merocel wicks (a type of expandable, nonabsorbable sponge) to prevent stenosis. If stenosis does occur after several months, a canaloplasty may be required. Soft tissue loss may require regional or free-flap reconstruction. Tympanic membrane perforation, ossicular discontinuity, and labyrinthine fracture are also common entities with a gunshot wound to the temporal bone. Epithelial elements can be introduced into the mastoid or middle ear cavities and not be detected as a cholesteatoma until years later.

1. Vascular Injury

The most important aspect of penetrating trauma to the temporal bone is the potential for injury to the internal carotid artery, internal jugular vein, or dural sinuses. Vascular injury is found in 32% of patients with penetrating trauma to the temporal bone; therefore, these injuries should be considered as penetrating trauma to Zone III of the neck and treated accordingly. Angiography should be performed on all patients, with embolization or balloon occlusion used

to control bleeding from the skull base. If the hemorrhage continues or there is evidence of major vessel injury on an angiogram, surgical exploration may be required. In the event that internal carotid artery laceration is found, Fogarty catheters can be used temporarily to control bleeding.

2. Facial Nerve Injury

The rate of facial nerve paralysis with penetrating trauma to the temporal bone is 36%. Facial nerve injury most commonly occurs in the tympanic and mastoid segments. Essentially all of these injuries are of immediate onset and occur because of nerve transection. Facial nerve electrophysiologic testing with a Hilger stimulator can be used to identify facial nerve trauma in a comatose patient. Facial nerve repair needs to be undertaken as soon as the patient is medically stable.

PERILYMPHATIC FISTULA

ESSENTIALS OF DIAGNOSIS

- History of head trauma or previous stapedectomy
- Fluctuating hearing loss and episodic vertigo worse with straining

General Considerations

The most common cause of a perilymph fistula is when a long thin object (eg, pencil, bobby pin, Q-tip) is jammed into the ear canal, pushing the stapes into the vestibule. Barotrauma during scuba diving, a rapid descent in an airplane, an explosion, or straining during a difficult childbirth may also cause a perilymphatic fistula. A postsurgical perilymphatic fistula is also a well-recognized entity. It can occur after stapedectomy if the oval window fails to seal appropriately. Poor surgical technique while performing a mastoidectomy can lead to an iatrogenic lateral canal fistula. In addition, an expanding cholesteatoma can erode into the lateral semicircular canal or cochlea, causing a fistula. Finally, patients may present with a congenital perilymphatic fistula. These patients typically have stapes footplate anomalies or other temporal bone anomalies that are identified on CT scan. The superior semicircular canal dehiscence syndrome may be identified by CT scan, with a fistula from the superior canal into the intracranial space.

Clinical Findings

A. Symptoms and Signs

While much has been written about chronic perilymphatic fistula as a cause of chronic, episodic vertigo, most of this literature was written prior to modern imaging techniques. Most commonly, patients with a perilymphatic fistula present with acute onset of hearing loss, disequilibrium, and vertigo, after some inciting trauma or event. Symptoms may worsen with a Valsalva maneuver, such as coughing, sneezing, or straining. Occasionally, an altitude change, such as going up and down in an airplane or in an elevator, can precipitate symptoms. Patients may complain of Tullio phenomenon, whereby loud noises precipitate a vertiginous attack. Clinically, the fistula test can be performed by insufflating air into the external auditory canal and observing the patient for evidence of nystagmus. This test is very insensitive and is positive in only about 50% of patients with a fistula. Also, it is nonspecific because many patients without a fistula experience disequilibrium during this test.

B. Laboratory Findings

None

C. Imaging Studies

Modern CT techniques are quite good at detecting subluxaton of the stapes into or out of the vestibule. As well, perilymph leakage out of the vestibule can be noted as a soft tissue density material around the oval window niche.

D. Special Tests

Audiometry typically will demonstrate a mixed hearing loss. Vestibular testing may demonstrate a unilateral deficit. Nystagmus elicited by straining can be documented using electronystagmography monitoring and then evaluated. An abnormally low VEMP (vestibular evoked myogenic potential) threshold is often associated with superior semicircular canal dehiscence syndrome.

The only definitive way to make the diagnosis of a perilymphatic fistula is surgical exploration with visualization of the leak. Even this evaluation is not necessarily definitive since it is difficult to verify that small amounts of clear fluid within the middle ear cavity represent a perilymphatic leak and not serous transudate from the middle ear mucosa. Fluid suggestive of perilymph can be sampled on an absorbable gelatin sponge (eg, Gelfoam pledget) and sent for β_2 transferrin testing. β_2 transferrin is a protein found only in CSF and perilymph; it is not found in other fluids of the body. Although the test result is not immediately available, it may be useful when following up these patients postoperatively.

Differential Diagnosis

The differential diagnosis includes all causes of hearing loss and dysequilibrium, most notably Meniere disease and bacterial labyrinthitis.

Complications

Complete sensorineural hearing loss and unilateral vestibular deficit can occur if the inner ear becomes inflamed (labyrinthitis). Since there is a fistula from the middle ear space to the inner ear, an episode of acute otitis media is worrisome because bacteria in the middle ear can easily enter the inner ear and CSF. This may lead to meningitis.

Treatment

When the suspicion for a perilymph fistula is high, an urgent middle ear exploration is usually performed. This is done by a transcanal approach with elevation of the tympanomeatal flap and careful examination of the oval and round windows. If the stapes has been subluxed, it can usually be repositioned in the correct location and held in place with Gelfoam pledgets until it heals properly. If a defect is noted, a graft of fascia, perichondrium, or vein should be laid over the defect. If needed, ossicular chain reconstruction may be performed simultaneously as long as the prosthesis is supported laterally (ie, clipped onto the incus) so it will not push down into the vestibule over time.

When the suspicion for a perilymph fistula is low, treatment is based on conservative therapy. The patient should be at bed rest with head elevated. Patients are placed on stool softeners and serial audiograms should be obtained to follow up for evidence of disease progression. If symptoms persist or the sensorineural hearing loss worsens, surgical treatment may be considered. One option is to simply draw blood from the patient's arm and inject it through the eardrum into the middle ear space. This blood seal may help allow a fistula to heal.

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Lesions of the Anterior Skull Base

60

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General Considerations

Neoplasms of the anterior skull base (ASB) continue to challenge skull base surgeons, despite tremendous advances in multidisciplinary management. These lesions represent a diverse group of tumor types located within a surgically treacherous region. Historically, these tumors were considered unresectable. If surgery was attempted, it generally consisted of a lateral rhinotomy which inevitably resulted in incomplete tumor resection and dismal survival outcomes. The first combined neurosurgical and transfacial resections were reported in the mid-1950s, and the craniofacial resection was popularized by Ketcham and colleagues in 1963. Since this time, advances in diagnostic technology, interventional radiology, endoscopic endonasal surgery, and minimally invasive neurosurgery have facilitated the emergence of the young subspecialty of skull base surgery. Contemporary ASB surgical techniques have significantly expanded the limits of technical resectability while consolidating the gains that have been made in reducing morbidity and mortality.

The ASB is located at the interface of the central nervous system and the upper aerodigestive tract. ASB lesions may therefore arise from the bones of the skull base, "from above" (intracranially), or "from below" (the sinonasal cavity and orbits).

Anatomy

Anatomy of the skull base is covered is detail in Chapter 1 and will only be briefly addressed in this section. The ASB is separated from the central or middle skull base by a line running through the chiasmatic sulcus, the anterior clinoid processes, along the posterior margin of the lesser sphenoid wings, and the superior rims of the greater sphenoid wings. The ASB borders the posterior wall of the frontal sinus anteriorly, the frontal bones laterally, and the planum sphenoidale, or roof of the sphenoid sinus, posteriorly. The major components of the ASB are the orbital plates of the frontal bone, the fovea ethmoidalis, and the cribriform plate. The cribriform plate, situated more inferiorly than the ethmoid roof, is composed of thin bone that is traversed by olfactory nerve fibers, and is easily invaded by tumors. The dura mater attaches anteriorly at the frontal crest and crista galli to form the falx cerebri. The anterior cranial fossa contains the frontal lobes, the olfactory bulb, and the olfactory tract.

It is important to clarify that the ASB is distinct from neighboring structures that are often surgically approached with similar techniques. The sella turcica and pituitary gland are constituents of the middle or central skull base, and the clivus is a component of the posterior skull base, not the ASB. The ASB overlaps partially with the anterolateral skull base, which is the region between the mid-orbit and the petrous internal carotid artery, and includes the lateral orbit, infratemporal fossa, and portions of the frontal, sphenoid and temporal bones. This chapter will focus on lesions of the ASB.

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Vrionis FD, Kienstra MA, Rivera M et al. Malignant tumors of the anterior skull base. C*ancer Control* 2004;11(3):144–151.

Pathogenesis and Differential Diagnosis

A. Tumors From Below

The most common lesions of the ASB arise from the sinonasal cavity. Further details of sinonasal malignancy can be found in Chapter 17. Nasal and paranasal sinus cancers are rare, comprising 3% of head and neck cancers. In the United States, the most common histology is squamous cell carcinoma, followed by adenocarcinoma and minor salivary gland neoplasms. The remainders of sinonasal tumors are those arising from olfactory neuroepithelium (esthesioneuroblastoma), lymphoma, melanoma, sarcomas, and undifferentiated carcinomas.

Squamous cell carcinomas comprise 50% of sinonasal cancers, with the maxillary antrum the most common epicenter. Tobacco exposure is a major risk factor. Metastases are uncommon, with fewer than 10% of patients presenting with cervical metastases, and approximately 5% of patients developing distant metastases. However, the rate of cervical recurrence is as high as 20–30% when the neck is not electively treated with neck dissection or radiation. These tumors are staged using the AJCC staging system (see Chapter 17). Tumors involving the cribriform plate, sphenoid or frontal sinus, are staged T4a. Tumors involving the dura, brain, orbital apex, or clivus are staged T4b.

Adenocarcinomas comprise 30% of sinonasal cancers in the United States although they are the most common histologic subtype in most European series. Risk factors for sinonasal adenocarcinoma are exposure to leather dust, wood dust, nickel, and asbestos. Survival outcomes are slightly better than for squamous cell carcinoma.

Adenoid cystic carcinoma arising from minor salivary glands accounts for approximately 10% of sinonasal cancers. These tumors are generally slow growing with a low rate of cervical metastasis, but exhibit a high rate of perineural invasion, which contributes to a 30% rate of local recurrence. Metastases at presentation are rare, but ultimately, the incidence of distant metastasis is approximately 40%, most commonly to the lungs and bone.

Esthesioneuroblastomas are also called olfactory neuroblastomas, and comprise 3–6% of sinonasal tumors. These tumors are believed to arise from the basal cells of the olfactory neuroepithelium, which is primarily located on the cribriform plate. Histologically, these tumors are defined by small, round, blue cells and a fibrous background. Homer-Wright pseudorosettes are commonly present, and Flexner-Wintersteiner rosettes are rarely present in high-grade tumors. Radiographically, CT images will demonstrate a solid, enhancing mass with bone erosion. Intralesional calcifications are pathognomonic for esthesioneuroblastoma. On MR, tumors homogeneously enhance with intermediate intensity on T1-weighted images, and ARE hyperintense on T2 on T2-weighed images. At the border of cerebral invasion, the tumor will be hypointense to brain on T1, and are hyperintense to brain on T2. These tumors may be staged using the traditional Kadish system, which is sometimes modified with the addition of Stage D for distant disease (Table 60–1). The modified Kadish system has been shown to effectively stratify tumors by survival outcome. A TNM staging system has also been developed (Table 60–2).

Table 60–1. The Modified Kadish Staging System for Esthesioneuroblastoma.

Stage	Description
A	Tumor limited to the nasal cavity
B	Tumor involves the nasal and paranasal cavities
C	Tumor extends beyond the nasal and paranasal cavities
D	Distant metastases

Table 60–2. The TNM (Tumor-Node-Metastasis) Staging System for Esthesioneuroblastoma.

Stage	Description
Tumor	
T1	Tumor involving the nasal cavity and/or paranasal sinuses, but not the sphenoid or superior ethmoid cells
T2	Tumor involving the nasal cavity and/or paranasal sinuses, including the sphenoid or cribriform plate
T3	Tumor extending into the orbit or anterior cranial Fossa, without dural invasion
T4	Tumor involving the brain
Node	
N0	No cervical metastases
N1	Any form of cervical metastases
Metastasis	
M0	No distant metastases
M1	Distant metastases

Less common cancers include melanoma, undifferentiated carcinoma, sarcoma and lymphoma. Mucosal melanomas are rare, comprising 1–3% of all melanomas, but occur most commonly in the nasal cavity. Sinonasal undifferentiated carcinomas (SNUC) are highly aggressive sinonasal tumors that commonly involve the orbital or intracranial compartments. Common sinonasal sarcomas include rhabdomyosarcoma and chondrosarcoma. The nasal cavity is a location of extranodal lymphoma, most commonly T-cell lymphoma. Previously called lethal midline granuloma, this tumor is now appreciated to be an angiocentric T-cell lymphoma that is associated with Epstein-Barr virus, and presents as a midline destructive lesion.

Less commonly, orbital tumors may involve the ASB. The most common histologies are lacrimal gland neoplasms, neurogenic tumors, lymphomas, rhabdomyosarcomas, and chloromas (extramedullary myeloblastomas). The thick orbital roof serves as a more effective barrier to intracranial extension than does the cribriform plate.

The most common benign neoplasms involving the ASB are inverted papillomas and juvenile angiofibromas. Inverted papillomas arise most commonly from the lateral nasal wall. These tumors exhibit a 5–15% rate of conversion to invasive squamous cell carcinoma. Juvenile angiofibromas occur in adolescent boys and arise from the junction of the nasopharynx and the posterior lateral nasal wall. Both tumors generally present with symptoms of nasal obstruction or epistaxis and usually remain extracranial.

B. Tumors From Above

Central nervous system tumors involving the ASB are nearly all meningiomas, which are intradural, extra-axial lesions. It is rare for primary brain tumors to involve the ASB, unless there is a pre-existing surgical defect. Olfactory groove meningiomas may involve the cribriform plate, and sometimes extend through it into the ethmoid sinuses. Less commonly, the planum sphenoidale, tuberculum sellae, or anterior clinoid processes may be involved. Superiorly, the frontal lobes may undergo subpial invasion and venous engorgement, and ASB meningiomas may render the optic apparatus vulnerable to compression and ischemia. On MRI, these tumors are isointense to brain on both T1 and T2 weighted images, and enhance intensely. A dural tail is common. Adjacent ASB bone may show evidence of remodeling or sclerosis. Far less common are subfrontal schwannomas, rare neoplasms believed to originate from the olfactory nerve. Although slow-growing, extension through the cribriform plate is common.

Chordomas are rare tumors arising from remnants of the notochord. Along the skull base, most chordomas arise from within the bone of the clivus, but they have been described in extra-axial locations such as the nasopharynx or sphenoid sinus. Although the clivus is technically part of the posterior skull base, these tumors may expand to involve the ASB.

C. Neural Invasion

A particular challenge in malignant lesions of the ASB (particularly sinonasal cancers) is the presence of neural invasion, either perineural invasion or intraneural invasion. Overall, 20% of nonneurogenic sinonasal cancers demonstrate evidence of neural invasion, which is most common in sinonasal undifferentiated carcinomas (60%) and adenoid cystic carcinomas (55%). Neural invasion is present in a smaller percentage of paranasal sinus squamous cell carcinomas and adenocarcinomas (15–20%), and is rare in sarcomas and melanomas. The presence of neural invasion significantly increases the likelihood of positive margins and local recurrence in skull base surgery.

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Clinical Findings

A. Symptoms

Common presenting symptoms include nasal obstruction, epistaxis, rhinorrhea, anosmia, facial pain, and facial swelling. Many of these symptoms are nonspecific and mimic chronic sinus disease. Certain symptoms, however, are more suggestive of neoplasm, such as unilateral nasal obstruction, significant bleeding, diplopia, epiphora, and numbness (especially of cranial nerve V2).

B. Imaging

Radiologic evaluation of a skull base tumor generally requires both computed tomography (CT) and magnetic resonance (MR) imaging. CT imaging is critical to evaluating skull base and paranasal sinus bone anatomy, in addition to cranial foramina. Modern multidetector techniques allow thin sections for the evaluation of small landmarks, 3D reconstruction, and CT angiography for the evaluation of vascular structures. MRI is critical for assessment of soft tissue involvement, dural invasion, intracranial extent, and perineural spread. In the paranasal sinuses, MRI can be particularly helpful in differentiating tumor from post-obstructive secretions, which do not enhance and generally show T1- and T2-weighted intensity that is distinct from tumor. MRI may be helpful in narrowing the differential diagnosis of intracranial lesions not easily amenable to biopsy. Because both CT and MRI imaging contribute vital anatomic information, several centers have developed CT/MR fusion technology.

Nuclear medicine imaging can be helpful in a subset of patients. Positron emission tomography, generally combined with CT (PET/CT), is not sufficiently sensitive to definitively rule out regional metastases, but may be helpful in identifying distant metastases, and in identifying recurrent disease after treatment. CT cisternography (with intrathecal contrast agents such as Omnipaque or metrizamide) and MR cisternography (which does not require intrathecal contrast) can both be helpful in the setting of suspected cerebrospinal fluid leak.

Interventional radiology techniques can be indispensable in certain challenging cases. When tumor involvement of the internal carotid artery or other vascular structures is suspected, carotid and cerebral angiography are essential, and the endovascular placement of stents may be considered in certain cases. A balloon occlusion test is mandatory if sacrifice of the internal carotid artery is countenanced. Endovascular embolization of highly vascular tumors such as juvenile angiofibromas can be helpful prior to surgery.

If an endoscopic or endoscopic-assisted surgical approach is being considered for the patient, the surgeon may elect to obtain diagnostic CT or MR images under a protocol for an intraoperative navigation system, some of which utilize a headframe or fiducial markers. Additionally, advances in imaging have now made intraoperative imaging feasible. Cone-beam

CT scanners on a mobile C-arm may prove valuable in providing real-time anatomic information during surgery.

When evaluating an ASB mass, it is critical to rule out lesions that do not usually require surgical resection, such as lymphoma or metastases to the skull base. Therefore, an endoscopic or image-guided biopsy should be performed in most cases. Some tumors may be diagnosed based on history, clinical and radiologic findings, such as juvenile angiofibroma, rendering biopsy unnecessary.

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Treatment

A. Indications for Surgery

Surgery is the preferred treatment for most ASB lesions, with the exception of most cases of lymphoma and metastatic disease. In select lymphoma or metastatic cases, however, the desire to palliate local symptoms such as bleeding, fungating tumor, or CSF leak may necessitate surgery for these tumors. Non-neoplastic conditions such as skull base trauma, encephalocele, mucocele, and CSF leak will not be covered in this chapter although surgical approaches are similar. In most cases of ASB malignant disease, surgery is the index treatment, followed by adjuvant radiation or chemoradiation, depending on tumor type and pathologic findings (see "Non-surgical therapy," below). The contraindications to surgical resection of ASB disease can be divided into patient and tumor factors. Patients with significant medical comorbidity may not be appropriate for the risks of craniofacial resection (see "Outcomes," below). Similarly, the patient's personal preferences and willingness to accept the potential cosmetic, functional, and neurological morbidities of surgery must also be discussed frankly prior to surgery.

The technical limits of tumor resectability have evolved over time and continue to be in flux. Initially, Ketcham argued that tumors were unresectable if they eroded the pterygoid plates, invaded the dura extensively, extended into the brain parenchyma, or demonstrated significant gross perineural spread. Many of these characteristics remain included in stage T4b, traditionally a signifier of nonresectability. Today, however, the limits of resectability are not as strictly defined. Certainly tumors should be considered inoperable if they invade the brain stem, both internal carotid arteries, or both cavernous sinuses. In many cases, invasion of the superior sagittal sinus or vital bridging veins is unresectable, as interruption of cerebral venous flow would be fatal. Most surgeons consider involvement of both optic nerves or both orbital apices to be unresectable. Many surgeons also consider involvement of only one internal carotid artery to be unresectable, and many surgeons consider invasion of the cerebral cortex to be unresectable although opinions differ with respect to the intracranial extent of disease. Some centers will accept minimal brain invasion in selected patients, when the area involved is noneloquent. Many of these locations may be technically resectable but often will represent incurable disease.

Skull base teams at UC Davis and MD Anderson Cancer Center have reported results with skull base surgery in tumors with transdural invasion. In selected patients, acceptable 5-year overall survival of 28–58% has been reported. Survival is highest, even in cases of gross brain parenchyma invasion, when gross total resection with negative margins is achieved. Accordingly, in some cases of transdural invasion of skull base cancer, if there is a high likelihood of gross total resection with negative margins, and if biologically effective adjuvant therapies are available, it may be reasonable to proceed with surgery.

In all cases of questionable resectability, a frank discussion with the patient is requisite in the decision to operate. Some patients, but not all, will accept the potential morbidity that accompanies optic nerve sacrifice or resection of the eloquent cerebral cortex. The extent of patient commitment and family support are not trivial. Presentation and discussion in a multidisciplinary tumor board setting are mandatory, and referral to experienced skull base surgical centers may be helpful in difficult cases.

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B. Nonsurgical Therapy

In cases of advanced disease where surgery is not being considered, primary concurrent chemoradiotherapy is a nonsurgical option. Generally, platinum or taxane-based regimens are utilized, with standard-fractionation intensity-modulated radiation therapy (IMRT). Experienced centers have reported locoregional control rates ranging from 30% to 94% although these studies have been, of necessity, small. Challenges to the radiation oncologist are the toxicity associated with nearby vital structures such as the eye, brain, and cranial nerves. Radiation-induced late ocular toxicity such as retinopathy or optic neuropathy are not uncommon, resulting in unilateral blindness in up to 27% of patients, and bilateral blindness in up to 5% of patients treated at the University of Florida.

Proton radiation therapy has recently gained popularity in the therapy of skull base tumors, because the depth of penetration of protons can be precisely calibrated, potentially

allowing higher dose delivery to tumor while sparing local structures. High rates of local control in adenoid cystic carcinoma of the skull base have been reported with a low incidence of ocular toxicity. Similar high rates of control have been reported for chordoma and chondrosarcoma of the skull base. Currently, there are only five operational proton radiation centers in the United States, with five more in development. Therefore, clinical data establishing superiority of proton therapy over IMRT in skull base tumors remains limited.

The role of neoadjuvant therapy remains largely investigational although it has been used for decades at the University of Virginia for esthesioneuroblastoma. Under this protocol, all esthesioneuroblastomas are treated with neoadjuvant radiotherapy, and advanced tumors with orbital or intracranial invasion, or cervical metastases, are also treated with neoadjuvant chemotherapy (cyclophosphamide and vincristine). Current protocols at MD Anderson Cancer Center triage sinonasal undifferentiated carcinoma to neoadjuvant chemotherapy followed by an attempt at surgical resection.

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C. Principles of Surgical Treatment

Skull base surgery is team surgery, requiring the close cooperation of the head and neck surgeon and the neurosurgeon. Even in ASB tumors technically resectable by one surgeon alone, it is preferable that all ASB patients be cared for by a multidisciplinary team, in order to harness complementary skills and build collaborative experience.

The emerging popularity of endoscopic approaches to ASB tumors has led several experts to argue that skull base surgeons undertaking an endoscopic operation should be facile in open approaches to the skull base, and be able to "convert to open" if necessary for adequate or safe surgery. At a minimum, it seems reasonable that all patients undergoing ASB surgery should be prepared for the possibility of open surgery, and that there be members of the skull base team immediately available to assist intraoperatively if necessary. It does not seem appropriate to attempt an endoscopic operation of the skull base, only to find that the tumor is endoscopically unresectable, and to be unable to perform the necessary open procedure in the same operative setting.

Regardless of the specific approach chosen, there is a consensus among skull base surgeons that critical surgical oncologic principles must be adhered to in order to achieve acceptable outcomes for patients with ASB tumors. The primary objective is that adequate negative margins be achieved. En bloc resection is believed to provide the best possible chance of excision with adequate margins, and is therefore preferred. However, complete monobloc resection is often not achievable, and endoscopic approaches are often not able to achieve this. Nevertheless, en bloc resection of *the area of tumor invasion* remains feasible and necessary in any surgical approach.

Important surgical principles specific to the skull base include the need for excellent visualization, the ability to deal with potentially catastrophic vascular complications, and the need for durable reconstruction after skull base resection. In many cases, ASB surgery necessarily creates a communication between the sinonasal cavity and the intracranial compartment. As a result, there are three potential classes of complications which must be anticipated, regardless of surgical approach: infection, pneumocephalus, and CSF leak.

An inevitable sequela of craniofacial surgery is bacterial contamination from the sinonasal cavity, making ASB surgery a clean-contaminated procedure. The spectrum of infection ranges from local wound complications to meningitis or abscess. In larger resections, patients developing CSF leaks, and patients with a history of radiation, the risk of postoperative infection is believed to be greater. The rate of postoperative infection after skull base surgery ranges from 0% to 23%, and the rate of postoperative wound complications after craniofacial resection in the International Collaborative Study was 19.8%. A broad-spectrum antibiotic regimen developed at Memorial Sloan-Kettering Cancer Center (ceftazidime, metronidazole, and vancomycin) was found to significantly reduce the risk of postoperative infectious complications. At a minimum, a broad-spectrum coverage of common sinonasal bacteria (*Staphylococcus aureus*, *Staphylococcus epidermis*, coliforms, *Haemophilus influenza*, and anaerobes) seems prudent during the period of time where transient sinonasal-intracranial communication may persist, or while nasal packing is in place.

A second worrisome complication of ASB surgery is tension pneumocephalus. Postoperatively, increased upper airway pressure resulting from coughing, sneezing, nose blowing, or Valsalva maneuver, may introduce air through the skull base, which acts as a one-way valve. As air collects in the epidural or subdural space, compression of the brain will occur, ultimately resulting in tension pneumocephalus, a potentially fatal complication. "Overdrainage" of CSF through the lumbar drain can also engender pneumocephalus. In the past, prophylactic tracheotomy was routinely performed during craniofacial resection in order to provide airway diversion. More recently, however, the performance of tracheotomy has been performed selectively by most experts. Pneumocephalus is uncommon, and tracheotomy is generally only performed prophylactically in cases of large skull base defects. The avoidance of nasal packing, or the placement of a nasal trumpet at the completion of surgery,

may theoretically be helpful in preventing this complication although there is no evidence to support these maneuvers.

Cerebrospinal fluid leaks are a well-known complication of any surgical procedure of the ASB. The major advance in open craniofacial resection was the recognition that vascularized tissue, using the pericranial or galeal-pericranial flap, could decrease the incidence of CSF leak from 25% to 6.5%. Microvascular free flaps have also significantly reduced the rates of CSF leak in large defects. Modern recognition of this has limited the use of avascular reconstruction to small defects. These principles are unchanged in endoscopic skull base surgery, where the rate of CSF leak in large resections was high until the advent of the vascularized septal mucosal flap.

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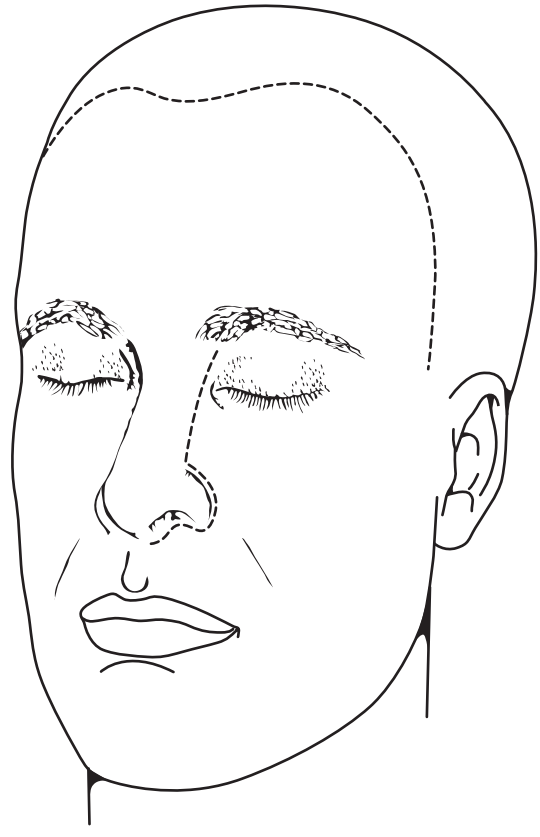


▲ **Figure 60–1.** Incisions utilized for open craniofacial resection.

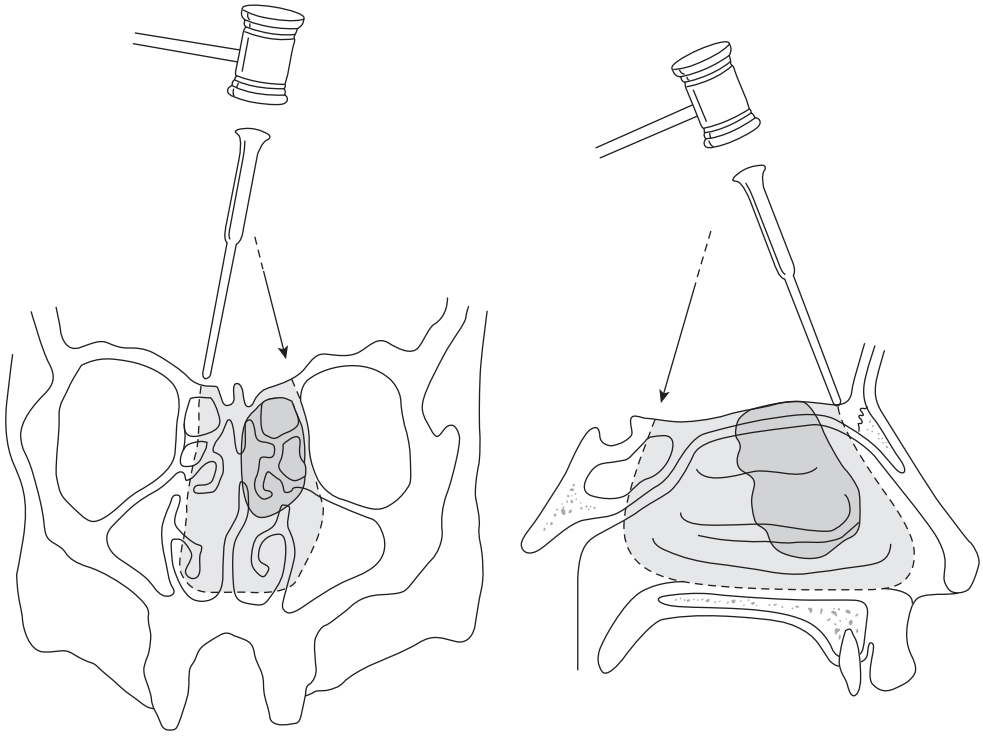
D. Choice of Surgical Technique

The major surgical approaches to resection of ASB benign and malignant tumors will be discussed here. The choice of approach depends on a multitude of factors, including local expertise, the need to avoid or work around critical neurovascular structures, the degree of frontal lobe retraction required, the anticipated reconstructive requirements of the surgical defect, and the immutable oncologic principles of negative margin resection with en bloc dissection of the area of tumor invasion.

E. Surgical Technique: Craniofacial Resection

The traditional open craniofacial resection combines a transcranial and a transfacial approach (Figure 60–1). At the beginning of the case, a lumbar spinal drain is placed. A Mayfield head clamp may be used. The eyelids are secured with tarsorrhaphy stitches and the abdomen and lower extremities sterilely prepped if abdominal fat or fascia lata may be needed. Prophylactic antibiotics are administered prior to incision, and mannitol or spinal drainage used as necessary for brain relaxation during the case.

Surgery begins with a coronal incision, reflecting the scalp anteriorly in a subgaleal plane. The incision should not be curved too far anteriorly in the scalp, in order to ensure that a suitably sized pericranial flap can be obtained. A large pericranial flap is raised, starting posterior to the incision, and extending anteriorly to the orbital rims. A bifrontal craniotomy is then performed with removal of the free bifrontal bone flap. The frontal sinus is completely obliterated and cranialized. An extradural dissection, if not prevented by tumor involvement, is then performed along the anterior cranial fossa, moving from lateral to medial, and anterior to posterior. Lacerations in the dura are repaired primarily. At this point, the skull base resection is defined. In unilateral esthesioneuroblastoma cases, the contralateral olfactory bulb may be preserved, although this is not always the case. At this point, the head and neck surgery team will perform the transfacial approach. A lateral rhinotomy is the most common incision, carried out along nasal subunits for optimal cosmesis. A Lynch or Weber-Ferguson incision may be used instead in some cases, depending on tumor extent. Transfacial access facilitates an external ethmoidectomy, maxillary swing or maxillectomy approach to the resection from below. Once dissection is near completed, skull base



▲ **Figure 60–2.** Placement of skull base osteotomies, ideally delivering the specimen in a monobloc fashion.

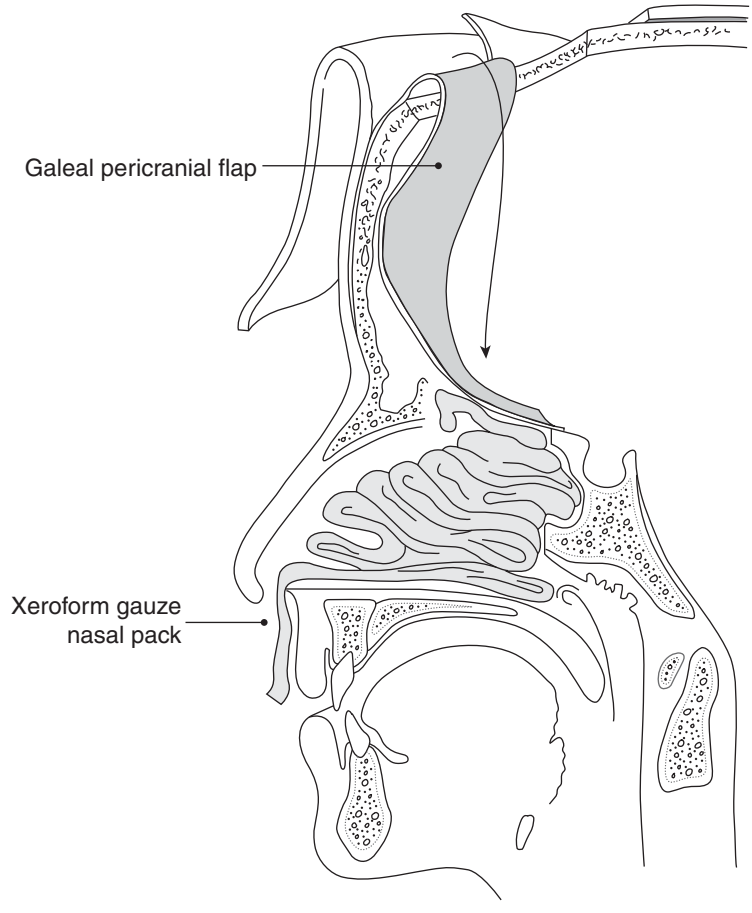
osteotomies are performed and the specimen ideally delivered in a monobloc fashion (Figure 60–2). Due to the fragility of the ethmoid complex and difficulty working around tumor, en bloc resection is not always possible. Debulking of the tumor in the nasal cavity may be necessary, and resection of intradural tumor may also need to be performed separately. The goal is en bloc resection of the skull base where tumor invasion has occurred. Margins are verified on frozen section.

Reconstruction of the skull base defect relies heavily on placement of the pericranial flap to separate the cranial and sinonasal cavities. The pericranium is reflected over the skull base defect and brought back to the planum sphenoidale posteriorly (Figure 60–3). Large dural defects may require a dural allograft, bovine pericardium, fascia lata or microvascular free flaps. Fibrin glue and abdominal fat may be required to bolster the reconstruction and fill in dead space. With large defects, or resection of the orbital roof, titanium mesh or a bone graft from the inner table of the bone flap may sometimes be needed to support the brain and avoid encephalocele. Management of the lacrimal system may require stenting or dacrocystorhinostomy. Nasal packing and a subgaleal drain are placed prior to closure.

An alternative to the trans-facial incision is the mid-facial degloving approach, which can provide exposure to both nasal cavities, the ethmoid complex, cribriform plate, sphenoid sinus, and nasopharynx. Another option is a LeFort I osteotomy, providing access to the nasal cavity and ethmoid complex via the oral cavity.

1. Surgical technique: craniotomy alone—In selected cases, tumors limited to the superior nasal vault may be approached entirely from above. Examples of suitable ASB tumors would be esthesioneuroblastoma limited to the cribriform area and superior and middle meatus, or olfactory groove meningiomas with minimal extension into the ethmoid sinuses. In these cases, a bifrontal craniotomy is performed and a pericranial flap used for skull base reconstruction.

2. Surgical technique: subcranial approach—The subcranial approach to the ASB was pioneered by Raveh in the 1980s for the treatment of trauma, congenital anomalies, and tumors of the ASB. It was a modification of various orbitofrontal operations that approached the ASB by combining the bifrontal craniotomy with orbital osteotomies. The subcranial approach includes an orbitonasal osteotomy, comprising the medial aspect of both orbital rims, the



▲ **Figure 60–3.** Reconstruction of the skull base defect with a pericranial or galeal-pericranial flap.

glabella, and most of the nasal bones. Advantages of this approach include an avoidance of facial incisions and frontal lobe retraction.

This operation begins with a standard bicoronal incision, and a pericranial flap is dissected from posterior to the incision in order to maximize length. As the scalp flap is raised, dissection is continued deep to the temporalis fascia in order to protect the frontal branch of the facial nerve. Dissection is carried forward to the nasal bones and orbital rims, down to the frontozygomatic suture lines, taking care to preserve the supraorbital neurovascular bundles by dissecting them free of the supraorbital canal or notch. Periorbita is dissected from the medial orbital walls, and the anterior ethmoid arteries ligated or cauterized. At this point, a low craniotomy is performed, stopping short of the midpoint of the orbit on each side. Dura is freed from the orbital roof bilaterally, and the frontal sinus cranialized. Orbitonasal osteotomies are then performed: vertical cuts down to the orbital rims, then antero-medially to the nasal process of the maxilla, and then horizontally across the inferior aspect of the nasal bones. The orbitonasal osteotomy is detached from the nasal septum and removed in one piece. This permits extradural dissection along the ASB without frontal lobe retraction. If needed, dural resection is performed and reconstructed. After complete tumor removal, the pericranial flap is secured in place and the bone flaps replaced with miniplates.

E. Surgical Technique: Orbitozygomatic Craniotomy

Not strictly an ASB approach, the orbitozygomatic craniotomy is commonly used for approach to the anterolateral skull base (orbital apex, paraclinoid, and parasellar regions), as well as portions of the anterior and middle skull bases. It is essentially an expansion of the classical pterional craniotomy. In brief, a curved pterional craniotomy incision is made along the hairline from the contralateral forehead to the tragus. The scalp flap is dissected forward, taking care to incise and remain deep to the temporalis fascia in order to protect the facial nerve. The zygomatic arch

and superolateral orbital rim are exposed. A frontotemporal craniotomy is performed, and the orbitozygomatic osteotomy performed separately. A wide angle of exposure to the orbital roof and portions of the anterior and middle skull bases is achieved with minimal brain retraction and no facial incisions.

F. Surgical Technique: Endoscopic-Assisted Craniofacial Resection

Har-El has noted that the term "endoscopic assisted" is best suited for ASB surgery performed entirely via craniotomy, where endoscopes are used only to guide the margins of resection. No significant tumor removal is performed endoscopically. This technique is particularly valuable in guiding entry into the ethmoid complex with safe margins around the tumor. This technique may be used in conjunction with a bifrontal, subfrontal, or subcranial craniotomy.

G. Surgical Technique: Cranioendoscopic Approach (CEA)

The term "cranioendoscopic approach" has been popularized by Hanna at MD Anderson Cancer Center and Castelnuovo in Italy, referring to a combined approach of frontal craniotomy with endonasal resection. Accordingly, facial incisions and facial skeleton disassembly are avoided. The advantages of endoscopic visualization from below are enjoyed, including magnification and angled endoscopes. Similarly, the advantages of open craniotomy are retained, allowing wide dural resection if necessary to clear margins, and facilitating watertight closure with durable techniques such as the pericranial flap. At MD Anderson and the Italian Universities of Brescia and Insubria, the skull base team extirpates most sinonasal cancers using an exclusively endonasal approach, but retains a low threshold to add a craniotomy and carry out the CEA approach, whenever there is significant involvement of the fovea ethmoidalis, trans-dural invasion, or more than focal dural involvement. In doing so, this group reported that of 120 endoscopic sinonasal cancer resections, negative margins were achieved in 85% of cases and CSF leaks occurred in only 3%.

H. Surgical Technique: Endoscopic Skull Base Surgery

Advances in supporting technologies now enable entirely endoscopic surgery of the skull base via endonasal corridors. This has been termed "endoneurosurgery" and the "expanded endonasal approach" by the University of Pittsburgh skull base team. Important advances in endoscopic instrumentation such as endoscopic coagulators, suction aspirators, and U-clip appliers, as well as in image guidance technology, have allowed experienced skull base teams to reach nearly the entire ventral cranial base through the nose. The range of endoscopic skull base surgery now encompasses the skull base far beyond the ASB: from the frontal sinus to C2 in the sagittal plane, and from the sella turcica to the jugular bulb in the coronal plane.

The pioneers of endoscopic skull base surgery have advocated its use when an endonasal corridor provides the most direct route of access to the skull base lesion, without having to mobilize neural or vascular structures. Therefore, it is argued, an ASB lesion medial to the cavernous carotid artery would be best approached endonasally, while an ASB lesion superolateral to the optic nerve would be best approached transcranially. It is evident that many ASB lesions are well suited to an endonasal resection that avoids the need to mobilize and retract the brain. Additional advantages cited for endoscopic skull base surgery are those of enhanced visualization with magnification and angled views around corners. Experienced centers are able to essentially perform endoscopic craniofacial resections with identical margins as an open procedure. For example, an endoscopic resection of an esthesioneuroblastoma is performed with excision of the cribriform plate, overlying dura, olfactory bulbs, and olfactory tracts. Intracranial invasion is included, including intradural dissection as necessary.

It is important to tailor endoscopic surgery to the anatomy and histology of the ASB tumor. Baseline surgical principles are retained. Therefore, for sinonasal malignancies, the site of invasion should be resected en bloc with adequate margins, not in a piecemeal fashion. Watertight closure of the skull base defect is paramount. For primary brain tumors, such as meningiomas, the microsurgical principles of neurosurgery are adhered to: internal debulking of the tumor, capsular mobilization, extracapsular dissection of critical neurovascular structures, focal coagulation, and complete capsule removal.

The advent of the pedicled nasoseptal mucosal flap, also known as the Hadad-Bassagasteguy flap, has been reported by the Pittsburgh group as responsible for reducing the incidence of CSF leak in endoscopic skull base surgery from 30% to 5%. This composite mucosal-periosteal-perichondrial flap is harvested at the beginning of the procedure. After resection of one middle turbinate to provide working room, the nasoseptal flap is raised, keeping intact the posterolateral vascular pedicle (posterior nasal septal artery). The flap is then pushed into the nasopharynx until it is needed for closure.

As an example, in the case of an esthesioneuroblastoma, surgery begins with endonasal debulking of the tumor in order to visualize its margins and site of skull base involvement. Anatomic landmarks in the nasal cavity, as well as the optic canals and carotid canals, are identified by performing a complete sphenoethmoidectomy and maxillary sinus antrostomy. If necessary, a posterior septectomy is performed in order to facilitate instrumentation through both nostrils. Adequate margins may require resection of the posterior wall of the frontal sinus, medial wall of both orbits, the roof of the sphenoid, and the nasal septum. Bilateral frontal sinusotomies are performed and the frontal sinus floor removed in the manner of a Draf III endoscopic modified Lothrop pro-

cedure. The nasal septum is transected below the tumor, as far posteriorly as the sphenoid rostrum. The anterior and posterior ethmoid arteries are ligated or cauterized at the skull base. The ASB bone is thinned with a drill and then elevated and removed from the crista galli to the planum sphenoidale, and from the medial orbital wall to the medial orbital wall. The dura is then cauterized and opened around the tumor. Cortical blood vessels are elevated out of the way, and the falx cerebri is cauterized and transected. One or both olfactory bulbs are dissected free of the brain and included with the specimen. The olfactory nerves are transected and the specimen removed. Margins are confirmed with frozen section.

Ideally, the ASB defect is closed with vascularized tissue such as the nasoseptal mucosal flap. The dural defect is first closed in a multilayered fashion with an inlay graft of the dural graft matrix in the subdural space, an onlay fascial graft, and then the nasoseptal flap. The flap is secured with fibrin glue and is supported with either fat or Gelfoam. Finally, a Foley catheter or nasal packing is used to buttress the reconstruction. Multi-layer avascular reconstruction has been reported by other groups such as the Cleveland Clinic, where free septal mucosa, acellular dermal allograft, septal or auricular cartilage, or temporalis fascia have been used with a reported CSF leak rate of 6.5%.

This expanded endonasal approach has been described for use beyond the ASB. The transplanum corridor affords access to the suprasellar and suprachiasmatic regions. Traditional open approaches via pterional or subfrontal craniotomy limit access to these regions because of the optic chiasm. A transclival approach is able to reach the posterior clinoid, clivus, and foramen magnum. Angled inferiorly, the upper cervical spine can be reached in a transpharygeal and a transodontoid approach.

I. Surgical Technique: Robotic Endoscopic Skull Base Surgery

The expanding use of the surgical robot in transoral surgery of the oropharynx, larynx, and hypopharynx will inevitably be modified for minimially invasive access to the ASB. Although not currently in clinical use, a robotic aproach to the ASB has been developed in a cadaver model at MD Anderson. This approach involves bilateral Caldwell-Luc procedures for entry into the maxillary sinuses, followed by large middle meatal antrostomies to access the nasal cavity and skull base. In addition to wide exposure of the ASB, this technique brings advantages of robotic surgery, such as the ability to work around angles, eliminate tremor, and suture endoscopically.

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Outcomes

Because of the rarity of ASB disease, the majority of outcomes data have been reported as small single-institutional series. To address this shortcoming, an International Collaborative Study (ICS) group was formed, pooling data from 17 institutions. A total of 1307 patients with malignant tumors of the ASB who underwent craniofacial resection were analyzed. A series of papers from this group has recently defined surgical outcomes for craniofacial resection, and form the data to which endoscopic surgical data will be compared.

Of the 1307 patients, the most common tumor types were squamous cell carcinoma (28.8%), adenocarcinoma (16.1%), and esthesioneuroblastoma (11.6%). Dural invasion occurred in 21.6% of cases, and brain invasion in 6.4%. Orbital wall invasion occurred in 24.6% of cases, periorbita in 10.5%, and orbital contents in 22.5%.

Among patients in the ICS, 41.7% experienced recurrence. The mean time to recurrence was 19 months. At 5 years, recurrence-free survival was 53%, disease-specific survival was 60%, and overall survival was 54%. On multivariate analysis, there were four factors independently associated with survival: histology, intracranial involvement, surgical margins, and prior treatment with radiotherapy. These data are summarized in Table 60–3. As expected, the risk of recurrence or death increased progressively as tumors invaded the skull base bone, dura, and then brain. Positive margins were associated with poorer outcome. A prior history of radiation rather than definitive surgery was associated with poorer outcome, likely because these were patients with advanced or high-risk disease. Histology separated tumors into three risk groups. The best recurrence and survival outcomes were seen with esthesioneuroblastoma, cutaneous cancer, salivary cancer, and low-grade sarcoma. Intermediate outcomes were seen with squamous cell carcinoma, adenocarcinoma,

Table 60–3. Predictors of Disease-Free Survival on Multivariate Analysis in the International Collaborative Study of Craniofacial Resection.

Variable	RR	95% CI
Intracranial involvement		
None	1.0	Reference
Bone	1.0	(0.8–1.4)
Dura	1.4	(1.0–1.9)
Brain	2.1	(1.4–3.1)
Histology		
Esthesioneuroblastoma	1.0	Reference
Skin malignancy	1.5	(0.8–2.7)
Low-grade sarcoma	2.6	(1.3–5.5)
High-grade sarcoma	2.6	(1.5–4.5)
Adenocarcinoma	3.0	(1.9–4.8)
Salivary malignancy	2.0	(1.1–3.4)
Squamous cell carcinoma	2.7	(1.7–4.2)
Undifferentiated carcinoma	2.8	(1.4–5.5)
Mucosal melanoma	11.1	(6.4–19.5)
Surgical margins		
Negative	1.0	Reference
Positive	2.3	(1.8–2.9)
Previous radiotherapy		
No	1.0	Reference
Yes	1.8	(1.4–2.2)

RR, relative risk of disease-specific death; CI, confidence interval.
(Data from Table 8 in Patel SG, Singh B, Polluri A et al. Craniofacial surgery for malignant skull base tumors: Report of an international collaborative study. *Cancer* 2003;98(6):1179–1187.)

Table 60–4. Survival Outcomes of Patients in the International Collaborative Study of Craniofacial Resection, by Tumor Histology.

Histology	5 year RFS	5 year DSS	5 year OS
Esthesioneuroblastoma	64.3	82.6	77.8
Skin malignancy	60.1	74.9	71.0
Low-grade sarcoma	62.6	74.0	68.9
High-grade sarcoma	52.2	68.7	57.4
Adenocarcinoma	53.1	58.7	51.5
Salivary malignancy	44.3	53.0	45.5
Squamous cell carcinoma	49.9	53.0	44.4
Undifferentiated carcinoma	45.5	41.9	37.3
Mucosal melanoma	19.2	19.2	18.3

RFS, recurrence free survival; DSS, disease specific survival; OS, overall survival.
(Data from Tables 7, 8, and 9 in Patel SG, Singh B, Polluri A et al. Craniofacial surgery for malignant skull base tumors: Report of an international collaborative study. *Cancer* 2003;98(6):1179–1187.)

and high-grade sarcoma. Poorest outcomes were seen with melanoma and undifferentiated carcinoma. Five-year disease-specific survival by tumor histology is summarized in Table 60–4.

Open craniofacial surgery is not without morbidity and mortality. Complications of craniofacial resection in the ICS study have been analyzed in detail. The overall rate of postoperative mortality was 4.5%, with medical comorbidity the only predictive factor on multivariate analysis. The incidence of postoperative complications was 36.3%. Wound complications (infection, dehiscence, flap necrosis) occurred in 19.8%. Central nervous system complications (CSF leak, meningitis, pneumocephalus) occurred in 16.2%. Systemic complications (cardiac, pulmonary, renal, metabolic) occurred in 4.8%, and orbital complications (epiphora, diplopia, visual loss) occurred in 1.7%. On multivariate analysis, medical comorbidity, prior radiation, dural invasion, and brain invasion were all associated with the development of postoperative complications.

Single institution longitudinal data on complications has been reported in detail by Memorial Sloan-Kettering Cancer Center. In a recent report, two time periods were compared: before and after the universal introduction of a three-agent broad-spectrum perioperative antibiotic regimen (ceftazidime, metronidazole, vancomycin) in 1996. The introduction of this regimen decreased the rate of postoperative complications from 60% to 40%, and the rate of postoperative mortality from 4.4% to 3.3%. The decrease in complication rate was attributed to a substantial decrease in the incidence of postoperative wound infections, from 28% to 7.5%. On multivariate analysis, only antibiotic regimen was a significant predictor of postoperative complications.

These outcomes data, based on the International Collaborative Study and large cohorts from high-volume skull base centers, have established baseline data for open craniofacial resection, to which endoscopic data can be compared as it emerges.

To date, two large series of endoscopic surgery for sinonasal cancers have been reported: one from MD Anderson and one from the Universities of Brescia and Insubria in Italy. In both series, patients underwent either an exclusively endoscopic approach (EEA) or a cranioendoscopic approach (CEA) when there was significant dural involvement. In the MD Anderson series, 5-year disease-specific survival was 76%, and did not differ significantly between the EEA and CEA groups. In the Italian series, 5-year disease-specific survival was 82%: 91% in the EEA group and 59% in the CEA group. Rates of CSF leak were 3–5% in the two series. It is important to clarify that both of these series contained a more favorable makeup of patients than the ICS open craniofacial resection series. Both series included all sinonasal cancers, most of which were limited to the sinonasal cavity and did not involve the skull base. Also, tumor histologies were more favorable. In the MD Anderson endoscopic series, the most common tumor histology was esthesioneuroblastoma; in the Italian series, adenocarcinoma was most common. While these two series do provide early evidence that endoscopic surgery can provide acceptable oncologic outcomes, it has only

been demonstrated in a highly selected group of patients. Therefore, these numbers cannot be meaningfully compared with outcomes data for open craniofacial resection.

Smaller endoscopic surgery series limited to tumors involving the skull base do exist. Recently, a series of 31 patients treated at the Cleveland Clinic, and a series of 23 esthesioneuroblastomas treated at the Universities of Pittsburgh and Miami have been reported. In the Cleveland Clinic series, 5-year recurrence free survival was 51.7%. In the Pittsburgh/Miami esthesioneuroblastoma series, all patients were free of disease at a mean of 45 months. Because delayed recurrences are more common in esthesioneuroblastoma, longer follow up will be instructive. The most common complications in the Pittsburgh/Miami series were nasal cavity crusting (34.8%), CSF leak (17.4%), and dacryocystitis (8.7%).

This very early evidence can be interpreted as supportive of the feasibility of endoscopic skull base surgery. Most experienced centers have reported that negative margins are usually achieved. At MD Anderson, 85% of cases had negative margins; at the Cleveland Clinic, 74%; at the University of Pennsylvania, 83%. These results would seem to support continued investigation into outcomes of endoscopic resection in appropriately selected patients. As more patients are treated endoscopically, more definitive data regarding oncologic effectiveness can be anticipated.

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We would like to acknowledge Michael J. Kaplan, MD for his contribution to this chapter in the previous editions of CDT.

Vestibular Schwannoma (Acoustic Neuroma)

Jacob Johnson, MD & Anil K. Lalwani, MD

61

ESSENTIALS OF DIAGNOSIS

- Asymmetric (unilateral) sensorineural hearing loss, tinnitus, and disequilibrium
- Disproportionately diminished speech discrimination score relative to deterioration in pure-tone average
- Facial and trigeminal nerve symptoms with larger tumors.

General Considerations

Vestibular schwannomas (VS) (acoustic neuromas) are nerve sheath tumors of the superior and inferior vestibular nerves (cranial nerve VIII). They arise in the medial internal auditory canal (IAC) or lateral cerebellopontine angle (CPA) and cause clinical symptoms by displacing, distorting, or compressing adjacent structures in the CPA.

VS are by far the most common tumors involving the CPA. VS make up 80% of CPA tumors and 8% of all intracranial tumors. Various epidemiology studies have shown an incidence of 10 per 1 million individuals each year. This figure correlates with 2000–3000 individuals diagnosed with VS each year in the United States. There is no gender bias and the age of presentation is between 40 and 60 y of age. Ninety-five percent of VS occur in a sporadic fashion. The remaining 5% of patients have neurofibromatosis type 2 (NF2) or familial VS. The age of presentation is earlier in nonsporadic VS and patients usually present in the second or third decades of life.

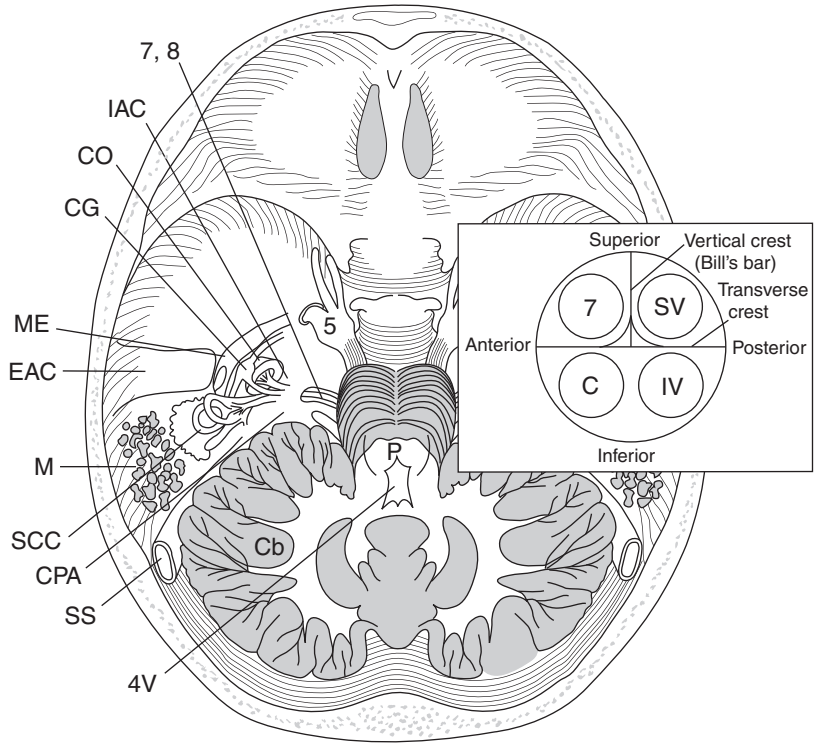
Anatomy

The CPA consists of a potential cerebrospinal fluid (CSF)-filled space in the posterior cranial fossa bounded by the temporal bone, cerebellum, and brainstem. The CPA is a roughly triangular-shaped structure in the axial plane and is filled with CSF (Figure 61–1). The superior boundary is the tentorium and the inferior boundary is the cerebellar tonsil and medullary olives. The anterior border is the posterior dural surface of petrous bone and clivus, and the posterior border is the ventral surface of the pons and cerebellum. The medial border is the cisterns of the pons and medulla and the apex is the region of the lateral recess of the fourth ventricle. The lateral opening of the fourth ventricle, the foramen of Luschka, opens into the CPA. Cranial nerves V–XI traverse the cephalic and caudal extent of the CPA. The central structures crossing the CPA to and from the IAC are the facial (CN VII) and vestibulocochlear nerves (CN VIII), respectively.

Cranial nerves VII and VIII are covered with central myelin provided by neuroglial cells as they cross the CPA and carry a sleeve of posterior fossa dura into the IAC. The transition to peripheral myelin made by the Schwann cells occurs at the medial opening of the IAC. The vestibulocochlear nerve divides into three nerves: (1) the cochlear nerve and (2 and 3) the superior and inferior vestibular nerves in the lateral extent of the CPA or medial IAC. The IAC is divided into four quadrants by a vertical crest, called Bill's bar, and a transverse crest. CN VII comes to lie in the anterosuperior quadrant and is anterior to the superior vestibular nerve and superior to the cochlear nerve, whereas the inferior vestibular nerve lies in the posteroinferior quadrant and is inferior to the superior vestibular nerve and posterior to the cochlear nerve (see Figure 61–1). The anteroinferior cerebellar artery (AICA) is the main artery in the CPA and is the source of the labyrinthine artery. The labyrinthine artery via the IAC is an end artery for the hearing and balance organs. The AICA has a variable relationship to cranial nerves VII and VIII and to the IAC.

Pathogenesis

VS originate in the Schwann cells of the superior or inferior vestibular nerves at the transition zone (Obersteiner–Redlich zone) of the peripheral and central myelin. This transition zone occurs in the lateral CPA or medial IAC. Therefore,



▲ **Figure 61–1.** The anatomy of the CPA and its relationship to the temporal bone within the skull is shown. Inset shows the location of the cranial nerves within the IAC: the facial nerve (7) and the cochlear nerve (C) are in the anterior compartment, whereas the superior and inferior vestibular nerves (SV and IV, respectively) are in the posterior half of the IAC. 5, trigeminal nerve; 7, facial nerve; 8, cochlear nerve; IAC, internal auditory canal; CO, cochlea; GG, geniculate ganglion; ME, middle ear; EAC, external auditory canal; M, mastoid; SCC, semicircular canal; CPA, cerebellopontine angle; SS, sigmoid sinus; 4V, fourth ventricle; Cb, cerebellum; P, pons.

VS most often arise in the IAC and occasionally in the CPA. These schwannomas rarely arise from the cochlear nerve and are rarely malignant. The propensity to develop from the vestibular nerves may be due to the vestibular ganglion in the IAC having the highest concentration of Schwann cells.

Recent studies have improved our molecular understanding of VS. VS occur as a result of mutations in a tumor suppressor protein, merlin, located on chromosome 22ql2. Merlin is a cytoskeletal protein encoded by the *NF2* gene that is necessary for the maintenance of contact inhibition of cellular growth. The formation of VS requires mutations of both copies of the *NF2* gene. One functioning merlin protein prevents the formation of VS. Somatic mutations in both copies of the *NF2* gene result in sporadic VS. The probabilities of two spontaneous, independent mutations at one locus predict a unilateral VS presenting in the fourth to sixth decades of life.

In contrast, familial VS occurring in NF2 only requires one occurrence of somatic mutation. People with NF2 inherit one mutated merlin protein and one normal merlin protein. A mutation in the normal allele leads to bilateral VS by age 20. Therefore, NF2 is an autosomal recessive mutation at the gene level since disease expression requires mutations in both alleles of the gene, but the inheritance is autosomal dominant (pseudodominant) since inheritance of one mutated allele often leads to a disease state. NF2 is a central form of neurofibromatosis, with affected patients having central nervous system tumors, including schwannomas, meningiomas, and gliomas. Most of these patients develop bilateral VS. In comparison, patients with NF type l (von Recklinghausen disease) have intra- and extracranial tumors, and <5% of these patients develop unilateral VS. Genetic screens for the NF2 mutation have been developed and offer genetic counseling for family members of patients with NF2. The severity of mutation involving the merlin gene in NF2 can predict the severity of disease manifestation.

Clinical Findings

A. Symptoms and Signs

1. Hearing loss—Hearing loss is present in 95% of patients with VS. Conversely, 5% of patients have normal hearing; therefore, unilateral vestibular or facial complaints without hearing loss do not rule out retrocochlear disease. Of patients with hearing loss, most have slowly progressive hearing loss with noise distortion. Twenty percent have an episode of sudden hearing loss. The improvement of hearing loss with or without treatment does not rule out retrocochlear disease. The level of hearing loss is not a clear predictor of tumor size.

2. Tinnitus and disequilibrium—Tinnitus is present in 65% of patients. The tinnitus is most often constant with a high buzzing pitch. This symptom is often not reported by patients because of the focus on the accompanying hearing

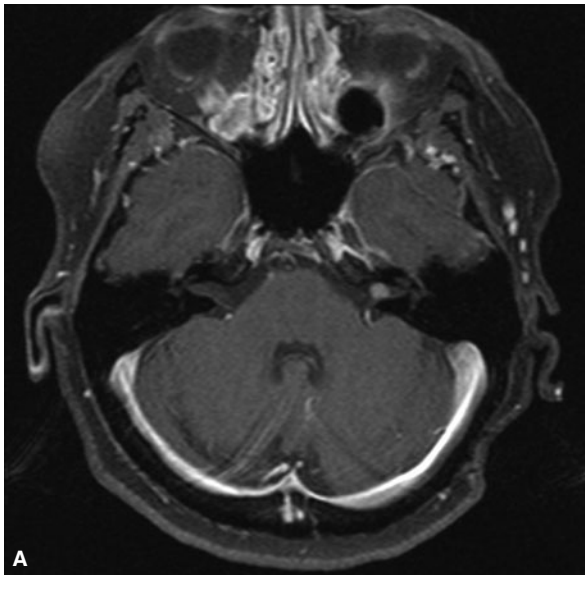
loss. Similarly, owing to the central compensation for the slowly evolving vestibular injury, patients tolerate and adapt well to the disequilibrium they experience. The majority of patients have self-limiting episodes of vertigo. The disequilibrium is initially mild and constant and often does not prompt a medical visit. Disequilibrium is present in 60% of patients.

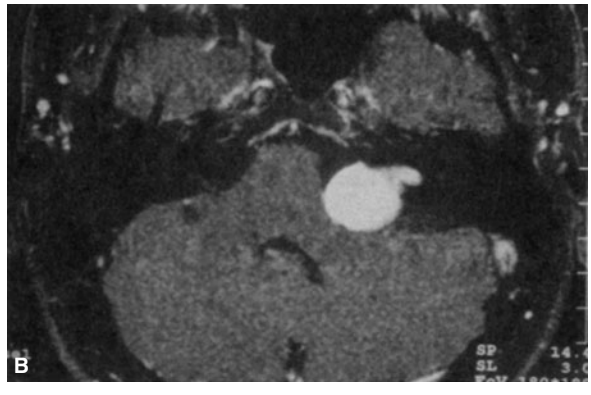
3. Facial and trigeminal nerve dysfunction—Facial and trigeminal nerve dysfunction occurs after the auditory and vestibular impairments. The patients usually have midface (V2) numbness and also often have an absent corneal reflex. The motor supply of the trigeminal nerve of the muscles of mastication is rarely affected. The sensory component of the facial nerve is first affected and causes numbness of the posterior external auditory canal and is referred to as Hitselberger sign. Facial weakness or spasm occurs in 17% of patients and usually leads to a diagnosis of VS within 6 months.

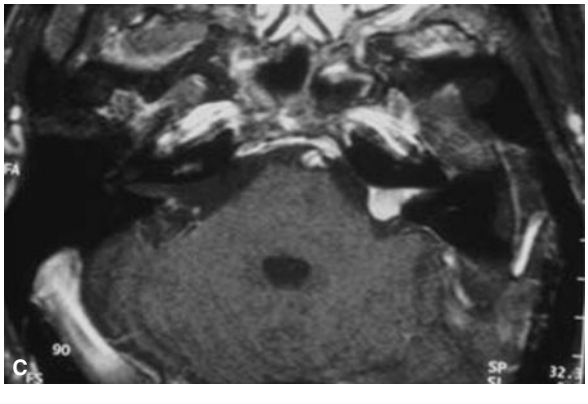
4. Other symptoms—Patients with large VS tumors or tumors that have undergone rapid expansion have visual complaints of decreased visual acuity and diplopia due to compromise of CN II, IV, or VI. Hydrocephalus leads to complaints of headache, altered mental status, nausea, and vomiting and, on examination, increased intracranial pressure and papilledema. Compression of the lower cranial nerves IX and X causes dysphagia, aspiration, and hoarseness, and examination reveals a poor gag reflex and vocal cord paralysis.

B. Imaging Studies

1. Magnetic resonance imaging—Magnetic resonance imaging (MRI) with gadolinium contrast is the gold standard for the diagnosis or exclusion of VS. An MRI scan also allows for surgical planning. The various lesions within the CPA may be differentiated based on their varying imaging and enhancing characteristics. The MRI characteristics of a VS include a hypointense globular mass centered over the IAC on a T1-weighted image with enhancement when gadolinium is added. VS are iso- to hypointense on T2-weighted images (Figure 62–2).







▲ **Figure 61–2.** MRI with gadolinium enhancement demonstrating **(A)** a intracanicular, **(B)** a large and **(C)** a small vestibular schwannoma. While the smaller tumor fills the cerebellopontine angle, the large tumor is displacing the brainstem and cerebellum and compressing the fourth ventricle.

2. Computed tomography scanning—When MRI scans cannot be used or are not accessible, a computed tomography (CT) scan with iodine contrast or an auditory brainstem response (ABR) offers a reasonable alternate screening modality. CT scanning with contrast provides consistent identification of CPA tumors that are larger than 1.5 cm or have at least a 5-mm CPA component. VS appear as ovoid masses centered over the IAC with nonhomogeneous enhancement. CT scans with contrast can miss intracanalicular tumors unless there is bony expansion of the IAC.

C. Special Tests

1. Audiology—The average patient requires 4 y from the onset of symptoms to the diagnosis of VS. The diagnostic dilemma lies in choosing the appropriate patient to undergo audiometric and imaging studies. Most patients present with complaints of unilateral hearing loss or hearing distortion, unilateral tinnitus, vertigo or disequilibrium, and facial numbness, weakness, or spasm. Patients with unilateral auditory, vestibular, and facial complaints need to undergo careful evaluation to rule out retrocochlear disease. The initial step in the evaluation includes an audiology exam. If the audiology exam suggests a retrocochlear lesion, then imaging of the CPA is performed to rule out a retrocochlear lesion. Vestibular testing lacks specificity in diagnosing VS.

The standard auditory evaluation should include pure-tone audiometry, a word recognition score (WRS), acoustic reflex thresholds, and acoustic reflex decay. Pure-tone audiometry of patients with VS shows asymmetric, downsloping, high-frequency sensorineural hearing loss in almost 70% of patients. The hearing may also be normal, may involve only the low frequency, or may be a flat hearing loss or a trough or peak hearing loss. A retrocochlear-based hearing loss causes WRS scores to be lower than that predicted by the pure-tone thresholds. This out-of-proportion depression of speech intelligibility is further accentuated when retested at a higher speech intensity. This phenomenon is called **rollover.** A poor WRS is present in about 50% of patients with VS. An abnormal WRS should trigger an imaging evaluation, but a normal WRS does not rule out a VS. A loss of acoustic reflexes or the presence of acoustic reflex decay is present in most cases of VS, but normal acoustic reflexes do not preclude VS.

2. Vestibular testing—Vestibular testing does not provide a sensitive or specific means of diagnosing VS. The most common test ordered to evaluate vestibular complaints includes an electronystagmogram (ENG). An ENG in a patient with VS will show a reduced caloric response in the problematic ear. The extent of the vestibular function predicts the amount of postoperative vertigo. The location of the VS on the inferior or superior vestibular nerve may also be predicted by the ENG because the ENG primarily evaluates the lateral semicircular canal innervated by the superior vestibular nerve.

3. Auditory brainstem response—An ABR is the measured electrical response of the cochlea and its brainstem pathway to short-duration, broadband clicks. The evoked response is a characteristic waveform with five identifiable peaks (I–V). The absolute latency or timing of each wave is recorded. In patients with VS, the ABR is fully or partially absent, or there is a delay in the latency of Wave V in the affected ear. The delay may be an absolute delay based on normative data or a delay compared with the latency of Wave V in the opposite ear. An interaural delay of Wave V latency >0.2 ms is considered abnormal. Overall, ABR has a sensitivity >90% and a specificity of 90% in detecting VS. However, when considering only small intracanalicular tumors, 18–33% of tumors are missed. As the detection limits and costs of imaging studies have improved, the role of ABR in diagnosis of VS has dramatically declined.

Differential Diagnosis

The three most common tumors of the CPA include schwannomas, meningiomas, and epidermoids (Table 61–1). Each of these tumors has a similar clinical presentation and each is primarily differentiated by its imaging characteristics. Other CPA lesions include congenital rest lesions (epidermoids,

Table 61–1. Lesions of the Cerebellopontine Angle (CPA).

Common CPA Lesions
Schwannomas (especially involving cranial nerves V, VII, and VIII)
Meningiomas
Epidermoids
Congenital Rest Lesions
Epidermoids
Arachnoid cysts
Lipomas
Vascular Lesions
Hemangiomas
Paragangliomas (glomus jugulare)
Aneurysms
Hemangioblastoma
Intra-Axial Tumors
Medulloblastomas
Astrocytomas
Gliomas
Fourth ventricle tumors
Hemangioblastomas
Lesions Extending from the Skull Base
Cholesterol granulomas
Glomus tumors
Chordomas
Chondrosarcomas
Other Malignant Disorders
Metastasis

arachnoid cyst, and lipoma), schwannomas of other cranial nerves, intraaxial tumors, metastasis, vascular lesions (paraganglioma and hemangioma), and lesions extending from the skull base (cholesterol granulomas and chordoma).

Complications

The natural history of VS includes a slow rate of growth in the IAC and then into the cistern of the CPA. Studies show that periods of growth are intermixed with periods of quiescence. The average growth rate is 1.8 mm/y. This slow growth causes progressive and often insidious symptoms and signs since there is displacement, distortion, and compression of the structures first in the IAC and then in the CPA. This slow growth via cellular proliferation provides a predictable progression of symptoms and signs. Occasionally, the tumor may undergo rapid expansion due to cystic degeneration or hemorrhage into the tumor. A rapid expansion causes rapid movement along the subsequent phases of VS symptoms and may cause rapid neurological deterioration.

The initial intracanalicular growth affects the vestibulocochlear nerve in the rigid IAC and causes unilateral hearing loss, tinnitus, and vertigo or disequilibrium. These three symptoms are the typical presenting complaint of not only patients with VS but also patients with other lesions of the CPA. It is interesting that the motor component of the facial nerve is resistant to injury during this phase of growth and patients have normal facial function. The tumor then grows into the CPA cistern and grows freely without causing significant new symptoms because structures in the CPA are initially displaced without injury (see Figure 61–2A). As the tumor approaches 3 cm, it abuts on the boundaries of the CPA and results in a new set of symptoms and signs. Compression of the CN V causes corneal and midface numbness or pain. Further distortion of CN VIII and now CN VII causes further hearing loss and disequilibrium and also facial weakness or spasms. Brainstem distortion leads to narrowing of the fourth ventricle (see Figure 61–2B).

Further growth leads to the final clinical spectrum of CPA syndrome. The patient develops cerebellar signs due to compression of the flocculus and cerebellar peduncle. The patient also develops obstructive hydrocephalus due to closure of the fourth ventricle. The increasing intracranial pressure manifests in ocular changes, headache, mental status changes, nausea, and vomiting. If the VS continues to grow without intervention, death occurs from respiratory compromise.

Treatment

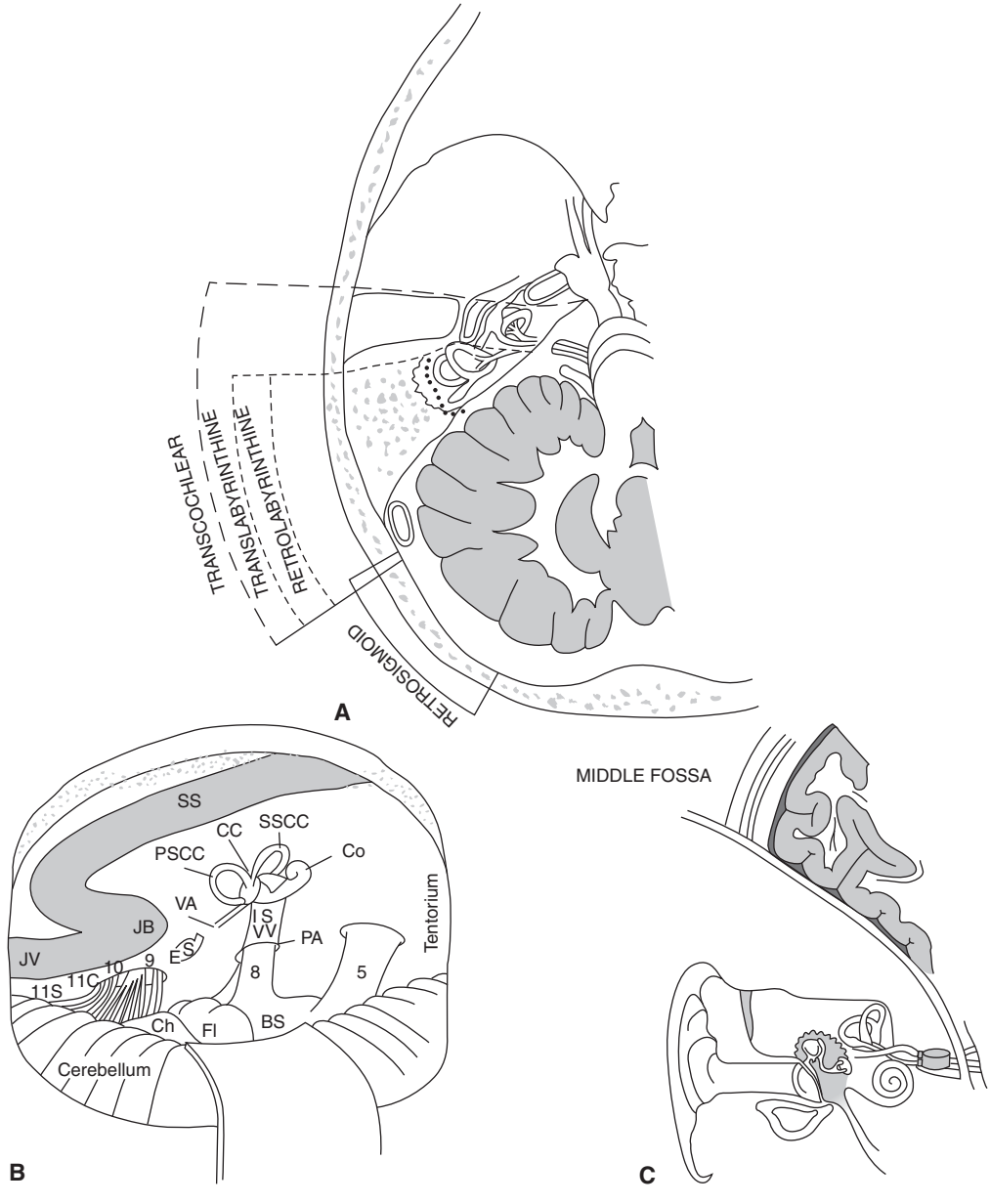
The treatment of patients with CPA tumors includes surgical removal, observation, and irradiation. Surgical removal has historically been the primary management modality for VS. More recently, observation with serial MRI and radiation therapy have increased in popularity. The size of the tumor, age of the patient, residual auditory function, vestibular dysfunction, and cranial neuropathies are some of the important factors in determining optimal intervention. Observation is reasonable in older patient or in whom the tumor is not growing. Gamma knife is preferentially used in older patient, those who cannot tolerate a surgical procedure or who have a limited life expectancy.

A. Surgical Measures

The surgical approaches to the CPA include translabyrinthine, retrosigmoidal, and middle fossa craniotomies (Figure 61–3A). The appropriate approach for a particular patient is based on the hearing status, the size of the tumor, the extent of IAC involvement, and the experience of the surgeon (Table 61–2). The approaches are either hearing preserving or hearing ablating. The retrosigmoidal and middle fossa approaches are hearing preserving. However, they have limitations of exposure to all aspects of the CPA and IAC. The middle fossa approach is well suited for patients with good hearing and a tumor that is <1.5 cm in the CPA. The retrosigmoidal approach is well suited for patients with good hearing and a tumor <4 cm and not involving the lateral IAC. In the retrosigmoid approach, the lateral IAC is usually only directly accessible following the removal of the posterior semicircular canal; the violation of the posterior semicircular canal leads to hearing loss. The translabyrinthine approach causes total hearing loss and so is well suited for patients with poor hearing (pure-tone average >50) or patients with good hearing and tumors not accessible by the hearing-preserving approaches. Generally, hearing preservation is poor with tumors >2 cm and those that involve the lateral IAC.

Three critical issues inherent in all three techniques are the extent of exposure of the IAC and CPA, the identification and preservation of the facial nerve, and the extent of brain retraction. These operations use electrophysiological monitoring of CN VII and an ABR in hearing preservation approaches.

1. Translabyrinthine approach—The primary approach for removal of VS is the translabyrinthine approach. The boundaries of the approach include the mastoid facial nerve and cochlear aqueduct anteriorly, middle fossa dura superiorly, posterior fossa dura posteriorly, and jugular foramen inferiorly (see Figure 61–3A). These boundaries are approached via the familiar postauricular incision. A complete canal mastoidectomy is accomplished with identification of the incus, tegmen, sigmoid sinus, and facial nerve. A compete labyrinthectomy is then performed with medial skeletonization of the middle and posterior fossa dura and decompression of the sigmoid sinus to the jugular foramen. After bony skeletonization of the IAC, the dura of the IAC is opened, and the facial nerve is identified medial to the transverse crest (Bill's bar). Once the facial nerve is identified in the fundus or lateral aspect of the IAC, tumor removal occurs from a lateral to medial direction along the IAC. In large tumors, the tumor is debulked internally and then the



▲ **Figure 61–3.** Surgical approaches to the cerebellopontine angle include **(A)** translabyrinthine **(A** and **B),** retrosigmoidal, and **(C)** middle fossa craniotomies. The retrosigmoidal and middle fossa approaches can preserve hearing, whereas the translabyrinthine approach necessarily deafens the patient because it involves drilling the balance portion of the inner ear.

tumor capsule is removed from the surrounding structures, including the facial nerve. After tumor removal, abdominal fat is placed into the defect.

The three advantages of the translabyrinthine approach are the ability to remove tumors of all sizes, minimal retraction of the brain, and the ability to directly visualize and preserve the facial nerve. The rate of facial nerve preservation is 97%. The rate of CSF leakage presenting under the incision or draining through the nose via the eustachian tube is 5–8%. The majority of these CSF leaks resolve with conservative management that includes mastoid dressing and fluid restriction. A minimal risk of meningitis is associated with a CSF leak.

Table 61–2. Surgical Approaches to the Cerebellopontine Angle (CPA) and Indications.

Hearing Preservation
Retrosigmoidal approach: Patient has good hearing and tumor not involving the lateral internal auditory canal (IAC)
Middle fossa approach: Patient has good hearing and tumor ≤1.5 cm in the CPA or IAC
Hearing Ablation
Translabyrinthine approach: Patient has poor hearing or larger tumors not accessible by other approaches

2. Retrosigmoidal approach—The retrosigmoidal approach is a modification of the traditional suboccipital approach used by neurosurgeons to address most posterior fossa lesions. The retrosigmoidal approach is a versatile approach with a panoramic view of the CPA from the foramen magnum inferiorly to the tentorium superiorly (Figure 61–3B). The medial two-thirds of the IAC are also accessible without violating the inner ear, therefore preserve hearing.

The surgical technique starts with a curvilinear skin incision 6 cm behind the ear over the retromastoid region. The soft tissue and posterior nuchal musculature are elevated to expose the mastoid and retromastoid bone. A 5 × 5 cm craniotomy is performed with the sigmoid as the anterior boundary and the transverse sinus as the superior boundary. An elevation of a bone plate is technically difficult, so the bone may be removed by drilling. The bone fragments are collected and are replaced during closure. The bone fragments will reform a bone plate and prevent adherence of the musculature to the dura. If decompression of the sigmoid sinus is needed for exposure, a mastoidectomy may also be performed. The dura is then opened along the sigmoid sinus and the cerebellum is seen. The CSF from the cisterna magnum needs to be released prior to retracting the cerebellum. Medial retraction of the cerebellum allows visualization of the CPA. To address the IAC component of the tumor, the posterior IAC bone needs to be removed. The bone dust created is carefully confined and removed to prevent meningeal irritation. The extent of IAC skeletonization is limited by the proximity to the inner ear. The endolymphatic duct and sac serve as landmarks to the proximity of the posterior semicircular canal and allow preservation of the inner ear and hearing. The facial nerve is normally anterior to the tumor or its position is ascertained with facial nerve monitoring. The tumor removal is as previously described. After tumor removal and hemostasis, air cells along the IAC and mastoid are closed with bone wax or bone cement to eliminate paths for CSF leak. A fat or muscle graft may also be placed into the petrosal defect to prevent CSF leak. The dura is closed and the bone plate or bone pate is replaced. The musculature and soft tissue are meticulously closed.

The primary advantage of the retrosigmoidal approach relative to the translabyrinthine approach is the ability for hearing preservation in properly selected tumors. If hearing preservation is not an issue, the retrosigmoidal approach allows a versatile approach to the CPA and IAC. The relative disadvantages compared with the translabyrinthine approach include persistent postoperative headache, increased difficulty in resolving CSF leaks, the need for cerebellar retraction, and the inability to have direct access to the facial nerve. The combination of intradural drilling leading to meningeal irritation by bone dust and dissection of suboccipital musculature causes nearly 10% of patients to have a persistent, severe, postoperative headache. In the case of extensive pneumatization of the IAC and mastoid, the air cells may be difficult to completely seal, and the inability to address the aditus-ad-antrum or the eustachian tube causes CSF leaks to be persistent, despite conservative treatment. The extent of cerebellar retraction is minimal in small tumors, but the amount of retraction increases with larger tumors. The surgical control of the facial nerve is adequate in the retrosigmoidal approach, but the exposure of the facial nerve is superior in the translabyrinthine approach.

3. Middle fossa approach—The middle fossa approach provides a hearing-preserving approach to intracanalicular tumors with a <1.5 cm cisternal component. The surgical technique involves an inverted U-shaped incision centered over the ear. The temporal muscle is reflected inferiorly to expose the squamous portion of the temporal bone. A 5 × 5 cm temporal craniotomy is performed and is centered over the zygomatic root. Extradural elevation of the temporal lobe is accomplished to reveal the floor of the temporal bone. The greater superficial petrosal nerve leading to the geniculate ganglion reveals the anterior, lateral boundary of the IAC, and the arcuate eminence reveals the posterior boundary of the IAC (Figure 61–3C). These landmarks may be difficult to identify, and the IAC dura may have to be identified medially by drilling toward the porus acousticus. Once the IAC is identified and well skeletonized medially, the bone removal continues laterally. However, the extent of IAC skeletonization laterally is limited by the basal turn of the cochlea anteriorly and the superior semicircular canal posteriorly. The IAC dura is opened posteriorly to avoid injury to the facial nerve. The tumor is dissected free of the facial nerve and removed in a medial to lateral direction. Any air cells are sealed and the dural defect is covered with a fat or muscle plug. The craniotomy bone flap is replaced and the incision is closed.

The middle fossa approach is unique compared with the posterior fossa craniotomies because the entire IAC is accessible without violating the inner ear; direct visualization of the medial IAC is difficult even with the middle fossa approach. This exposure allows for the removal of intracanalicular tumors while maintaining hearing preservation. The limitations of the middle fossa approach include tumors with a >1.5 cm cisternal component. In situations of hearing preservation, an extended middle fossa approach with further removal of

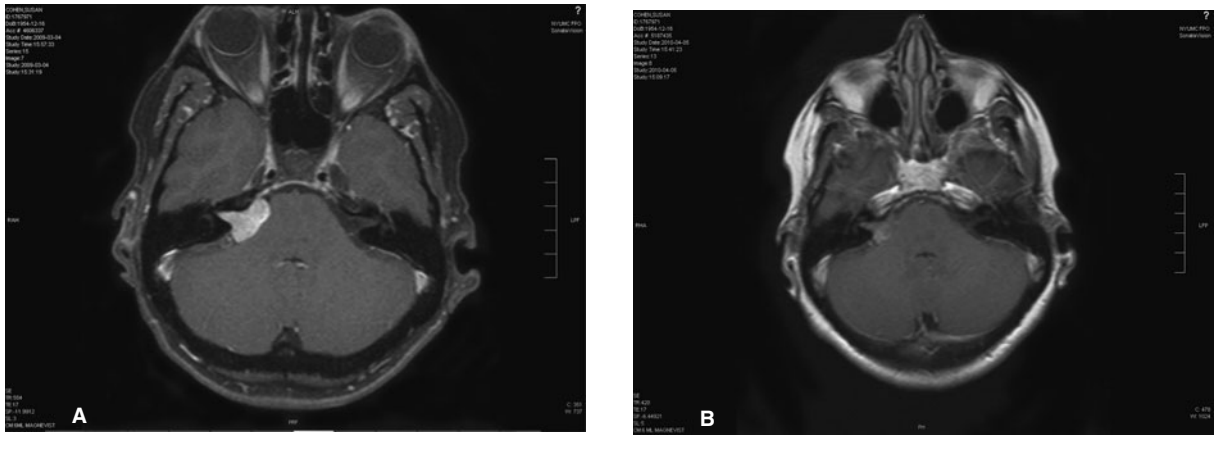
bone around the IAC as well as the elevation or division of the superior petrosal sinus and tentorium allow improved exposure into the CPA. The relative merits of the procedure with increased temporal lobe retraction and limited access to the posterior fossa in the event of bleeding relative to a retrosigmoidal approach continues to be defined. The disadvantages of the middle fossa approach include temporal lobe retraction and poor surgical position of the facial nerve relative to the tumor. Temporal lobe retraction may cause transient speech and memory disturbances and auditory hallucinations. The facial nerve, especially if the tumor originates from the inferior vestibular nerve, will be between the surgeon and the tumor. The increased manipulation of the facial nerve during tumor removal increases the risk of transient facial paresis.

B. Nonsurgical Measures

1. Observation—The predictable correlation between VS size and significant neurological symptoms and the relative slow growth of VS allow observation to be a management option for VS. Patients may be observed if their life expectancy is shorter than the growth time required for the VS to cause significant neurological symptoms. The growth pattern of the VS should be assessed in these patients with a second radiological evaluation in 6 months and then in yearly radiological evaluations. Studies have shown that 15–24% of patients undergoing conservative management require surgery or stereotactic radiation. If the growth rate in the first year exceeds 2–3 mm, then the patient is likely to need the treatment for the VS. The patient should understand that the initial conservative management, rather than immediate surgical intervention, may necessitate a resection of a larger tumor that is less amenable to hearing preservation or stereotactic radiation (or both) if intervention becomes necessary in the future.

2. Stereotactic radiation—The goal of stereotactic radiation is to prevent further growth of VS while preserving hearing and facial nerve function. This goal directly differs from the goal of complete tumor removal in microsurgical therapy. The mechanism of stereotactic radiation relies on delivering radiation to a specific intracranial target by using several precisely collimated beams of ionizing radiation. The beams take various pathways to the target tissue, therefore creating a sharp dose gradient between the target tissue and the surrounding tissue. The ionizing radiation causes necrosis and vascular fibrosis, and the time course of the effect is >1–2 y. There is an expected transient swelling of the tumor in the short term with modest shrinkage over time. The ionizing radiation is most commonly delivered using a 201-source cobalt-60 gamma knife system. The standard linear accelerator can also be adapted to deliver stereotactic radiation. The practical aspects include the patients wearing a stereotactic head frame, computer-assisted radiation planning using an MRI scan, and a single treatment for delivery of the radiation Figure 61–4.

The success of stereotactic radiation in arresting tumor growth depends on the dose of radiation delivered. However, the rate of cranial nerve neuropathies, including hearing loss, is decreased by lowering the radiation dose. The current trend has been to lower the marginal radiation dose, and the long-term tumor control with these current dosing plans is under investigation. Since VS have a slow growth rate, these studies require 5- to 10-y follow-ups to provide reliable data about tumor control. Studies have shown control rates from 85% to more than 95%. The hearing preservation rate decreases each year after radiation and stabilizes after 3 y in 50% of patients. The rate of facial nerve dysfunction varies from 5% to 20% based on the radiation dose at the margin of the tumor and the length of the facial nerve in the radiation



▲ **Figure 61–4.** MRI with gadolinium enhancement demonstrating typical appearance of pre- **(A)** and 1-y post- **(B)** gamma knife-treated appearance of VS. The tumor is slightly smaller and there is less intense enhancement following gamma knife therapy. The low signal intensity within the posttreated tumor may represent areas of tumor necrosis.

field. Approximately 25% of patients have trigeminal nerve neuropathy. The persistence and extent of these neuropathies with the lower dosing protocols continue to be studied. Hydrocephalus is also a complication of radiation.

As the long-term effectiveness and sequelae of stereotactic radiation are further defined, the indications for radiation therapy will become further refined. Radiation therapy is useful in patients in whom the arrest of tumor growth is acceptable. These patients have either short-life expectancies or a high surgical risk. Compared with microsurgery, stereotactic radiation may allow improved hearing preservation in patients with 2–3 cm VS. Radiation therapy in large tumors (>3 cm) or tumors causing brain compression will exacerbate symptoms because of initial tumor swelling.

Prognosis & Surgery-Related Complications

A. Operative Complications

The intraoperative complications for all three approaches include vascular injury, air embolisms, parenchymal brain injury, and cranial nerve injury. The anteroinferior cerebellar artery originates from the basilar artery and supplies the labyrinthine artery as well as the lower portion of the cerebellum and the vein of Labbé, which can be the only venous drainage of the temporal lobe. The anteroinferior cerebellar artery and vein of Labbé are vulnerable to injury during VS surgery. In the event of an air embolism via an open vein, the patient should be placed into a left lateral and Trendelenburg position to trap the air in the right ventricle; the air can then be aspirated via a central venous catheter. The cerebellum during a retrosigmoidal craniotomy and the temporal lobe during a middle fossa craniotomy are at risk from retraction injury.

B. Postoperative Complications

Postoperative complications include hemorrhage, stroke, venous thromboembolism, the syndrome of inappropriate antidiuretic hormone, CSF leak, and meningitis. Postoperative hemorrhage manifests as neurological and cardiovascular deterioration and requires evacuation. Studies have shown that, postoperatively, low-molecular-weight heparin in addition to compression stockings and intermittent pneumatic compression devices may further reduce the risk of thromboembolism in high-risk patients (eg, elderly and obese patients) without increasing the risk of intracranial bleeding. The most common complication is CSF leak. CSF leak occurs in 5–10% of cases either via the wound or via a pneumatic pathway to the eustachian tube. Most of these leaks resolve with conservative care, which includes placing wound sutures at the leak site, replacing the mastoid dressing, and decreasing intracranial pressure with acetazolamide (Diamox), fluid restriction, and bed rest. Some patients also require a lumbar subarachnoid drain, and a very few patients need surgical reexploration.

A related complication is meningitis. Meningitis occurs in 2–10% of patients and may be aseptic, bacterial, or due to CSF leak and arachnoid irritation from the fat graft (lipoid). The distinction between aseptic and bacterial meningitis is necessary because the treatment for aseptic meningitis is a steroid taper and antibiotics for bacterial meningitis. Delayed meningitis should be considered bacterial and likely due to a CSF leak.

C. Operative Prognosis and Rehabilitation

The most concerning issues to patients are deafness, imbalance, and facial nerve weakness. The most important factors for hearing preservation are the tumor size and the preoperative hearing level. Hearing preservation ranges from 20% to 70%. Patients with contralateral hearing tolerate the unilateral loss but may benefit from bone-anchored hearing aids. Patients with poor contralateral hearing may be rehabilitated with a CROS (contralateral routing of signal) hearing aid or a cochlear implant if the cochlear nerve fibers are preserved. Almost half of the patients will have vertigo or imbalance beyond the postoperative period, but these symptoms have a minimal impact on daily activities.

The rapidity of vestibular compensation after unilateral vestibular loss is determined by the patient's efforts to exercise and challenge the vestibular system. Patients who continue to have disequilibrium in the extended postoperative period are referred for vestibular rehabilitation therapy. Facial nerve function is also best predicted by tumor size. In smaller tumors, more than 90% of patients are found to have House-Brackmann Grade 1 or 2 function (Grade 1 is normal and Grade 6 is complete paralysis). If all tumor sizes are considered, then approximately 80% of patients have Grade 1 or 2 function.

The rehabilitation of facial nerve injury is based on the general principles of nerve injury, recovery, and rehabilitation. If the nerve is transected intraoperatively, the nerve should be repaired primarily, if possible, or with a greater auricular interposition graft. The postoperative function may be predicted in an anatomically intact nerve by the intraoperative stimulability of the nerve. If the nerve stimulates at <0.2 V, then there is a >85% chance of Grade 1 or 2 function at 1 y. The lack of facial function (Grade 6) at 1 y and no reinnervation potentials on electromyograph should lead to a hypoglossal–facial transposition, an interposition nerve graft, or a crossfacial graft. If facial rehabilitation has been delayed and there is electrical "silence" of the facial muscle on electromyograph, muscle transpositions with the temporalis or masseter muscle to the lip give improved tone and symmetry to the lower face. The upper face can be rehabilitated with a brow lift and gold weight for the eye. The eye must be protected with lubrication, ointment, and an eye bubble if there is either incomplete eye closure or a lack of sensation to the cornea due to trigeminal nerve involvement. The lack of eye care leads to corneal injury and blindness.

Arts HA, Telian SA, El-Kashlan H et al. Hearing preservation and facial nerve outcomes in vestibular schwannoma surgery: results using the middle cranial fossa approach. *Otol Neurotol.* 2006;27(2):234. [PMID: 1643699] (Middle cranial fossa approach for the resection of small tumors is associated with excellent hearing preservation and facial nerve outcome.)

Bassim MK, Berliner KI, Fisher LM et al. Radiation therapy for the treatment of vestibular schwannoma: a critical evaluation of the state of the literature. *Otol Neurotol.* 2010. [Epub ahead of print; PMID: 20300044] (A critical review of the literature suggests that the lack of uniform reporting guidelines is a big impediment to assess postradiation therapy outcome for VS.)

Cheng S, Naidoo Y, da Cruz M et al. Quality of life in postoperative vestibular schwannoma patients. *Laryngoscope.* 2009;119(11):2252. [PMID: 19753619] (Patients quality of life following surgical excision was nearly the same as healthy population.)

Hillman TA, Chen DA, Quigley M. Acoustic tumor observation and failure to follow-up. *Otolaryngol Head Neck Surg.* 2010;142(3):400. [PMID: 20172388] (This study found that nearly half of the patients failed to follow-up as recommended.)

Nikolopoulos TP, Fortnum H, O'Donoghue G et al. Acoustic neuroma growth: a systematic review of the evidence. *Otol Neurotol.* 2010. [Epub ahead of print; PMID: 20147867] (While VS usually grow at 1–2 mm/y, there are no reliable predictors of no growth, normal growth, or fast growth.)

Meyer TA, Canty PA, Wilkinson EP et al. Small acoustic neuromas: surgical outcomes versus observation or radiation. *Otol Neurotol.* 2006;27(3):380. [PMID: 16639278] (Small tumors are best treated by surgery for hearing and facial nerve preservation.)

Nonacoustic Lesions of the Cerebellopontine Angle

62

Jacob Johnson, MD & Anil K. Lalwani, MD

Vestibular schwannomas (acoustic neuromas) account for 80% of all lesions of the cerebellopontine angle (CPA). This chapter discusses some of the other common neoplasms (meningiomas and epidermoid cysts) as well as uncommon tumors of the CPA that commonly present with injury to the cochlear–vestibular system. Each of these tumors has a similar clinical presentation; they are primarily differentiated by their imaging characteristics.

The CPA consists of a potential space filled with cerebrospinal fluid (CSF) in the posterior cranial fossa bounded by the temporal bone, the cerebellum, and the brainstem. The CPA is traversed by cranial nerves V–XI and most prominently the facial (CN VII) and vestibulocochlear (CN VIII) nerves. CPA tumors account for 10% of all intracranial tumors (Table 62–1). Nearly 90% of all CPA tumors include vestibular schwannomas (acoustic neuromas) and meningiomas. Other CPA lesions include congenital rest lesions (eg, epidermoid cysts, arachnoid cysts, and lipomas), schwannomas of other cranial nerves, intra-axial tumors, metastases, vascular lesions (eg, paragangliomas and hemangiomas), and lesions extending from the skull base (cholesterol granulomas and chordomas). CPA lesions become clinically symptomatic by causing compression of the neurovascular structures in and around the CPA. The classic description of these symptoms initially includes unilateral hearing loss, vertigo, altered facial sensation, facial pain that later progresses to nystagmus, facial palsy, vocal cord palsy, dysphagia, diplopia, respiratory compromise, and death (Table 62–2).

Lalwani AK. Meningiomas, epidermoids, and other nonacoustic tumors of the cerebellopontine angle. *Otolaryngol Clin North Am*. 1992;25(3):707. [PMID: 1635871] (A thorough review of nonacoustic lesions of the cerebellopontine angle.)

MENINGIOMAS

ESSENTIALS OF DIAGNOSIS

- Asymmetric (unilateral) sensorineural hearing loss, tinnitus, or both
- More likely than vestibular schwannomas to have facial or trigeminal nerve findings, or both
- Dural tail and calcification are distinctive on imaging.

General Considerations

Meningiomas are the second most common CPA tumors and account for 3–10% of neoplasms at this location. Compared with schwannomas, meningiomas are a more heterogeneous group of tumors with regard to pathology, anatomic location, and treatment outcome. Most of these tumors are benign and slow growing; 1% will become symptomatic. Meningiomas differ in pathogenesis, anatomic location, and imaging characteristics from vestibular schwannomas but are nearly indistinguishable in terms of clinical presentation and audiovestibular testing. Meningiomas are primarily managed by surgical excision.

Pathogenesis

Meningiomas arise from arachnoid villi cap cells and are located along dura, venous sinuses, and neurovascular foramina. Meningiomas are most commonly sporadic but may occur in familial syndromes such as NF2, Werner syndrome, and Gorlin syndrome. More than one-third of

Table 62–1. Lesions of Cerebellopontine Angle (CPA).

Common CPA Lesions
Schwannomas (cranial nerves V, VII, and VIII)
Meningiomas
Epidermoids
Congenital Rest Lesions
Epidermoid cysts
Arachnoid cysts
Lipomas
Vascular Lesions
Hemangiomas
Paragangliomas (glomus jugulare)
Aneurysms
Hemangioblastomas
Intra-Axial Tumors
Medulloblastomas
Astrocytomas
Gliomas
Fourth ventricle tumors
Hemangioblastomas
Lesions Extending from the Skull Base
Cholesterol granulomas
Glomus tumors
Chordomas
Chondrosarcomas
Metastasis
Breast cancer
Lung cancer
Melanoma
Prostate cancer

Table 62–2. CPA Syndrome.

Unilateral hearing loss
Tinnitus
Vertigo
Hypesthesia and neuralgia
Nystagmus
Facial palsy
Vocal cord palsy
Dysphagia
Diplopia
Respiratory compromise
Death

patients with NF2 have meningiomas. Molecular studies have shown deletions in chromosome 22 in nearly 75% of meningiomas. Specifically, mutations in the *NF2* gene encoding the merlin protein have been shown in 30–35% of meningiomas. Although most meningiomas are benign, 5% are malignant. Chromosomal abnormalities in 1p, 6q, 9p, 10q, and 14q are seen in more aggressive or malignant meningiomas.

Clinical Findings

A. Symptoms and Signs

From the onset of symptoms, meningiomas take an average of 5 y to be diagnosed. The typical patient is a woman in her fourth or fifth decade of life. Unlike vestibular schwannomas, there is a 2:1 female bias. Meningiomas presenting in younger patients or multiple meningiomas in the same patient should prompt an evaluation for NF2. The most common complaints are the same as vestibular schwannoma and include unilateral hearing loss (80%), vertigo or imbalance (75%), and tinnitus (60%). The symptoms and signs more common to meningiomas relative to vestibular schwannomas include trigeminal neuralgia (7–22%), facial paresis (11–36%), lower cranial nerve deficits (5–10%), and visual disturbances (8%).

B. Imaging Studies

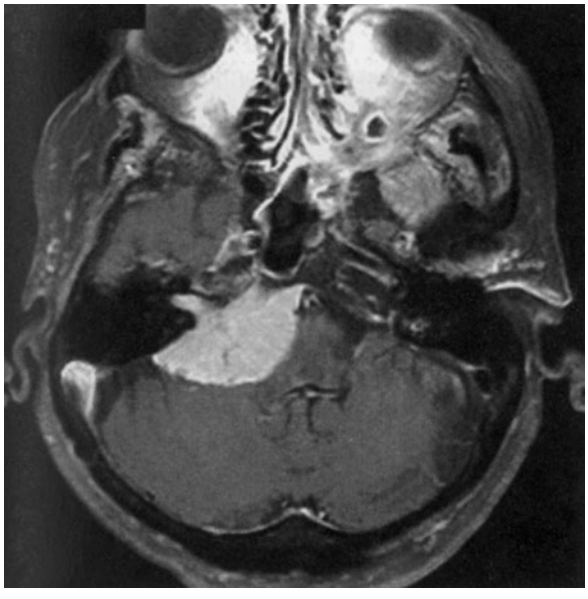
Imaging provides the diagnosis of meningioma and allows the differentiation between meningioma and vestibular schwannoma (Table 62–3).

1. Computed tomography scanning—Computed tomography (CT) scanning without contrast shows an iso- or hyperdense mass with areas of calcification in 10–26% of cases and provides information regarding hyperostosis or bony invasion. Meningiomas enhance homogeneously with CT contrast, and 90% of these neoplasms can be detected by contrast-enhanced CT.

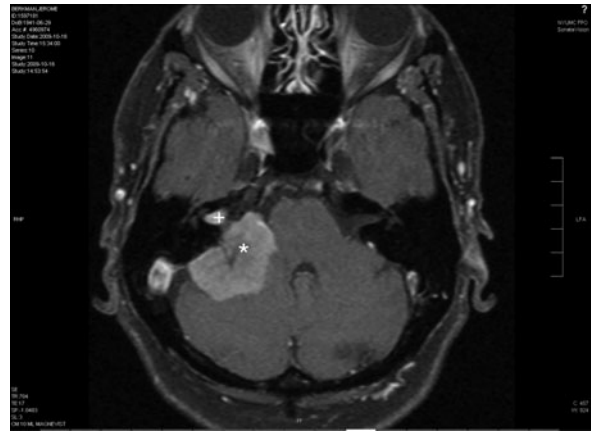
2. Magnetic resonance imaging—MRI is the study of choice for the diagnosis of meningiomas. Meningiomas are hypo- to isointense on MRI T1-weighted images and have

Table 62–3. Differential Diagnoses of Meningioma and Vestibular Schwannoma.

	Meningioma	Vestibular Schwannoma
Shape	Sessile	Globular
Internal auditory canal	Eccentric, extrinsic, and not eroded	Centered, penetrating, and eroded
Calcification	Present	Absent
Hyperostosis	Present	Absent
Tumor-bone angle	Obtuse	Acute
Meningeal sign	Present	Absent



A



B

▲ **Figure 62–1.** **(A)** Meningioma of the cerebellopontine angle. A T1-weighted, gadolinium-enhanced MRI scan demonstrates a meningioma of the right cerebellopontine angle. The enhancing lesion has a broad dural base and does not expand the internal auditory canal. **(B)** Vestibular schwannoma of the internal auditory canal (IAC) and meningioma of the jugular foramen. A T1-weighted, gadolinium-enhanced MRI scan demonstrating an unusual case of small vestibular schwannoma involving the medial IAC (+) and a meningioma involving the lateral IAC, cerebellopontine angle, and jugular foramen (*).

a variable intensity on T2-weighted images. Areas of calcification appear dark on both T1- and T2-weighted images (Figure 62–1A and B). Unlike vestibular schwannomas, meningiomas are broad based (sessile) and usually not centered over the porous acoustics. The broad-base attachment to the petrous wall leads to an obtuse bone-tumor angle. There is no widening of the internal auditory canal (IAC). Also unlike vestibular schwannomas, meningiomas more commonly herniate into the middle fossa. T1-weighted enhanced images can show an enhancing dural tail (meningeal sign) adjacent to the bulk of the tumor in 50–70% of meningiomas.

C. Special Tests

The hearing loss on an audiogram has no characteristic pattern. The speech discrimination scores suggest a retrocochlear pathology in 50% of cases. The auditory brainstem response may be normal in 25% of cases.

Treatment

The management options include surgery, stereotactic radiotherapy, and observation. The latter two are indicated in patients with limited life expectancy or in whom the expected morbidity of surgical excision is not justified.

A. Surgical Measures

Surgical treatment ideally consists of total meningioma removal, excision of a cuff of surrounding dura, and drilling of the underlying bone. The surgical approach is based on the tumor location and the patient's hearing status.

In contrast to vestibular schwannomas, the anatomic location of posterior fossa meningiomas is varied. The site of the meningioma is a major determinant of types of morbidity from the tumor and the success of treatment. A simple classification differentiates whether the tumor is medial or lateral to the IAC. Meningiomas medial to the IAC are more common. These meningiomas commonly arise along the inferior petrosal sinus and may involve the petrous apex, the lateral clivus, and Meckel cave. Meningiomas lateral to the IAC involve the sigmoid sinus, the jugular bulb, and the superior petrosal sinus. In an uncommon pattern, meningiomas may be centered on the IAC and most closely mimic a vestibular schwannoma. IAC meningiomas may invade the inner or middle ear.

Meningiomas may also be superior to the IAC and considered a midpetrosal meningioma.

Meningiomas lateral to the IAC are approached via a retrosigmoidal approach. The facial nerve in lateral meningiomas is most often displaced anteriorly and so does not lie between the surgeon and the tumor. Therefore, the facial nerve is less traumatized during tumor removal. The retrosigmoidal approach also allows for hearing preservation. Limited intracanalicular meningiomas may be managed by the **middle cranial fossa approach**, especially if hearing preservation is possible. Meningiomas involving the IAC in patients with poor hearing are approached via the translabyrinthine approach. If the tumor invades the cochlea and has an anteromedial extension to the clivus or Meckel cave, then a **transcochlear approach** should be considered. The transcochlear approach sacrifices hearing and requires rerouting of the facial nerve. Sixty percent of CPA meningiomas involve the middle fossa and may require a **craniotomy of the combined middle and posterior fossae**. The type of posterior fossa craniotomy in the combined approach depends on the need for hearing preservation and the extent of the surgical exposure required.

B. Adjunctive Therapies

Adjunctive therapies include external-beam radiation and stereotactic radiation therapy. Radiation therapy should be considered in cases of inoperable tumors, subtotal resection, recurrent tumors, and malignant tumors.

Prognosis

Total tumor removal is accomplished in 70–85% of meningioma cases. Incomplete tumor removal is often associated with either adherence of the meningioma to the brainstem or cavernous sinus involvement. The long-term recurrence after total tumor removal is between 10% and 30%, whereas that of subtotal removal is more than 50%. In contrast to vestibular schwannoma, hearing preservation is more likely and approaches 70%. The facial nerve function has a 17% rate of deterioration from preoperative levels. Less frequently, gait disturbance and CSF leak may occur (8%). The mortality rate is between 1% and 9%.

Devèze A, Franco-Vidal V, Liguoro D et al. Transpetrosal approaches for meningiomas of the posterior aspect of the petrous bone. Results in 43 consecutive patients. *Clin Neurol Neurosurg.* 2007;109(7):578. [PMID: 17604904] (Surgical excision is associated with minimal morbidity and the outcome are better for posteriorly attached meningiomas than medially inserted ones.)

Lalwani AK, Jackler RK. Preoperative differentiation between meningioma of the cerebellopontine angle and acoustic neuroma using MRI. *Otolaryngol Head Neck Surg.* 1993;109(1):88. [PMID: 8336973] (This paper defines the radiological features that can be used to preoperatively differentiate a vestibular schwannoma from a meningioma.)

EPIDERMOID CYSTS

ESSENTIALS OF DIAGNOSIS

- Asymmetric (unilateral) sensorineural hearing loss, tinnitus, or both
- More likely than vestibular schwannomas to have facial or trigeminal nerve findings, or both
- A distinguishing characteristic relative to vestibular schwannomas and meningiomas is that epidermoid cysts show no enhancement with intravenous contrast.

General Considerations

Epidermoid cysts are much less common than vestibular schwannomas or meningiomas. They account for approximately 5% of CPA lesions. Epidermoid lesions are slow growing and often grow to a significant size before causing CPA symptoms because they initially grow around structures via pathways of least resistance rather than cause compression. Epidermoid cysts are treated by surgical excision, but total removal is more difficult than vestibular schwannomas because they become adherent to normal structures.

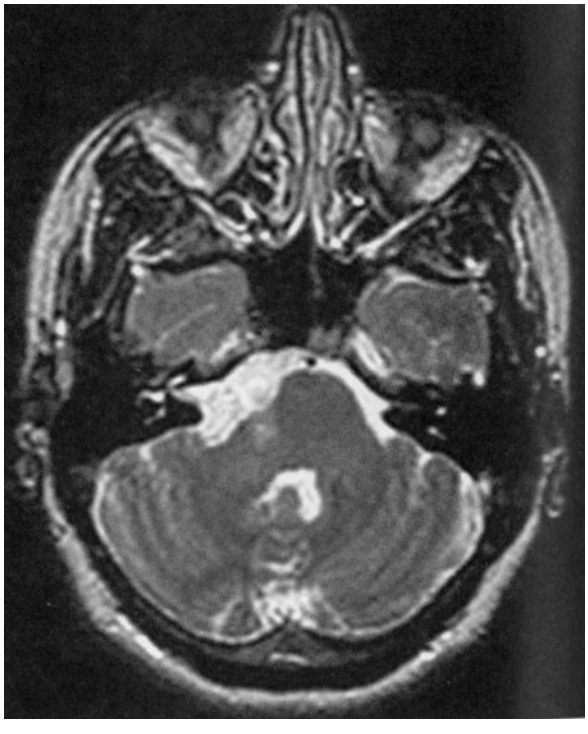
Pathogenesis

Epidermoid cysts likely develop from ectodermal inclusions that become trapped during embryogenesis. These ectodermal inclusions lead to a keratinizing squamous epithelium in the CPA. The squamous epithelium produces a cyst filled with sloughed keratinaceous debris. The gross appearance is of a nodular cyst. The cyst is lined with squamous epithelium and filled with lamella of desquamated keratinaceous debris. Most epidermoid cysts are benign, with rare reports of squamous cell carcinoma arising in epidermoid lesions.

Clinical Findings

A. Symptoms and Signs

The presentation of epidermoid cysts is similar to other CPA lesions, with hearing loss being the most common symptom. Epidermoid cysts have a higher rate of preoperative facial and trigeminal nerve involvement—40% and 50%, respectively—compared with vestibular schwannomas. Patients may present with hemifacial spasm, facial hypesthesia, neuralgia, or wasting of the muscles of mastication.



▲ **Figure 62–2.** Epidermoid cyst of the cerebellopontine angle. A T2-weighted MRI scan demonstrates a bright lesion in the cerebellopontine angle with the same signal as cerebrospinal fluid. The epidermoid cyst has the characteristic irregular borders and is not centered on the internal auditory canal.

B. Imaging Studies

On CT scanning, epidermoid cysts are hypodense compared with the brain. A distinguishing characteristic relative to vestibular schwannomas and meningiomas is that epidermoid lesions show no enhancement with intravenous contrast. Epidermoid cysts have irregular borders, are not centered on the IAC, and do not usually widen the IAC (Figure 62–2). Epidermoid cysts have imaging characteristics similar to CSF on MRI (hypointense on T1-weighted imaging and hyperintense on T2-weighted imaging) and do not enhance with gadolinium contrast.

C. Special Tests

Audiovestibular testing does not show any patterns distinguishing for epidermoid cysts.

Treatment

The primary treatment of epidermoid cysts is surgical. The approaches include a **retrosigmoidal approach** for hearing preservation and a **translabyrinthine approach** in patients with significant hearing loss. Any extension into the middle fossa can usually be removed via a **posterior fossa craniotomy**. The ability to completely remove the tumor is limited by the propensity of epidermoid cysts to adhere to neurovascular structures. Attempts at complete tumor removal may increase the rate of postoperative transient or permanent cranial nerve palsies.

Prognosis

Total tumor removal is accomplished in less than 50% of cases, and the recurrence rate may be as high as 50%. Regardless, most patients have excellent or good postoperative function.

Liu P, Saida Y, Yoshioka H et al. MR imaging of epidermoids at the cerebellopontine angle. *Magn Reson Med Sci*. 2003;2(3):109. [PMID: 16322102] (Hyperintense lesion on diffusion-weighted imaging is specific for cerebellopontine angle epidermoid cyst.)

Schiefer TK, Link MJ. Epidermoids of the cerebellopontine angle: a 20-year experience. *Surg Neurol*. 2008;70(6):584. [PMID: 18423548] (A series of 24 cases showing that the recurrence rate following surgery was similar for "total tumor removal" and near/subtotal resection.)

NONVESTIBULAR SCHWANNOMAS

Nonvestibular schwannomas represent more than 95% of all CPA schwannomas. In addition to CN VIII (the vestibulocochlear nerve, schwannomas of cranial nerves V (the trigeminal nerve), VII (the facial nerve), IX (the glossopharyngeal nerve), X (the vagus nerve), XI (the accessory nerve), and XII (the hypoglossal nerve) can involve the CPA. CPA schwannomas share clinical, pathological, and imaging characteristics. The primary treatment, similar to that for vestibular schwannoma, is surgical resection. The surgical approach is based on the location of the schwannoma and the patient's hearing status. Resection of cranial nerve schwannomas may lead to significant cranial nerve dysfunction; therefore, preoperative cranial nerve function and postoperative rehabilitation are important issues to consider.

1. Facial Nerve Schwannomas

Facial nerve schwannomas most commonly occur at the geniculate ganglion, but can involve any portion of the facial nerve. Similar to a vestibular schwannoma, a facial nerve schwannoma presents with hearing loss, tinnitus, and imbalance (CPA symptoms). Facial nerve symptoms such as facial spasm or weakness usually present with larger tumors. Audiovestibular testing shows an abnormality in acoustic reflex testing because of impairment of the CN VII motor supply to the stapedius muscle. Facial nerve schwannomas are associated with the reduction of electroneuronography

(ENOG) potentials on the ipsilateral side, even when there is no clinically evident palsy. Imaging often does not allow for the differentiation between a vestibular and a facial nerve schwannoma.

Distinguishing features on imaging of facial nerve schwannomas include expansion of the fallopian canal, extension from the geniculate ganglion into the middle fossa, and location of the schwannoma in the anterior superior portion of the IAC (a position eccentric to the axis of the IAC). These schwannomas may be observed until facial nerve function has deteriorated or a neurological complication becomes imminent since resection usually requires division and grafting of the facial nerve. Mimetic function following interposition grafting is poor and is limited to House–Brackmann Grade 3 functioning at best.

2. Trigeminal Nerve Schwannomas

Trigeminal nerve schwannomas initially present with ipsilateral facial hypesthesia, paresthesias, neuralgia, and difficulties with chewing. Trigeminal schwannomas arise from the gasserian ganglion in the middle fossa and grow posteriorly to involve the CPA or arise from the root of the nerve and directly involve the anterior CPA and Meckel cave. These tumors frequently involve both the middle and the posterior fossa, and a combined approach may be necessary for resection.

3. Lower Cranial Nerve Schwannomas

Schwannomas of CN IX, X, and XI cause smooth enlargement of the jugular foramen and may grow superiorly into the CPA or inferiorly into the parapharyngeal space. Schwannomas of these cranial nerves produce symptoms based on their cranial nerve functions, thereby causing hypesthesia and weakness of the palate, vocal cords, and shoulders, respectively. Patients present with dysphagia, hoarseness, and shoulder weakness. CPA involvement also leads to CPA symptoms. Schwannomas of cranial nerve XII cause hemiatrophy of the tongue and expansion of the hypoglossal canal. The treatment is surgical removal and rehabilitation of the patient's functional deficit.

Semaan MT, Slattery WH, Brackmann DE. Geniculate ganglion hemangiomas: Clinical results and long-term follow-up. *Otol Neurotol*. 2010. [Epub ahead of print; PMID: 20351611] (Facial nerve hemangiomas involving the geniculate ganglion often are associated with facial paralysis despite their small size. During surgery, the facial nerve was preserved in 73% of cases.)

Wiggins RH 3rd, Harnsberger HR, Salzman KL et al, The many faces of facial nerve schwannoma. *AJNR Am J Neuroradiol.* 2006;27(3):694. [PMID: 16552018] (MR imaging appearance of facial nerve schwannoma depends on the segment that is involved.)

CONGENITAL REST LESIONS

Congenital rest lesions involving the CPA include epidermoid cysts, arachnoid cysts, and lipomas. These lesions occur because of errors in embryogenesis that allow vestigial structures to remain and grow during adult life. These lesions are not aggressive but rather slow growing and have a tendency to envelop the neurovascular structures in the CPA. The presenting symptoms are very similar to, if not indistinguishable from, those of vestibular schwannoma, and only imaging allows their differentiation. The imaging characteristics on CT scan are very similar and include a well-encapsulated, hypodense mass that does not enhance with contrast. MRI allows differentiation based on the signal characteristics of desquamated epithelium, CSF, or fat. The treatment is surgical, but total removal is more difficult than in vestibular schwannoma and is not always necessary.

1. Arachnoid Cysts

Arachnoid cysts are CSF-filled cysts surrounded by an epithelial lining. This epithelial lining originates from a duplication of the arachnoid membrane and has secretory capabilities. The rate of growth is unpredictable and patients may present with arachnoid cysts in the CPA or IAC at any age. The key imaging point is that these cysts match the signal intensity of CSF on every MRI sequence and do not enhance with gadolinium. The treatment involves diuretics, shunting procedures, and marsupialization of the cyst into the subarachnoid space.

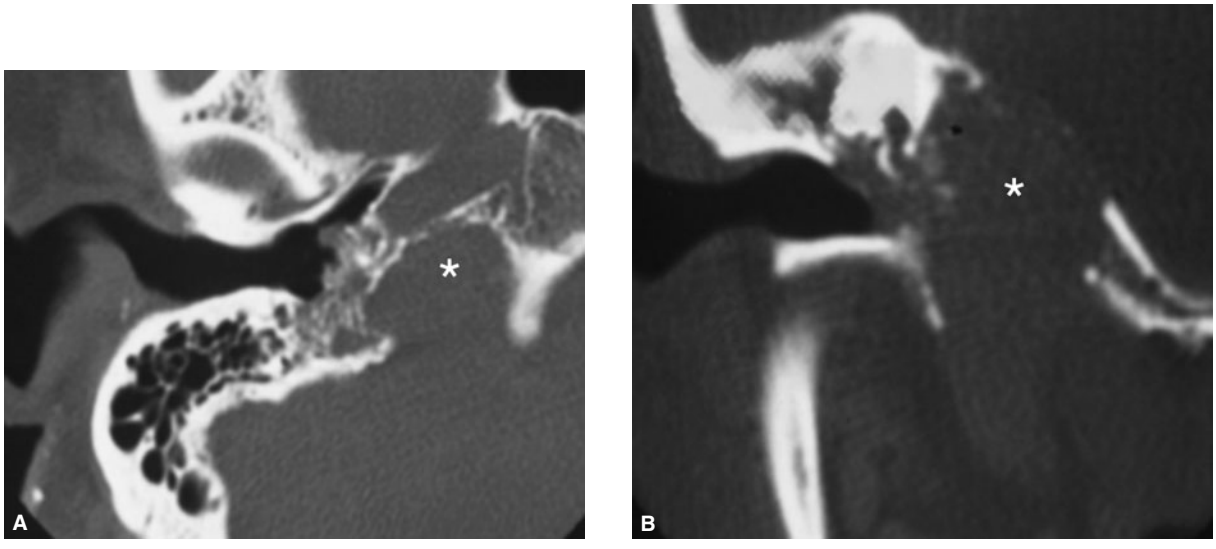
2. Lipomas

Lipomas are rare lesions of the CPA and IAC. They are due to congenital malformations that lead to proliferation of adipocytes in subarachnoid cisterns or ventricles. MRI parallels the intensities of fat, and so lipomas are hyperintense on T1-weighted imaging, show no enhancement with gadolinium, are hypointense on T2-weighted imaging, and become hypointense on T1-weighted imaging with fat suppression. The neurovascular structures of the CPA travel through the lipoma. Therefore, the surgical treatment of these lesions, if they become symptomatic, is conservative debulking.

Alaani A, Hogg R, Siddiq MA, Chavda SV, Irving RM. Cerebellopontine angle arachnoid cysts in adult patients: what is the appropriate management? *J Laryngol Otol*. 2005;119(5):337. [PMID: 15949094] (A small series suggesting that the observation alone is often sufficient as management of arachnoid cyst.)

VASCULAR LESIONS

A variety of vascular lesions may directly or via extension involve the CPA. These include paragangliomas (glomus jugulare neoplasms), hemangiomas, and aneurysms.



▲ **Figure 62–3.** Jugular foramen paraganglioma. Axial **(A)** and coronal **(B)** CT scan demonstrating a large jugular foramen tumor with extension into the middle ear, mastoid, and the neck (B). There is expansion of the jugular bulb region (*).

1. Paragangliomas (Glomus Jugulare Neoplasms)

Glomus jugulare tumors arise from paraganglionic tissues (chief cells) and have intracranial extension in 15% of cases. These neoplasms are slow growing and present initially with pulsatile tinnitus and conductive hearing loss. Further growth at the jugular foramen causes lower cranial nerve neuropathies, and then intracranial extension into the posterior fossa may lead to sensorineural hearing loss and dizziness. Paragangliomas have a variable appearance on CT scans, but bone algorithms show the extent of temporal bone involvement (Figure 62–3). Paragangliomas cause irregular expansion of the jugular foramen, whereas lower cranial nerve schwannomas cause smooth enlargement of the jugular foramen. Paragangliomas have a "salt and pepper" appearance on T2-weighted MRI scans, and MRI shows the extent of intracranial involvement. There is presence of flow voids and pronounced enhancement with gadolinium. Magnetic resonance angiography (MRA) and angiography provide information on the involvement of the great vessels and allow for preoperative embolization of larger neoplasms. The treatment requires surgical excision. Jugular bulb involvement may be addressed by a transmastoid-neck approach. Extension to the carotid artery or intracranial extension requires an infratemporal fossa approach.

2. Hemangiomas

Hemangiomas of the temporal bone often involve the geniculate ganglion and the internal auditory meatus. Hemangiomas are benign, slow-growing vascular hamartomas. The hemangiomas involving the geniculate ganglion cause progressive facial paresis. Patients also complain of facial twitches, tinnitus, and facial pain. Hearing loss, if present, is conductive because of middle ear involvement. The facial paresis occurs sooner with hemangiomas than with facial nerve schwannomas.

CT imaging shows a small, soft tissue mass at the geniculate ganglion, with surrounding smooth or irregular bony enlargement of the fallopian canal. The small size of the soft tissue mass, irregular bony erosion, and presence of calcium in the tumor are all suggestive of a geniculate ganglion hemangioma versus a facial nerve schwannoma. MRI shows isointense T1-weighted images, intense enhancement, and hyperintense T2-weighted images.

Hemangiomas in the IAC present similarly to vestibular schwannomas, and a preoperative differentiation may be very difficult. The treatment involves surgical removal when there is significant facial nerve dysfunction. Because hearing is often intact, the middle fossa approach provides good surgical exposure and allows for hearing preservation. The chance of an intact facial nerve after removal of a hemangioma is higher than with a facial nerve schwannoma. Regardless, facial nerve anastomosis or grafting is often still required.

3. Aneurysms

Aneurysms and vascular anomalies of the posterior circulation (anterior and posterior cerebellar artery, carotid artery, vertebral artery, and basilar artery) are rare but produce CPA symptoms by causing compression on neurovascular

structures. Aneurysms are seen as enhancing lesions on CT scanning. In addition to MRI, MRA and angiography allow the characterization of these vascular lesions.

Fayad JN, Keles B, Brackmann DE. Jugular foramen tumors: clinical characteristics and treatment outcomes. *Otol Neurotol.* 2010;31(2):299. [PMID: 19779386] (The most common presenting symptoms of jugular foramen tumors were pulsatile tinnitus and conductive hearing loss.)

Poznanovic SA, Cass SP, Kavanagh BD. Short-term tumor control and acute toxicity after stereotactic radiosurgery for glomus jugulare tumors. *Otolaryngol Head Neck Surg.* 2006;134(3):437. [PMID: 16500441] (A small series suggesting that stereotactic radiosurgery is effective in controlling symptoms and stabilizing tumor growth.)

INTRA-AXIAL NEOPLASMS

Intra-axial tumors of the brainstem (gliomas), cerebellum (medulloblastomas, astrocytomas, and hemangioblastomas), and fourth ventricle (ependymomas and choroid plexus papillomas) may extend into the CPA and present with CPA symptoms. The CPA extension occurs as a result of exophytic growth, growth into the CPA via the foramen of Luschka, and, rarely, extra-axial origin directly in the CPA from an embryonic rest.

To appropriately counsel and treat patients, intra-axial tumors involving the CPA must be differentiated from extra-axial CPA masses. The differentiation is based primarily on imaging characteristics. Imaging characteristics suggestive of an extra-axial neoplasm include bony changes, widening of the subarachnoid cistern, displacement of brain and blood vessels away from the skull or dura, and sharp definition of the tumor margin. Characteristics suggestive of intra-axial tumors include irregular and poorly defined brain tumor margins, widening of the foramen of Luschka, brain edema out of proportion to the CPA component of the tumor, and hydrocephalus. The management of intra-axial lesions includes angiography, conservative surgical resection, and adjunctive therapy.

Bonneville F, Sarrazin JL, Marsot-Dupuch K et al. Unusual lesions of the cerebellopontine angle: a segmental approach. *Radiographics.* 2001;21(2):419. [PMID: 11259705] (Reviews the critical role of CT and MRI findings in establishing the preoperative diagnosis for unusual lesions of the cerebellopontine angle.)

LESIONS EXTENDING FROM THE SKULL BASE

Lesions involving the skull base—specifically, the petrous apex (cholesterol granulomas), the clivus (chordomas), and the petrooccipital fissure (chondrosarcomas)—may grow posteriorly and laterally to involve the CPA. Each of these lesions has characteristic presentations and imaging criteria but at times may present solely with CPA symptoms. The treatment is primarily surgical.

1. Cholesterol Granulomas

The petrous apex of the temporal bone lies anterior and medial to the inner ear and posterior and lateral to the clivus and contains pneumatized air cells in one-third of temporal bones. The obstruction of these air cells leads to inflammation and hemorrhage into the air cells. The phagocytosis of red cells leads to deposition of cholesterol crystals and a foreign body reaction in the petrous apex. This process leads to a cholesterol granuloma that may extend beyond the petrous apex to involve the CPA. Patients may have CPA symptoms in addition to symptoms of headache and sixth cranial nerve (the abducens nerve) dysfunction.

The key differential diagnosis in the petrous apex and CPA of a cholesterol granuloma is an epidermoid cyst. The distinguishing factor is that cholesterol granulomas are hyperintense on T1- and T2-weighted MRI scans, whereas epidermoid cysts are hypointense on T1-weighted images. When symptomatic, the treatment is surgical drainage rather than complete excision. The petrous apex may be accessed via a transmastoid or transcanal approach.

2. Chordomas

Chordomas arise from remnants of the notochord, and skull base chordomas occur at the clivus (sphenooccipital synchondrosis). Patients usually present with headache and diplopia, but posterolateral extension to the CPA may lead to CPA symptoms. CT scans show an isodense mass with bone destruction, intratumor calcifications, and marked enhancement with contrast. MRI shows hypointense T1-weighted images, marked gadolinium enhancement, and hyperintense T2-weighted images. The midline location and bony destruction without sclerosis are characteristics of chordomas. The treatment is complete surgical excision and radiation for subtotal removal or recurrence.

3. Chondrosarcomas

The main differential diagnosis of chordomas is chondrosarcomas. These tumors arise along the sphenooccipital synchondrosis and are laterally located relative to chordomas. Chondrosarcomas may arise from embryonal cartilage rests located at the skull base synchondrosis. Tumor growth laterally causes involvement of the IAC and CPA. Hearing loss may very well be the presenting complaint. The differential diagnosis from chordoma may require immunohistochemistry stains since chondrosarcomas, unlike chordomas, do not stain positively with epithelial tissue markers.

Hoch BL, Nielsen GP, Liebsch NJ et al. Base of skull chordomas in children and adolescents: a clinicopathologic study of 73 cases. *Am J Surg Pathol.* 2006;30(7):811. [PMID: 16819322] (Base of skull chordomas in children and adolescents treated with proton-beam radiation have better survival than chordomas in adults.)

METASTASES

Metastatic disease from the lungs, breasts, skin, prostate, nasopharynx, and kidney are the most common extra-axial malignant neoplasms of the CPA. In contrast to benign lesions of the CPA, malignant lesions of the CPA cause rapid progression of CPA symptoms. On imaging, the lesions are small, isointense to brain on T1- and T2-weighted images, and enhanced with gadolinium. There is high likelihood of parenchymal brain metastases and bilateral CPA lesions. The extent of treatment is based on the extent of the metastatic and primary disease and includes multimodality treatment with surgical biopsy or resection, radiation, and chemotherapy. The other aspect of treatment includes relieving symptoms of hydrocephalus or brainstem compression. The primary extra-axial malignant neoplasms of the CPA are exceedingly rare and include lymphomas, squamous cell carcinomas, malignant acoustic neuromas, and malignant meningiomas.

Eisen MD, Smith PG, Judy KD et al. Cerebrospinal fluid cytology to aid the diagnosis of cerebellopontine angle tumors. *Otol Neurotol*. 2006;27(4):553. [PMID: 16791049] (Patients with cerebellopontine angle tumors and progressive facial palsy should undergo cytological examination of the cerebrospinal fluid before undergoing surgical intervention to evaluate for a malignant process.)

63 Neurofibromatosis Type 2

Anil K. Lalwani, MD

ESSENTIALS OF DIAGNOSIS

- Bilateral vestibular schwannomas
- Posterior subcapsular lenticular opacities
- Spinal tumors
- Skin tumors or lesions

General Considerations

Neurofibromatosis type 2 (NF2) is the official name for the syndrome whose hallmark is bilateral vestibular schwannomas (VS) (Figure 63–1). NF2 replaces a variety of synonyms that have been associated with this entity: central neurofibromatosis, bilateral acoustic neurofibromatosis, cranial neuromatosis, central schwannomatosis, neurofibromatosis universalis, familial bilateral acoustic neuroma syndrome, familial bilateral acoustic neurofibromas, Wishart–Gardner–Eldridge syndrome, neurinomatosis, and neurofibrosarcomatosis. The first known description of the clinical course and postmortem findings of NF2, almost two centuries ago, was of a patient who developed bilateral deafness, had intractable headaches and vomiting, and died at age 21.

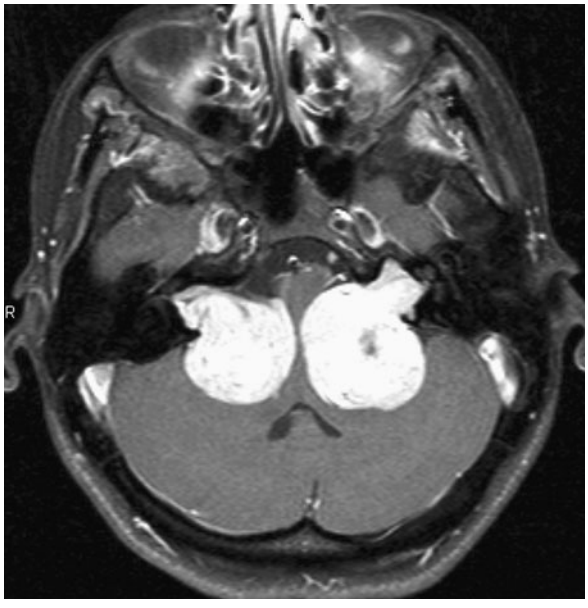
NF2 has long been confused with classic von Recklinghausen syndrome and has only recently been recognized as a distinct diagnostic entity. In 1987, a consensus panel of the National Institutes of Health officially differentiated the clinical manifestations associated with classic von Recklinghausen syndrome or peripheral neurofibromatosis from those of a predominantly intracranial subtype or central neurofibromatosis. The two syndromes were designated NF1 and NF2, respectively. Molecular genetic investigations confirmed this clinical differentiation: the gene responsible for NF1 was located near the proximal long arm of chromosome 17, whereas the gene responsible for NF2 was located on chromosome 22.

NF2 is much rarer than NF1, with an incidence estimated between 1:33,000 and 1:50,000. Inheritance of NF2 is autosomal dominant and gene penetrance is above 95%. NF2 most frequently presents in the second and third decades of life. VS represent approximately 8% of intracranial tumors and account for approximately 80% of the tumors found in the cerebellopontine angle. Most cases of VS occur sporadically, are unilateral, and present in the fifth decade. Patients with NF2 have bilateral VS and represent 2–4% of patients with VS.

The recent identification of the gene responsible for NF2 has significantly advanced our understanding of the molecular pathology, as well as the factors responsible for the clinical heterogeneity among patients with NF2. The *NF2* gene encodes for the protein merlin or schwannomin, has been shown to have homology to the ezrin–radixin–moesin family of genes, which functions as membrane-organizing proteins. These proteins have a basic function indigent to all cells, which are postulated to link cytoskeletal proteins to the plasma membrane. It has been proposed to represent a recessive tumor suppressor, whose deletion or inactivation alters the abundance, localization, and turnover of cell-surface receptors, thus initiating tumorigenesis. Understanding the function of merlin in tumor formation will lead to the development of novel therapies that may eventually alleviate the suffering associated with NF2.

Pathogenesis

NF2 results from the inheritance of a mutation in merlin (or schwannomin) protein on chromosome 22. The *NF2* gene is spread over approximately 100 kb on chromosome 22q12.2 and contains 17 exons. The coding sequence of the messenger RNA is 1785 bp in length and encodes a protein of 595 amino acids. The gene product is similar in sequence to a family of proteins the include moesin, ezrin, radixin, talin, and members of the protein 4.1 superfamily. These proteins are involved in linking cytoskeletal components with the plasma membrane and are located in actin-rich surface



▲ **Figure 63–1.** MRI scan with gadolinium, demonstrating bilateral VS.

projections such as microvilli. The N-terminal region of the merlin protein is thought to interact with components of the plasma membrane and the C-terminal with the cytoskeleton. Although the exact function of the NF2 protein is as yet unknown, the evidence available so far suggests that it is involved in cell–cell or cell–matrix interactions and that it is important for cell movement, cell shape, and communication. The loss of function of the merlin protein therefore could result in a loss of contact inhibition and consequently lead to tumorigenesis. *NF2* gene defects have been detected in other malignant disorders including meningiomas, malignant mesotheliomas, melanomas, and breast carcinomas.

Approximately 50% of affected patients have no family history of NF2. Therefore, these patients represent new germ line mutations in the *NF2* gene. To date, more than 200 mutations of the *NF2* gene have been identified, including single-base substitutions, insertions, and deletions. Genotype–phenotype correlation studies suggest that mutations in the *NF2* gene, which result in protein truncation, are associated with a more severe clinical presentation of NF2 (Wishart type), whereas missense and splice site mutations are associated with a milder (Gardner type) form of the disease. Retinal abnormalities were associated with the more disruptive protein truncation mutations of the *NF2* gene. Although mutations in the *NF2* gene play a dominant role in the biology of VS, it is also possible that other genetic loci contribute to the development of VS.

Rouleau GA, Merel P, Lutchman M et al. Alteration in a new gene encoding a putative membrane-organizing protein causes neurofibromatosis type 2. *Nature*. 1993;364:515. [PMID: 8379998]. (Neurofibromatosis 2 is due to mutations in the merlin gene.)

Trofatter JA, MacCollin MM, Rutter JL et al. A novel moesin-, ezrin-, radixin-like gene is a candidate for the neurofibromatosis 2 tumor suppressor. *Cell*. 1993;72:791. [PMID: 8242753]. (Neurofibromatosis 2 is due to mutations in the merlin gene.)

Clinical Findings

A. Symptoms and Signs

Patients with NF2 usually present in the second and third decades of life, rarely after age 60. Patients' symptoms are attributable to VS, cranial meningiomas, and spinal tumors. The presentation of NF2 can vary considerably, but has been broadly divided into two subtypes based on the severity of disease: Gardner and Wishart NF2 subtypes (Table 63–1). The more severe Wishart type of NF2 is characterized by an early onset of tumors, a more rapid course of disease progression, and the presence of multiple other tumors in addition to bilateral VS. In contrast, the milder Gardner subtype is characterized by a later onset of symptoms, a more benign course of disease, and a tumor burden usually limited to bilateral VS. Many patients with NF2, however, cannot easily be categorized into these subtypes and have many overlapping features.

Hearing impairment is the presenting symptom in nearly 50% of patients. The hearing loss is usually progressive and is associated with poor speech discrimination. Auditory dysfunction is accompanied with tinnitus in 10% of patients. Although the tumors arise from the vestibular nerve, acute vertigo is uncommon since the slow-growth pattern of the tumors allows the central nervous system to compensate. The tumor size at presentation is variable. Generally, younger patients have smaller tumors and older patients harbor larger tumors. VS are larger in patients with the more severe type of NF2 associated with spinal tumors or meningiomas.

Skin tumors are present in nearly two-thirds of patients with NF2. Café-au-lait spots, which are the hallmark of NF1, are also frequently found in patients with NF2. In contrast to patients with NF1, patients with NF2 invariably have fewer than six of these hyperpigmented lesions. Juvenile posterior

Table 63–1. Characteristics of Gardner and Wishart NF2 Subtypes.

Gardner	Wishart
Early onset	Later onset
Smaller tumors	Larger tumors
Few tumors	Multiple tumors
Slower-growing tumors	Faster-growing tumors
Hearing loss related to tumor size	Hearing loss not related to tumor size
Missense mutations	Truncation mutations

subcapsular lenticular opacities are common and have been reported in up to 51% of patients with NF2. A proportion of these opacities are thought to be congenital and can be useful in the early diagnosis of NF2 in related family members. Retinal abnormalities are usually associated with the more disruptive protein truncation mutations of the *NF2* gene. Muscular weakness or wasting is the initial presenting feature in up to 12% of patients with NF2. Distal, symmetric, sensorimotor neuropathy, though uncommon, may complicate NF2. Because of the heightened awareness of familial risks in individuals diagnosed with NF2, nearly 10–15% of patients diagnosed with NF2 are asymptomatic and are diagnosed as a result of screening.

B. Imaging Studies

Magnetic resonance imaging (MRI) with gadolinium-diethylenetriamine pentaacetic acid enhancement is the current gold standard for the radiological investigation of VS and spinal tumors. VS are typically isointense or mildly hypointense to brain on T1-weighted images, but they enhance markedly with gadolinium. As a group, VS enhance far more than any other intracranial tumors, but there is sufficient overlap among tumors of different types that the degree of enhancement alone is not pathognomonic. The enhancement may or may not be homogeneous owing to cystic components in the schwannomas. Intratumoral hemorrhage may cause focal areas of hypointensity or hyperintensity, largely dependent on the age of the hemorrhage. With T2-weighted images, VS have an intensity between that of brain and cerebrospinal fluid.

The resolution of thin-sectioned gadolinium-enhanced MRI scans centered on the internal auditory meatus is such that lesions as small as 1 mm can be picked up. False-negative images are thought to be very rare, but the exact incidence is hard to establish because more sensitive study techniques are currently unavailable. Occasional false-positive gadolinium-enhanced MRI scans have been reported, most commonly as a result of viral mononeuronitis of the seventh or eighth cranial nerves. MRI imaging has an important role in the postoperative evaluation of patients with NF2. It also plays an important role in monitoring tumor growth rates when a nonsurgical approach is undertaken and in screening family members at risk of having NF2. MRI of the cervical spine should be performed on every patient with NF2 to exclude asymptomatic spinal cord lesions, assess therapeutic options in symptomatic patients, and assist in surgical planning.

C. Special Tests

1. Audiological testing—Patients with NF2, as well as their family members, should undergo complete audiological testing to assess the level of hearing. Although audiological evaluation alone is not sufficient to screen patients or family members for NF2, it can play a valuable role in management. Pure-tone audiometry is useful as a means of monitoring the function in patients diagnosed with NF2, in deciding when function is deteriorating significantly, and in determining the better hearing ear.

It is a commonly held belief that sporadic VS have a more predictable audiological profile when compared with that of NF2-associated vestibular tumors. This is incorrect. The auditory phenotype of a large number of patients with NF2 who were enrolled in an ongoing clinical and genetic study at the National Institutes of Health demonstrated that patients with NF2 had a more predictable audiological profile for a given size tumor than had been previously described with sporadic VS. However, this association between tumor size and auditory findings did not hold true for the subgroup of patients with spinal tumors, meningiomas, or both.

Auditory brainstem response testing has limited usefulness in reliably diagnosing VS in NF2. Interaural latency measurements are not useful in this population because of their bilateral tumors. Auditory brainstem response also is not reliable in detecting small tumors. The bilateral presentation of VS in NF2 means that there is potential for symmetric abnormalities in audiological investigations; therefore, audiometry alone cannot be used to exclude NF2. Pure-tone audiometry, speech audiometry, acoustic reflexes, and brainstem-evoked response audiometry are poor screening modalities for patients with NF2.

2. Genetic testing—Genetic testing for the detection of mutations in the *NF2* gene is available at some medical centers and private genetic testing centers. However, it is expensive and its exact role in the management of a patient with NF2 and the identification of family members at risk has not been clearly delineated.

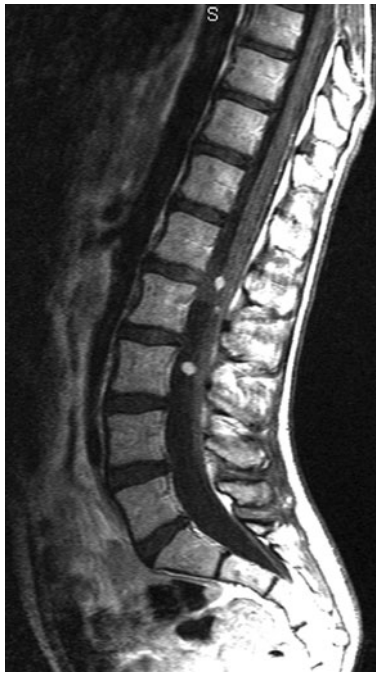
Lalwani AK, Abaza MM, Makariow EV et al. Audiologic presentation of vestibular schwannomas in neurofibromatosis type 2. *Am J Otol*. 1998;19:352. [PMID: 9596188]. (This paper describes the relationship between the audiological findings, the clinical severity of neurofibromatosis 2, and tumor size.)

Differential Diagnosis

The criteria for confirmed or definite NF2 are listed in Table 63–2. Some patients who do not meet the diagnostic

Table 63–2. Diagnostic Criteria for NF2.

Bilateral VS or Family History of NF2 and
1. Unilateral vestibular schwannoma or
2. Any two of the following:
Meningioma
Glioma
Neurofibroma
Schwannoma
Posterior subcapsular lenticular opacity



▲ **Figure 63–2.** MRI scan with gadolinium demonstrating multiple spinal tumors.

criteria for NF2 should still be considered at risk for this disorder. These include people with a family history of NF2, those younger than 30 y of age with unilateral VS or meningioma, and those with multiple spinal tumors (Figure 63–2). In addition, it would be prudent to evaluate the following people for NF2: (1) patients with a unilateral VS plus any one of the following: meningioma, glioma, schwannoma, or juvenile posterior subcapsular lenticular opacity; (2) patients with two or more meningiomas and unilateral VS; and (3) patients with two or more meningiomas and one or more of the following: glioma, schwannoma, or a juvenile posterior subcapsular lenticular opacity.

NF2 should be differentiated from NF1. The diagnostic criteria for NF1 are met by an individual if two or more of the following are found: (1) six or more café-au-lait macules >5 mm in greatest diameter in prepubertal individuals, and café-au-lait macules >15 mm in diameter in postpubertal individuals, (2) two or more neurofibromas of any type or one plexiform neurofibroma, (3) freckling in the axillary or inguinal regions, (4) optic glioma, (5) two or more Lisch nodules (iris hamartomas), (6) a distinct osseous lesion (eg, sphenoid dysplasia or thinning of the long bone cortex) with or without pseudoarthrosis, or (7) a first-degree relative with NF1 by the above criteria.

The differential diagnosis of cerebellopontine angle lesions includes meningiomas, epidermoid tumors, lipomas, and arachnoid cysts. In cases of unilateral VS, consideration of NF2 should clearly arise when unilateral VS is encountered in a patient under the age of 30. NF2 is implicated in half of all cases of VS presenting before the age of 20. In these young patients with unilateral VS, it behooves the clinician to obtain ophthalmological consultation to look for posterior subcapsular cataracts associated with NF2. A spinal MRI scan should also be performed to detect spinal tumors.

Treatment

The management of VS in patients with NF2 is a clinically challenging problem in contemporary neurotology. The bilaterality of vestibular tumors makes the common complications associated with surgical intervention more significant. Hearing loss following surgical removal in a patient with NF2 with a large contralateral VS or in what may be an only-hearing ear represents a significant morbidity. In patients with NF2 who are followed up medically, the complications associated with natural growth, including eventual hearing loss, cranial nerve palsies, and brainstem compression, are also important management considerations. The population of patients with NF2 often presents a difficult therapeutic dilemma because neither operative nor nonoperative management offers an acceptable risk–benefit ratio. Characteristics identifying the more aggressive or faster-growing tumors would be useful in planning treatment such as choosing between expectant observation and the surgical extirpation of disease. Recently, great deal of excitement has been generated by clinical trials with bevacizumab, an antibody against vascular endothelial growth factor. This treatment rationale is based on the presence of VEGF and its receptors in VS. Early results are promising and have demonstrated reduction in tumor volume and preservation of hearing.

Plotkin SR, Stemmer-Rachamimov AO, Barker FG 2nd et al. Hearing improvement after bevacizumab in patients with neurofibromatosis type 2. *N Engl J Med.* 2009;361(4):358. [PMID: 19587327] (VEGF blockade with bevacizumab showed reduction in volume of most growing VS and improved hearing in some patients.)

A. Surgical Management

The decisions concerning the management of patients with NF2 are significantly different from those of sporadic unilateral VS, and are guided by the fact that patients with NF2 eventually develop bilateral profound deafness. It is advisable for these patients to learn lip reading at an early stage after the initial diagnosis. Patients with NF2 have a lifelong tendency to form intracranial tumors and are never cured of their underlying disease. The management priority should therefore be to maintain function even at the expense of incomplete tumor removal, if that is required. Once an ear has become deaf, total tumor resection should be performed.

However, when both ears hear well, some divergence in opinion exists. Some surgeons advocate a resection of the larger tumor via a hearing-sparing approach, whereas others favor removal of the smaller tumor with the rationale that this provides a better chance of hearing preservation. The tumor associated with brainstem compression or central nervous system dysfunction should always be resected first, regardless of the hearing status. If the initial operation is successful in preserving hearing, the surgical excision of the second tumor could be undertaken. If the hearing is not preserved, the second tumor is followed expectantly until the hearing is lost, brainstem encroachment requires removal, or the tumor appears to be enlarging rapidly. Incomplete removal in an only-hearing ear has been recommended to preserve hearing. Unfortunately, even incomplete removal may impair or eliminate residual hearing.

The surgical treatment of spinal tumors, meningiomas, as well as VS requires a team approach with a neurotologist, a neurosurgeon, a neuroanesthesiologist, and a neurophysiologist for cranial nerve monitoring. Spinal tumors and meningiomas are generally observed; signs of growth, neurological compromise, or clinical deterioration usually lead to surgical intervention. Occasionally, a meningioma can be resected at the same time as another intracranial tumor, such as a VS, is being addressed.

B. Stereotactic Radiation Therapy

Stereotactic radiosurgery is a method of using ionizing radiation to destroy a precisely defined area of intracranial tissue. The technique combines a stereotactic delivery device with ionizing radiation. The radiation dose in stereotactic radiosurgery is delivered by several precisely collimated beams of ionizing radiation. The radiation dose gradient is extremely sharp at the target tissue, resulting in a sharply circumscribed area of high-dose radiation. As a result, the delivery of radiation to adjacent tissues and, hence, associated adjacent tissue damage is minimized. Stereotactic radiosurgery as a treatment option is usually not recommended in patients with NF2.

C. Hearing Restoration

The preservation of hearing, if technically possible, is far preferable to hearing restoration. Because of the short-life expectancy of patients with NF2, partial tumor removal in an attempt to preserve hearing is more acceptable as a strategy in these patients. An increased awareness of NF2 and an earlier presentation and diagnosis mean that the likelihood that hearing will be preserved is increased. However, sooner or later, in all cases, hearing is lost owing to either tumor progression or the surgical intervention designed to remove the tumor.

1. Cochlear implants—A cochlear implant may be an option in patients in whom the cochlear nerve has been preserved. Of concern, however, is the impact of a cochlear implant on the ability of the patient to obtain MRI scans for diagnostic or follow-up purposes. This problem may be overcome by either removing the magnet from the receiver or developing newer-generation implants without magnets.

2. Auditory brainstem implant—An auditory brainstem implant is a method of restoring hearing when hearing loss is due to the destruction of the auditory nerve. It is an alternate treatment option for the profoundly deaf because cochlear implants cannot be used in this patient population. The Nucleus 22-channel auditory brainstem implant design was first presented at the Second International Symposium on Cochlear Implants in Iowa in 1989. This is a multichannel brainstem prosthesis with transcutaneous signal transmission. The original design was slightly modified in 1993 and is now approved by the Food and Drug Administration. The implantation of an auditory brainstem implant can be carried out at the same time as tumor removal. During surgery, the visualization of the cochlear nucleus complex is necessary, with a recommendation for intraoperative monitoring of the facial and glossopharyngeal nerves. The measurement of electrically evoked auditory brainstem potentials is important in determining the optimum placement of the auditory brainstem implant on the cochlear nucleus complex.

Colletti V, Shannon RV. Open set speech perception with auditory brainstem implant? *Laryngoscope*. 2005;115(11):1974. [PMID: 16419608] (Tumor resection may negatively impact speech recognition outcome in patients with neurofibromatosis 2.)

Prognosis

The severity of the clinical phenotype determines the prognosis for patients with NF2. In turn, the severity of the clinical phenotype is determined by the underlying genotype or the type of genetic mutation. Patients with nonsense and frameshift mutations in the *NF2* gene have a clinically more severe disease with an earlier onset than those with missense mutations. The onset of hearing loss was earlier (20.2 vs 28.4 y) and more prevalent (85% vs 81.3%) in patients with the more significant mutations. Therefore, the type of mutation of the *NF2* gene is likely to have a large effect on the severity of the disease and the aggressiveness of the VS. Furthermore, because some sporadic VS are also associated with mutations in the *NF2* gene, the variety of clinical presentations in these tumors could be related to the location and type of the mutation.

Ruttledge MH, Andermann AA, Phelan CM et al. Type of mutation in the neurofibromatosis type 2 gene (NF2) frequently determines severity of disease. *Am J Hum Genet*. 1996;59:331. [PMID: 8755919]. (Missense mutations in the *NF2* gene are associated with a less severe clinical phenotype than nonsense mutations.)

Osseous Dysplasias of the Temporal Bone

64

Betty S. Tsai, MD & Steven W. Cheung, MD

Patients with osseous dysplasias of the temporal bone, notably, fibrous dysplasia, Paget's disease, osteopetroses, and osteogenesis imperfecta, present with hearing loss and external auditory canal obstruction that result in infection, lower cranial neuropathies, and temporal bone deformation. Differentiation among these entities is greatly helped by using coronal and axial high-resolution computed tomography (CT) imaging of the temporal bone and skull base. Outer, middle, and inner ear structures are detailed and foraminal stenoses are identified. Bone mineralization density appearance is the single most important imaging feature to secure a diagnosis.

FIBROUS DYSPLASIA

ESSENTIALS OF DIAGNOSIS

- External auditory canal stenosis
- Progressive conductive hearing loss
- Enlargement of the temporal bone
- Abnormal skin pigmentation
- Radiographic "ground glass" appearance.

General Considerations

Fibrous dysplasia is perhaps the most common benign fibro-osseous disorder of the temporal bone. This poorly understood entity has three major classifications: (1) monostotic, (2) polyostotic, and (3) the McCune–Albright syndrome.

The **monostotic variant** is the most common variety, accounting for approximately 70% of all cases, and is seen late in childhood. The disease may enter a dormant phase in puberty. **Polyostotic disease** manifests as multiple bony lesions and often has long bone involvement. The active phase of the disease extends into the third and fourth decades. The **McCune–Albright syndrome** affects mostly females and is characterized by polyostotic fibrous dysplasia with cutaneous hyperpigmentation, and endocrinopathy, often manifested as precocious puberty. Within the skull base, the temporal bone is involved approximately 24% of the time.

Pathogenesis

The radiographic appearance of fibrous dysplasia reflects the erosion of cortical bone by fibro-osseous tissue in the medullary cavity. The cortical bone is thinned by medullary fibrous tissue that is vascular, compressible, and weak. Histologically, there are interspersed regions of predominantly soft tissue or bone. Soft areas are abundant in collagen, and occasionally contain cysts. Areas of intermediate consistency are populated by fibroblasts.

Clinical Findings

A. Symptoms and Signs

Common clinical manifestations of fibrous dysplasia of the temporal bone include external auditory canal stenosis and/or ossicular chain erosion, progressive hearing loss, most commonly conductive (~80%), and increased temporal bone size presenting as painless postauricular swelling. The dysplastic process may entrap skin within the external auditory canal, resulting in cholesteatoma formation. Uncommonly, facial nerve paralysis may ensue from infected or erosive cholesteatoma.

B. Imaging Studies

The CT appearance of fibrous dysplasia may have several radiographic patterns: pagetoid, sclerotic, and cystic. **Pagetoid (>50%)** is characterized by a mixture of dense and radiolucent areas of fibrosis with bone expansion. **Sclerotic (~25%)** is homogeneously dense with bone expansion.

Cystic (~**20%**) has either spheric or ovale lucent regions with dense boundaries.

Treatment & Prognosis

The treatment for fibrous dysplasia is aimed at maintaining patency of the external auditory canal and cranial nerve conduits. For ear canal stenosis, wide meatoplasty is performed to restore an open channel and exteriorize entrapped skin. Although sarcomatous degeneration is rare for those with fibrous dysplasia, the estimated incidences are 0.4% in monostotic and polyostotic disease, and 4% in the McCune–Albright syndrome. Clinical features that suggest sarcomatous degeneration include pain, swelling, and radiographic evidence of bony destruction. The prognosis for malignant transformation is poor.

OSTEOPETROSES

ESSENTIALS OF DIAGNOSIS

- Conductive or sensorineural hearing loss
- Cranial neuropathies
- Facial dysfunction.

General Considerations

The osteopetroses are a group of inheritable metabolic bone disorders. They result in diffuse, dense sclerosis, and faulty bony remodeling. There are two forms: congenital and tarda. The **congenital** or **lethal form** is autosomal recessive, and manifests during infancy with pancytopenia secondary to obliteration of marrow spaces. Death due to hemorrhage, anemia, or overwhelming infection is common in infancy or childhood. The **tarda** or **adult form** is also known as Albers–Schönberg disease and is most commonly autosomal dominant. The adult form is benign and has a variable clinical course. Symptomatic patients present with problems that relate to bony overgrowth and foraminal stenosis. Hearing loss may be conductive or sensorineural owing to ossicular involvement or cochlear nerve impingement. The facial nerve function may be weak and spastic as a result of internal auditory canal narrowing. Other cranial nerve neuropathies may result from progressive stenosis of neural foramina.

Pathogenesis

The osteopetroses result from osteoclast dysfunction. Remodeled bone is faulty. Histologically, regions of endochondral ossification contain abnormal calcified cartilage. The osteopetrotic bone is immature, thick, dense, and brittle. This appearance gives rise to the names *chalk* or *marble bone disease.*

Clinical Findings

A. Symptoms and Signs

In osteopetrosis congenita, infants present with severe anemia and early visual problems secondary to optic nerve atrophy. Hearing loss often develops by childhood and tends to be conductive as a result of ossicular infiltration by osteopetrotic bone and exostoses. Temporal bone findings include external auditory canal stenosis, poor mastoid pneumatization, ossicular chain fixation, Eustachian tube narrowing, and stenosis of the petrous carotid and internal auditory canals. In adult-type osteopetrosis, patients suffer multiple cranial nerve palsies involving cranial nerves I, II, III, V, and VII. Facial nerve paralysis can be recurrent and results from narrowing of the internal auditory, and labyrinthine and vertical fallopian canals. Conductive or mixed hearing loss is also due to ossicular chain involvement. Sensorineural hearing loss may arise from otic capsule and internal auditory canal infiltration by osteopetrotic bone.

B. Imaging Studies

Temporal bone CT findings in **osteopetrosis congenita** are notable for a small middle ear cavity with normal ossicles, obliteration of the mastoid antrum, and normal-appearing otic capsule.

Temporal bone CT findings in **osteopetrosis tarda** are remarkable for a diffusely chalky, thickened cranial vault. Stenosis of neural foramina, encroachment of pneumatic spaces, infiltration of ossicles, and involvement of the otic capsule are other findings.

Treatment & Prognosis

There is no effective medical therapy for the osteopetroses, so limited surgical intervention may be indicated to decompress cranial canals and foramina. Of note, conductive hearing loss resulting from osteopetroses may be caused by either direct bony ossicular infiltration or epitympanic fixation. Treatment of conductive hearing loss by ossiculoplasty may be technically difficult because of dense middle ear bony disease and footplate abnormalities. Nonsurgical therapy with hearing aid rehabilitation should be considered before surgical intervention. It may be necessary to perform surgery to enlarge the external auditory canal to accommodate a hearing aid. Surgical decompression of the acoustic nerve for stabilization of sensorineural hearing loss is unproven.

Facial nerve dysfunction generally presents with acute and recurrent episodes of facial palsy. Presurgical planning with a fine-resolution temporal bone CT scan can delineate stenotic sites for decompression.

PAGET'S DISEASE

ESSENTIALS OF DIAGNOSIS

- External auditory canal stenosis.
- Mixed hearing loss.
- Facial nerve dysfunction.
- Radiographic "cotton wool" appearing lesions.

General Considerations

Paget's disease, or **osteitis deformans,** is a disorder of excessive bone remodeling, primarily of the axial skeleton. Most cases are sporadic, but up to 15% are inherited in an autosomal pattern. The disease tends to occur after the fifth decade. The diagnosis is often made during evaluation for skeletal pain or incidentally on routine radiography.

Pathogenesis

The development of Paget's disease is believed to be due to a combination of genetic and environmental factors. Findings of inclusion bodies in osteoclasts resembling paromyxoviruses have suggested a viral etiology although recent evidence has been conflicting. Inherited forms of Paget's disease have been associated with mutations on chromosome 5 as well as chromosome 10. The histologic pattern in Paget's disease is one of alternating waves of osteoclastic and osteoblastic activity. Bone remodeling activity results in haphazard bony resorption followed by deposition of structurally weakened, demineralized cancellous bone. The early phase of the disease is dominated by bone resorption, which is seen as lytic lesions. The marrow space subsequently fills with fibrovascular tissue, which later undergoes sclerosis. Multifocal areas of lysis and sclerosis within the temporal bone and cranial base are seen.

Temporal bone findings in Paget's disease are notable for a tortuous external auditory canal, constriction of the middle ear cleft, bony changes of the ossicular chain, and demineralization of the otic capsule. Narrowing of the internal auditory canal can also cause acoustic-vestibular-facial dysfunction.

Clinical Findings

A. Symptoms and Signs

Patients with Paget's disease of the temporal bone present with tinnitus, vertigo, and hearing impairment. The pattern of hearing loss is mixed. The conductive component is most pronounced in the lower frequencies, whereas the sensorineural component most commonly involves the higher frequencies. Other cranial neuropathies due to foraminal stenosis are hemifacial spasm, trigeminal neuralgia, and optic atrophy.

B. Imaging Studies

Plain film x-rays of the skull may be diagnostic in Paget's disease. The "cotton wool" appearance (coexistence of osteolysis and sclerosis) is almost pathognomonic. The only other diagnostic consideration is the pagetoid variant of fibrous dysplasia. In approximately 10% of cases, Paget's disease may present as a sharply delineated osteolytic skull lesion, *osteoporosis circumscripta cranii.* The CT appearance of the temporal bone reflects varying degrees of bone remodeling activity. There are two radiographic patterns: mosaic and translucent. In the **mosaic pattern,** diffuse areas of radiolucency adjacent to foci of irregular sclerosis are seen. In the **translucent variant,** the appearance is homogeneous, "washed out," and blurred. The otic capsule may lack its usual sharply demarcated boundary and may be accompanied by an overall diffuse demineralization of the petrous pyramid. The internal and external auditory canals and middle ear cleft may appear stenotic.

Treatment

A. Nonsurgical Measures

Treatment of symptomatic Paget's disease (bone pain, neuropathies, and cardiovascular stress) with calcitonin and bisphosphonates has been shown to induce biochemical and clinical improvement. Decremental levels of alkaline phosphatase and urinary hydroxyproline are seen in association with clinical improvement. Radiographic evaluation may document the arrest of bony lesions.

B. Surgical Measures

Surgical therapy for hearing loss and cranial neuropathy in Paget's disease should be considered only as the last resort. Surgery for conductive hearing loss in Paget's disease has not been satisfactory. Modern hearing devices are excellent alternatives to middle ear exploration and should be encouraged. Persistent symptomatic internal auditory canal stenosis with sensorineural hearing loss and facial nerve dysfunction following medical therapy may be an indication for surgical decompression.

OSTEOGENESIS IMPERFECTA

ESSENTIALS OF DIAGNOSIS

- Fragile bones
- Blue sclera
- Conductive and sensorineural hearing loss.

General Considerations

Osteogenesis imperfecta carries the hallmark of fragile bones susceptible to easy fracture. Historically, osteogenesis imperfecta was classified as two major variants: congenita and tarda, with the congenital variant being lethal. More recently, the disease has been classified into eight different types. The majority of the cases (85–90%) are associated with autosomal dominant mutations in type I collagen and have been classified as types I–IV with type I being the mildest and most common form. Patients with osteogenesis imperfecta types V and VI present clinically similar to type IV with mild bone disease and normal appearing sclera; however, they do not have mutations in type I collagen. Types VII and VIII are inherited in an autosomal recessive manner, and tend to present in a similar manner to types II and III, which are perinatally lethal and severe phenotypes, respectively. These patients demonstrate the classic triad of blue sclera, multiple fractures in childhood, and early hearing loss.

Pathogenesis

The histopathology of osteogenesis imperfecta is marked by the deposition of osteopenic immature bony tissue that is weak and fragile. There is an increase in osteocytes in both woven and lamellar bone, and a relative reduction of matrix substance. The bone turnover rate is high. Conflicting theories have been proposed to explain the pathogenesis of this disease. Some advocate the hypothesis of osteoblast dysfunction that is responsible for immature bone deposition; others advocate the hypothesis of increased osteoclast activity. Still others implicate abnormal cell signaling due to defects of the extracellular matrix. Clinically, the regulatory defect in bone turnover results in pathologic fractures and hearing loss.

Clinical Findings

A. Symptoms and Signs

The clinical presentation is highly variable from a severe perinatal lethal form to extremely mild forms that are often confused with early onset osteoporosis. Osteogenesis imperfecta is a systemic disease and thus affects multiple organ systems, producing a broad array of clinical manifestations. Some of these conditions are dentinogenesis imperfecta, blue sclerae, loose joints, mitral valve prolapse, easy bruising, and growth deficiency. The hearing loss pattern may be conductive, sensorineural, or mixed. The onset of hearing loss is between the second and third decades. Hearing loss in osteogenesis imperfecta can be audiometrically indistinguishable from otosclerosis. However, osteogenesis imperfecta has an earlier onset of hearing impairment and a higher incidence of sensorineural loss compared with otosclerosis. Footplate fixation in osteogenesis imperfecta can arise either from an otospongiosis-like focus, as seen in early otosclerosis, or diffuse changes within the otic capsule.

Several operative findings during stapedectomy differentiate osteogenesis imperfecta from otosclerosis. The canal wall skin is thin and fragile, and the scutum is brittle. Crural fractures are not uncommon, and there is excessive bleeding. The sensorineural component of the hearing loss in osteogenesis imperfecta is poorly understood but may involve microfractures of the otic capsule and encroachment of the bony labyrinth by dysplastic bone. Facial nerve dysfunction is a rare complication of osteogenesis imperfecta.

B. Imaging Studies

Temporal bone CT findings in osteogenesis imperfecta have substantial overlap with those found in otosclerosis. Both entities may have fenestral and retrofenestral findings. In fenestral disease, CT scanning shows an excrescent mass at the level of the promontory. In retrofenestral disease, the cochlea may be demineralized, with or without sclerosis. The "double ring" sign refers to the hypodense band that spirals along the cochlea. Extensive endochondral demineralization of the otic capsule is evident in severe cochlear otosclerosis. However, diffuse resorptive changes in vast areas of the otic capsule are more often seen in osteogenesis imperfecta. The findings of extensive facial nerve canal involvement and severe proliferative otic capsule dysplasia differentiate osteogenesis imperfecta tarda from cochlear otosclerosis.

Treatment & Prognosis

The primary otologic symptom in osteogenesis imperfecta is conductive hearing loss that occurs between the second and third decades. The benefit of medical therapy with calcitonin, sodium fluoride, and vitamin D is unclear. Surgical intervention with stapedectomy to improve conductive hearing loss in osteogenesis imperfecta tarda is technically more demanding than in otosclerosis. There is a greater tendency for bleeding and difficult footplate mobilization. Despite these challenges, stapes surgery in osteogenesis imperfecta has favorable short- and long-term results. Alternately, patients may choose to improve hearing with an amplification device. In patients with severe to profound bilateral sensorineural hearing loss, cochlear implantation is a viable option, although the hypervascular spongiotic bony changes may pose additional challenges.

In the rare event of facial nerve dysfunction, CT imaging is useful to evaluate the fallopian canal. Sites obstructed by dysplastic bone can be delineated for surgical decompression.

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We would like to acknowledge Karsten Munck, MD for his contribution to this chapter in the previous editions of CDT.

65 Neoplasms of the Temporal Bone & Skull Base

John S. Oghalai, MD

The skull base includes the frontal bone, the sphenoid bone, the temporal bone, and the occipital bone. Tumors of the temporal bone and skull base tend to arise in one of three locations: (1) the mastoid or middle ear, (2) the jugular foramen, or (3) the petroclival junction or petrous apex. Tumors of the cerebellopontine angle and Meckel cave are not considered in this chapter (see Chapter 61, Nonacoustic Lesions of the Cerebellopontine Angle). Tumors arising within the skull base are rare and usually cause few symptoms until they grow to a size in which they begin to affect cranial nerves. Table 65–1 lists the various skull base neoplasms and their imaging characteristics.

The majority of skull base tumors are benign and can typically be successfully managed by an otolaryngologist specialized in neurotology and skull base surgery. Surgical approaches to these three areas are numerous, and the nomenclature is confusing. To remove a lesion of the middle ear or mastoid, a mastoidectomy through a postauricular incision or a middle ear exploration through the ear canal is usually adequate. Tumors of the jugular foramen require a postauricular incision that extends down into the upper neck. A mastoidectomy is performed along with skeletonization of the facial nerve, the sigmoid sinus, and the jugular bulb. One classic approach to the jugular foramen is the Fisch Type A approach (Figure 65–1). This involves dissecting the facial nerve out of its bony canal and rerouting it anteriorly. Permanent facial paresis or synkinesis can occur. Closure of the ear canal is also part of the Fisch Type A approach, which leaves the patient with a maximal conductive hearing loss. However, newer approaches are available that may permit adequate exposure of the jugular foramen without requiring facial nerve rerouting and closure of the ear canal. Finally, tumors of the petroclival junction and petrous apex require either a middle fossatranspetrous approach with removal of the petrous apex bone (Kawase triangle, Figure 65–2) or a combined subtemporal-retrolabyrinthine approach (Figure 65–3). The Fisch Type B and C approaches can also be used to access the petroclival junction and can be extended all the way to the nasopharynx, orbital apex, and cavernous sinus. Surgical strategies are chosen by the skull base surgeon based on approaching the tumor with enough exposure to perform a complete and safe resection while minimizing neurologic morbidity.

It is also important to consider the roles of conservative observation, particularly in patients who are elderly and have tumors that are typically slow growing. Stereotactic radiation must also be considered as a viable treatment option to slow or stop tumor growth. Modern techniques of delivering radiation appear to have excellent tumor control rates and side effect profiles, although the long-term consequences have yet to be fully elucidated.

PARAGANGLIOMAS

ESSENTIALS OF DIAGNOSIS

- Pulsatile tinnitus
- Reddish-blue middle ear mass.

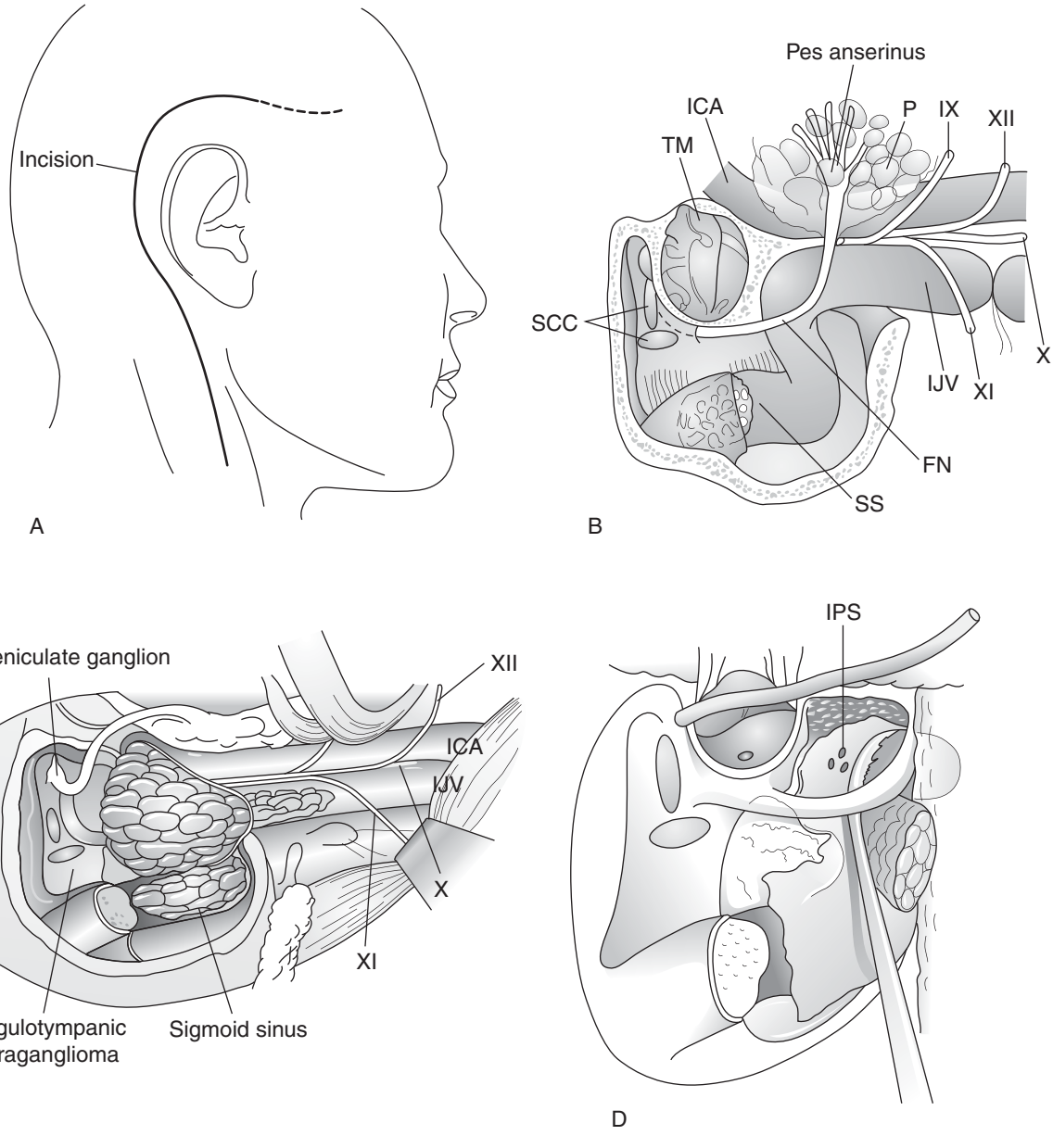
General Considerations

Paragangliomas (or glomus tumors) are tumors of paraganglionic tissue, which originally derive from the migration of neural crest cells during fetal development. These tissue rests are distributed predominantly throughout the middle ear, the jugular foramen, the vagus nerve, and the carotid body, but are also found in the upper mediastinum and the retroperitoneum. These cell clusters are innervated by the parasympathetic nervous system and function as chemoreceptors for circulatory regulation.

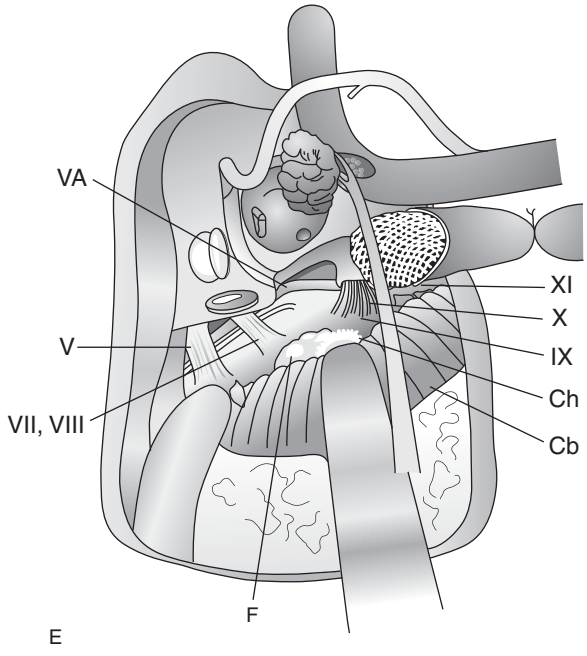
The most common paraganglioma is the **carotid body tumor**. A well-known, but rare, paraganglioma is the **pheochromocytoma**. Within the temporal bone, there are two main types of paraganglioma: **glomus tympanicum**

Table 65–1. Radiographic Appearance of Skull Base Neoplasms.

Neoplasm	Most Common Site of Origin in Skull Base	CT	T1-Weighted MRI	T2-Weighted MRI	Contrast Enhancement
Paraganglioma	Jugular foramen and middle ear	Bone destruction	Intermediate, with flow voids	High, with flow voids	Strong
Facial nerve schwannoma	Geniculate ganglion	Smooth remodeling and dilation of the surrounding bone of the facial canal	Intermediate	Intermediate	Strong; follows the course of the facial nerve
Geniculate hemangioma	Geniculate ganglion	Erosion of surrounding bone with bony spicules within tumor	Intermediate	High	Strong
Leukemia, lymphoma, and plasmacytoma	Petrous apex	Lytic lesion	Low	Intermediate	Moderate
Langerhans cell histiocytosis	Mastoid	Irregular bone destruction; may have other skull lesions as well	Intermediate	High	Moderate
Chondrosarcoma	Petroclival junction	Bone destruction, but can produce calcium matrix in 50% of tumors	Intermediate	High	Moderate or mixed
Chordoma	Clivus	Bone destruction, but can have bone remnants within it	Intermediate, with some areas of low signal representing mucus	High	Moderate or mixed
Meningioma	Posterior face of temporal bone	Surrounding hyperostosis and intratumoral calcification	Intermediate	Intermediate	Strong; characteristic dural tail
Intralabyrinthine schwannoma	Within the inner ear	Mass within labyrinth; no bone erosion	Low	Intermediate	Strong
Schwannoma of jugular foramen	Jugular foramen and middle ear	Soft tissue mass posterior to jugular bulb; mild, smooth bone erosion	Low	Intermediate	Strong
Rhabdomyosarcoma	Anywhere, predominant tumor of children	Bone destruction	Intermediate	High	Strong
Osteosarcoma	Anywhere	Either lytic osteoblastic or osteolytic; may have concentric rings of calcium	Intermediate	High	Strong
Fibrosarcoma	Anywhere	Bone destruction	Intermediate	High	Strong
Adenoma	Middle ear	Middle ear soft tissue mass; no bone erosion	Low	Intermediate	Strong
Endolymphatic sac tumor	Posterior face of temporal bone	Bone destruction and erosion of otic capsule	Mixed, due to localized areas of mucus	Mixed	Strong
Carcinoma	Middle ear	Bone destruction	Intermediate	Intermediate	Strong
Metastatic disease	Petrous apex and internal auditory canal (IAC)	Lytic lesion	Intermediate	High	Strong

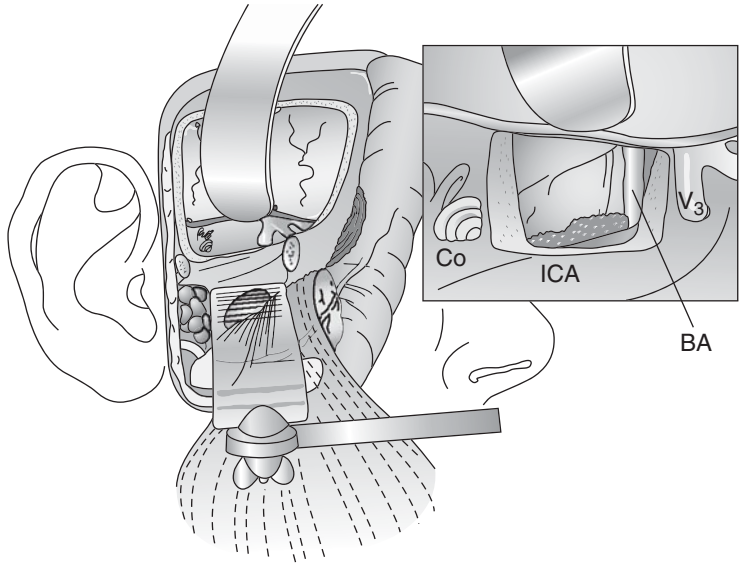


▲ **Figure 65–1.** Surgical resection of a large jugulotympanic paraganglioma (Fisch Type A approach). **(A)** The incision runs from above the ear down into the upper neck. **(B)** The external auditory canal is oversewn and the pinna reflected anteriorly, exposing the facial nerve, middle ear, parotid gland, internal carotid artery, and internal jugular vein. **(C)** The facial nerve is rerouted out of its bony canal and transposed anteriorly. **(D)** The sigmoid sinus is occluded superiorly and the internal jugular vein is ligated inferiorly; the tumor is then removed from the jugular foramen. Although the classic Fisch Type A approach involves closure of the external auditory canal and rerouting of the facial nerve, these procedures are not often required to resect even large jugular foramen tumors as shown in this example. ICA, internal carotid artery; TM, tympanic membrane; SCC, semicircular canals; P, parotid gland; SS, sigmoid sinus; FN, facial nerve; IJV, internal jugular vein. Roman numerals indicate cranial nerves; IPS, inferior petrosal sinus. *(Continued)*

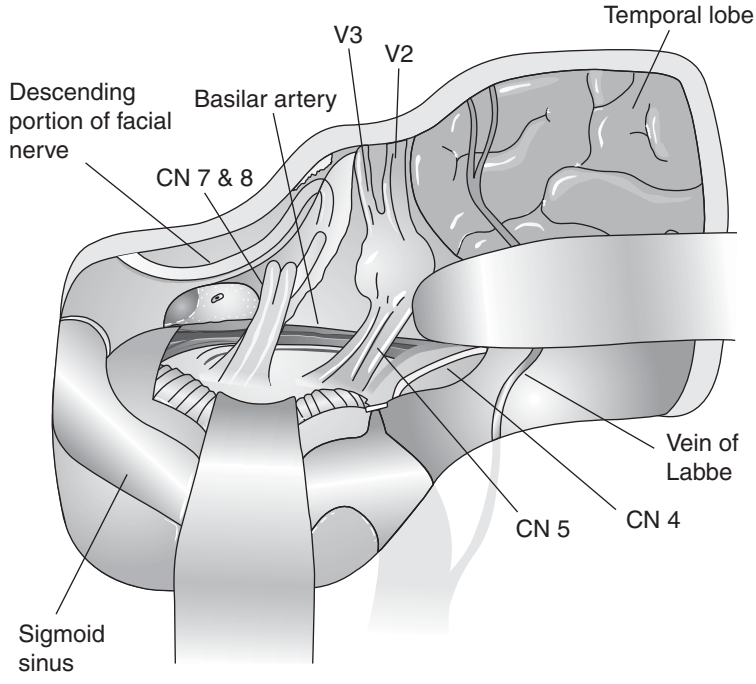


▲ **Figure 65–1.** *(Continued)* **(E)** If necessary, any remaining tumor is removed off from the internal carotid artery or cerebellopontine angle. Fisch Type B and C approaches (not shown) are not used to approach the jugular foramen, but instead are used to approach tumors of the infratemporal fossa, petroclival junction, and nasopharynx. VA, vertical artery; CH, choroid plexus; CB, cerebellum.

and **glomus jugulare**. Glomus tympanicum tumors arise within the middle ear, from paraganglionic cell rests associated with branches of cranial nerves IX and X (the glossopharyngeal and vagus nerves, respectively), which run over the promontory. Together these nerves are called the tympanic plexus, which consists of the Jacobsen nerve (a branch of CN IX) and the Arnold nerve (a branch of CN X). Glomus jugulare tumors arise within the jugular foramen from cell rests associated with cranial nerves IX, X, and XI. **Glomus vagale** tumors are just below the temporal bone in the upper neck and may invade the skull base as well.



▲ **Figure 65–2.** Middle fossa-transpetrous approach for resection of petrous apex tumors. These tumors can grow to involve the petroclival junction, around foramen lacerum, and extend posteriorly into the ventral brainstem and superiorly into the temporal lobe. They can be approached by a middle fossa craniotomy with drill-out of the anterior petrous apex (Kawase triangle). Good visualization of the petroclival junction, as well as the anterior brainstem, is obtained by this approach. Co, cochlea; BA, basilar artery; ICA, internal carotid artery.



▲ **Figure 65–3.** Combined subtemporal-retrolabyrinthine approach for resection of tumors of the petroclival junction. This involves opening both the posterior and middle cranial fossa dura, with division of the tentorium. Excellent exposure of the entire brainstem from the posterior circle of Willis to the jugular foramen is obtained.

Pathogenesis

Paragangliomas are most common in white populations. They typically occur in the fourth or fifth decades of life, although they can be identified at any age. Paragangliomas are slow-growing tumors, and metastases are extremely rare. They grow by spreading along the paths of least resistance. Within the skull base, they tend to extend through fissures and foramina, vascular channels, and air-cell tract lines. Paragangliomas also demonstrate locally aggressive behavior with bone destruction and the invasion of soft tissue. They can extend from the temporal bone down into the upper neck.

Approximately 1% of paragangliomas display functionally significant catecholamine secretion similar to a pheochromocytoma. Pathologically, the chief cell is the cell of origin of the tumor and contains acetylcholine, catecholamines, and serotonin. Classic findings are clusters of chief cells, termed *Zellballen*, with a rich vascular plexus throughout the entire tumor. Indeed, these tumors are highly vascular and may bleed substantially during surgical excision.

The overall incidence of multiple lesions is about 10% in sporadic tumors. There is a 1–2% incidence of bilateral glomus jugulare tumors and a 7% incidence of an associated carotid body tumor. Paragangliomas can be based on germline mutations and can be hereditary. Mutations in the mitochondrial complex II genes *SDHB, SDHC*, and *SDHD* cause hereditary paragangliomas. In addition, another form of the disease has an autosomal dominant mode of transmission, and the causative genetic defect has been localized to two separate loci: 1lq13.1 and 11q22–23. Patients with hereditary disease display a much higher incidence of synchronous paraganglioma, approximately 25–35%.

Paragangliomas are also associated with phakomatoses (neurologic diseases with cutaneous manifestations). These include von Recklinghausen neurofibromatosis, Sturge–Weber syndrome, tuberous sclerosis, and von Hippel–Lindau disease. In addition, they can be associated with multiple endocrine neoplasia Type I syndrome.

Classification

There are two main classification schemes for paragangliomas of the temporal bone: Fisch and Glasscock–Jackson.

A. Fisch Classification

The Fisch classification includes four main categories: (1) Type A (tumors limited to the middle ear), (2) Type B (tumors limited to the tympanomastoid area), (3) Type C (tumors extending into the petrous apex), and (4) Type D (tumors with intracranial extension).

B. Glasscock–Jackson Classification

The classification scheme of Glasscock and Jackson differentiates between glomus tympanicum and glomus jugulare tumors.

1. Glomus tympanicum neoplasms—For glomus tympanicum neoplasms, this staging system includes (1) Type I (small masses limited to the promontory of the middle ear), (2) Type II (tumors filling the middle ear space), (3) Type III (tumors filling the middle ear and mastoid), and (4) Type IV (tumors extending into the external auditory canal or around the internal carotid artery).

2. Glomus jugulare neoplasms—For glomus jugulare tumors, this staging system includes (1) Type I (small tumors involving the jugular bulb, the middle ear, and the mastoid), (2) Type II (tumors extending under the IAC), (3) Type III (tumors extending into the petrous apex), and (4) Type IV (tumors extending beyond the petrous apex into the clivus or infratemporal fossa).

Clinical Findings

A. Symptoms and Signs

The two most common presenting symptoms of a patient with a paraganglioma of the temporal bone are conductive hearing loss and pulsatile tinnitus. Patients may also complain of aural pain, facial nerve weakness, and a neck mass. The patient should be questioned as to symptoms of sympathetic discharge, which may represent a functionally secreting tumor, such as tachycardia, arrhythmias, flushing, or labile hypertension. Moreover, the patient should be queried about any symptoms of dysphagia or hoarseness, which may represent palsy of cranial nerves IX or X.

Physical examination demonstrates a reddish–bluish mass behind the eardrum. An aural polyp may be noted. There are two clinical signs associated with paraganglioma that can be identified during microscopic exam of the tympanic membrane: (1) **brown sign** is the cessation of tumor pulsation and tumor blanching with positive pressure using the pneumatic otoscope; and (2) **Aquino sign** is the blanching of the mass with manual compression of the ipsilateral carotid artery. A complete examination of the cranial nerves is indicated, with particular attention to cranial nerves VII (the facial nerve), VIII (the vestibulocochlear nerve), IX (the glossopharyngeal nerve), X (the vagus nerve), XI (the accessory nerve), and XII (the hypoglossal nerve).

Ascultation of the ear and upper neck can be performed with a stethoscope if a patient complains of pulsatile tinnitus. Pulsatile tinnitus from a vascular tumor gets louder and faster when the patient exercises. Therefore, having the patient jog in place or go up and down some steps facilitates the ability of the clinician to hear the bruit.

B. Laboratory Findings

Patients with a suspected paraganglioma can be screened for a catecholamine secretion by collecting a patient's urine for 24 hours and determining the vanillylmandelic acid and metanephrine levels. An audiogram will reveal conductive hearing loss if the middle ear space is invaded with tumor. If the inner ear is invaded, a sensorineural hearing loss will be found. Impedance audiometry will reveal a flat tympanogram if a middle ear mass is present and touches the eardrum. Occasionally, vascular pulsations may be noted on the tympanogram.

C. Imaging Studies

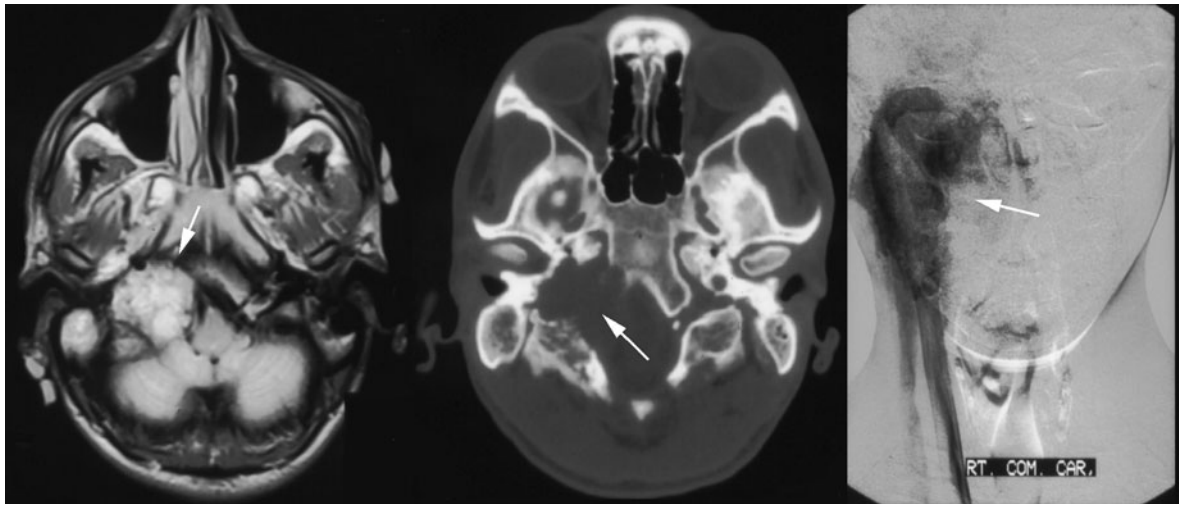
The importance of imaging paraganglioma of the skull base cannot be underestimated (Figure 65–4). Imaging is critical to delineate the extent of these tumors precisely. The first thing to determine is whether the jugular foramen is involved with the tumor. A glomus tympanicum is limited to the promontory and the mastoid though a glomus jugulare begins in the jugular foramen and extends superiorly into the middle ear and mastoid. In addition, the studies should be reviewed with careful attention to the middle ear, jugular foramen, and carotid bifurcation to look for a synchronous tumor.

1. Computed tomography (CT) scanning—CT scanning is useful to visualize the bony structures of the temporal bone. Of key importance is to evaluate the bone above the jugular bulb, the jugular plate. If the tumor is a glomus jugulare tumor that has extended into the middle ear cavity, this bone will be eroded. In contrast, if the tumor is a glomus tympanicum tumor, the bone surrounding the jugular bulb is usually intact. Inner ear or facial nerve involvement may also be noted. There may be a semicircular canal fistula or the tumor may be in close proximity to the fallopian canal, particularly along the vertical segment. The tumor may extend anterior to the IAC or along the petrous portion of the internal carotid artery. These findings may affect the planned surgical approach.

2. MRI scanning—MRI studies are useful to identify whether there is intracranial extension of the tumor. MRI gives excellent soft tissue contrast resolution and permits delineation of the tumor from the brainstem, the cerebellum, and the cranial nerves. The tumor has intermediate signal intensity on T1-weighted MRI and high intensity on T2-weighted MRI. Both may demonstrate a speckled pattern within the tumor, termed as "salt and pepper" pattern. This pattern is due to flow voids from the large number of intratumoral blood vessels. The tumor enhances strongly with gadolinium contrast.

3. Magnetic resonance angiography and venography—Magnetic resonance angiography can be used to evaluate for compression of the internal carotid artery. Magnetic resonance venography is useful to assess collateral circulation within the dural sinuses of the skull, since blood flow within the sigmoid sinus is often blocked by the tumor.

4. Angiography—Angiography of glomus jugulare tumors is usually done 1 or 2 days before surgical excision. This permits definitive diagnosis of the tumor by visualizing the tumor blush characteristic of such highly vascular tumors. In



▲ **Figure 65–4.** Jugulotympanic paraganglioma. **(A)** Axial view, T1-weighted image MRI with gadolinium contrast demonstrates a large enhancing mass in the right jugular bulb extending intracranially into the cerebellopontine angle (arrow). **(B)** Computed tomography at the same level shows significant bone destruction of the temporal bone and clivus (arrow). **(C)** Coronalview angiogram demonstrates the highly vascular tumor extending from the skull base inferiorly into the upper neck. This mass was embolized prior to surgical excision.

addition, the feeding vessels can be identified and embolized to reduce blood loss during surgery. The typical feeding vessels for a glomus jugulare tumor are the ascending pharyngeal artery and the stylomastoid branch of the occipital artery. Glomus tympanicum tumors typically do not need to be embolized preoperatively because of their small size and easy accessibility.

Differential Diagnosis

The differential diagnosis of a patient with a middle ear mass includes otitis media, cholesterol granuloma, other types of middle ear neoplasms—including middle ear adenoma or carcinoma—a vascular anomaly such as a high-riding dehiscent jugular bulb, an aberrant carotid artery, or a persistent stapedial artery. Other temporal bone neoplasms that might involve the middle ear space include meningiomas, schwannomas or neuromas, adenomas, or endolymphatic sac tumors.

Complications

A. Hearing Loss

Progressive conductive hearing loss usually is the presenting symptom of patients with a temporal bone paraganglioma. This may occur directly if the tumor contacts the ossicular chain or indirectly if the tumor blocks the eustachian tube, producing a serous middle ear effusion. Sensorineural hearing loss is uncommon but can occur if the tumor erodes the dense otic capsule bone and invades the inner ear. Alternately, the tumor may extend intradurally and affect cranial nerve VIII in the cerebellopontine angle and IAC.

B. Facial Nerve Palsy

Paragangliomas of the temporal bone may cause facial nerve palsy (21%) by invading the nerve within the temporal bone. Usually, this occurs along the vertical portion of the nerve within the mastoid. Even if nerve function is unaffected, most glomus jugulare tumors grow to wrap around the facial nerve and erode its bony canal in this location. A microsurgical dissection of a dehiscent nerve surrounded by tumor is the norm and can be quite challenging. (A dehiscent nerve is one in which the bony canal surrounding the nerve has been eroded.)

C. Jugular Foramen Syndrome

If the jugular foramen is involved with the paraganglioma, the insidious onset of neuropathy of the lower cranial nerves (IX, X, and XI) ensues as they are slowly encroached upon by the tumor. Symptoms include dysphagia and aspiration, as the sensation to the pharynx (CN IX) and the larynx (CN X) is diminished. Also, hoarseness may be noted owing to vocal cord paralysis (CN X). It should be noted that rather than an isolated recurrent laryngeal nerve injury that causes vocal cord paralysis (such as with a Pancoast tumor), the jugular foramen syndrome includes a high vagal nerve injury. This is more severe because the combination of a lack of sensation

to the upper larynx and vocal cord paralysis puts these patients at extremely high risk of aspiration. The paralysis of cranial nerve XI can be noted as weakness and atrophy of the sternocleidomastoid and trapezius muscles.

D. Hypoglossal Nerve Paralysis

The hypoglossal nerve exits the skull base through the hypoglossal foramen in the occipital bone, anteroinferior to the jugular foramen. Large paragangliomas that extend inferiorly may affect the hypoglossal nerve. The patient may complain of worsening articulation, and the physical exam will demonstrate ipsilateral tongue atrophy, muscular fasciculations, and deviation to the affected side with protrusion.

E. Horner Syndrome

The sympathetic nerves to the head run from the superior cervical ganglion up along the internal carotid artery into the skull base. Paragangliomas that envelop the petrous portion of the internal carotid artery may cause an ipsilateral Horner syndrome with ptosis, miosis, and ipsilateral facial flushing and sweating.

F. Other Complications

Large paragangliomas can affect other neurologic functions, depending on the tumor extension. Intradural tumors can grow within the cerebellopontine angle, producing cerebellar dysfunction and imbalance, brainstem compression, and even obstructive hydrocephalus. Tumors that grow superiorly or medially can affect other cranial nerves, causing diplopia (CN IV or VI), facial numbness or pain (CN V), or dry eye (the greater superficial petrosal branch of CN VII).

Treatment

A. Nonsurgical Measures

1. Observation—Observation with no treatment is reasonable in patients with minimal symptoms, particularly if they are older. Because glomus tumors are slow growing, serial MRI scans can be obtained, reserving surgery or radiation therapy for obvious tumor growth. This approach is less acceptable for younger patients in whom the tumor would be expected to grow substantially during their life span.

2. Radiation—The role of radiation therapy in the management of paragangliomas is controversial. Radiation is thought to reduce the growth rate of these tumors; however, it does not eliminate viable tumor cells within the mass. Tumors have been known to recur even more than a decade after radiation therapy. Radiation therapy for paragangliomas of the temporal bone can be useful as a treatment for elderly patients with symptomatic tumors or for patients who are unwilling to undergo a surgical resection. Postoperative stereotactic radiation therapy may be used for patients in whom total tumor removal could not be achieved.

B. Surgical Measures

Microsurgical total tumor removal is the treatment of choice for most patients. Patients with functionally secreting tumors need to be alpha-blocked with phentolamine before and during surgical resection to prevent life-threatening hypertension as the alpha-adrenergic hormones are released with tumor manipulation.

The surgical approach for resection of paragangliomas of the temporal bone depends on the tumor extent. For a glomus tympanicum tumor that is limited to the middle ear cavity, a simple middle ear exploration through the ear canal may be all that is indicated. After raising the tympanic membrane, the tumor can be visualized on the promontory. It may then be cauterized with a bipolar cautery and removed. If the tumor is larger and extends into the mastoid air cells, a tympanomastoidectomy with an extended facial recess approach may be required. This is a standard mastoidectomy via a postauricular incision with sacrifice of the chorda tympani nerve to allow exposure of the middle ear and hypotympanum from the mastoid. A tumor extending medially to the facial nerve (the retrofacial air cells) can be resected after exposing the facial nerve along its vertical segment to prevent injury to it.

For glomus jugulare tumors, a larger surgical approach is required. One very important aspect during the removal of these tumors is delineation and preservation of the facial nerve. Unfortunately, the vertical segment of the facial nerve lies in the middle of the operative field, and the tumor is usually based directly behind it, wrapping around it. A tympanomastoid approach with an extended facial recess and complete skeletonization of the facial nerve to the stylomastoid foramen typically provides adequate exposure. If possible, the preservation of a thin layer of bone surrounding the facial nerve circumferentially is ideal to minimize risk to the facial nerve (the fallopian bridge technique). It is also important to extend the skin incision into the neck and identify the internal carotid artery and internal jugular vein. The sternocleidomastoid and digastric muscles are separated from the mastoid tip so that the great vessels can be followed up to the skull base. These vessels need to be controlled both proximally and distally to the tumor in case a great vessel rupture occurs.

The most important part of the surgery is resection of the jugular bulb. Superiorly, the sigmoid sinus is occluded in the mastoid cavity, inferior to the junction of the transverse sinus and sigmoid sinus because the vein of Labbé enters at that location. Occlusion of the vein of Labbé may cause venous infarction of the temporal lobe since it is the only vein draining this territory. Inferiorly, the internal jugular vein is divided and ligated in the neck. Next, the jugular bulb (the lateral wall of the sigmoid sinus and the tumor filling the sinus) is dissected from the posterior fossa dura and cranial nerves IX, X, and XI. There is usually substantial bleeding from the entry point of the inferior petrosal sinus to the jugular bulb during this process. It is important to quickly

remove this tumor and pack this area with an absorbable knitted fabric (eg, Surgicel) to control the bleeding. After tumor removal, the mastoid cavity is often packed with fat harvested from the abdominal wall and closed in layers.

Large glomus jugulare tumors, which extend anteriorly along the internal carotid artery, typically require a larger infratemporal fossa surgical approach (Fisch Type A, see Figure 65–1). This approach involves following the facial nerve from the geniculate ganglion to the pes anserinus, lifting it out of the bony canal, and transposing it anteriorly to displace it out of the surgical field. The jugular spine, the bone between the internal jugular vein and the internal carotid artery as they enter the skull base, can then be fully delineated and removed. This permits dissection of the tumor from the internal carotid artery into the petrous apex. If needed, tumor dissection can extend from the jugular foramen all the way to the nasopharynx. If the tumor extends intracranially, this portion of the tumor should be removed after the vascular base of the tumor around the great vessels has been controlled. This reduces potentially massive intracranial hemorrhage. Large tumors require complete exenteration of the middle ear cavity, packing of the eustachian tube, and closure of the external auditory canal to form a blind pouch. If the tumor is extensive, it is possible that some type of soft tissue reconstructive flap may be needed to reconstruct the defect, such as a pedicled temporalis muscle flap.

Prognosis

Paragangliomas have a slow but relentless growth pattern. For most patients, the treatment of choice is a complete microsurgical removal to prevent worsening morbidity from tumor progression. Observation with no treatment can be performed if the patient is elderly and has only minimal symptoms. The use of radiation therapy is limited to elderly patients with symptomatic tumors, hopefully slowing the growth rate of an already slow-growing tumor. The main question, however, is whether this tumor will cause serious morbidity or mortality in the patient's remaining years. In the end, the treatment of paragangliomas needs to be individualized based on the patient, the disease, and the physician.

The most common complications from surgical excision are those related to cranial neuropathy. These include paresis or palsy of the jugular foramen nerves (CN IX, X, and XI) with resultant hoarseness, dysphagia, and aspiration. These complications may be temporary or permanent. In either case, patients can usually regain the ability to eat within the first few weeks after surgery with swallowing therapy. Facial nerve palsy also can occur during tumor removal, although if the facial nerve is anatomically intact at the end of surgery, a good return of function is expected. As with any skull base surgery, meningitis or cerebrospinal fluid (CSF) leak may occur. There can be significant amounts of blood loss during the resection of these tumors because of their highly vascular nature. Preoperative embolization is quite helpful in reducing the amount of blood loss.

Fayad JN, Keles B, Brackmann DE. Jugular foramen tumors: Clinical characteristics and treatment outcomes.*Otol Neurotol.* 2009;24. [PMID: 19779386] (Good overview of treatment considerations and outcomes.)

Oghalai JS, Leung MK, Jackler RK et al. Transjugular craniotomy for the management of jugular foramen tumors with intracranial extension. *Otol Neurotol.* 2004;25:570; discussion 579. [PMID: 15241237] (Newer approaches for jugular foramen tumors.)

FACIAL NERVE SCHWANNOMAS

ESSENTIALS OF DIAGNOSIS

- Facial twitch
- Slowly progressive facial palsy
- Conductive hearing loss.

General Considerations

Primary tumors of the facial nerve can arise anywhere from the Glial–Schwann cell junction in the cerebellopontine angle into the parotid gland. These are very slow-growing tumors and tend to spread longitudinally along the course of the facial nerve within the temporal bone (the fallopian canal). These tumors are histologically similar to vestibular schwannomas (acoustic neuromas) except for the fact that they rise along a different cranial nerve.

The diagnosis of a facial nerve schwannoma is frequently delayed because of the slow rate of tumor growth and symptom development. Patients with Bell's palsy in whom facial nerve function was not of acute onset should be evaluated for a facial nerve schwannoma. Also, patients with facial palsy that does not begin to demonstrate the return of function within 6–9 months of onset should be evaluated for a facial nerve schwannoma.

Clinical Findings

A. Symptoms and Signs

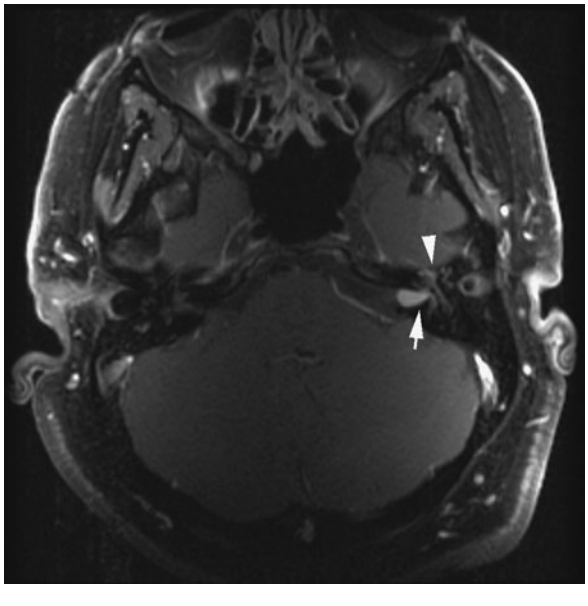
The clinical findings depend on the precise location of the tumor. For facial nerve schwannomas that begin in the cerebellopontine angle or IAC, the most common clinical findings are sensorineural hearing loss, tinnitus, vestibular dysfunction, and balance. These findings are precisely the same symptomatology as those of a patient with an acoustic neuroma. Patients with facial nerve schwannomas within the fallopian canal present with facial nerve palsy and twitch. They can also present with conductive hearing loss if the mass impinges upon the middle ear ossicles. Extratemporal facial nerve schwannomas typically present as an asymptomatic firm mass in the parotid gland.

For all locations, a common patient history is a slow onset of facial nerve palsy over 3–6 months, which has not improved even after several years. Usually, facial spasm is noted before the onset of facial paralysis. Occasionally, a patient with a facial nerve schwannoma presents with facial palsy of rapid onset (over 1–2 days). These patients are diagnosed with idiopathic Bell's palsy and treated with corticosteroids. Although steroids may reduce tumor edema and initially lead to an improvement in facial nerve function, the facial nerve palsy will return over the next few weeks as the effects wear off.

B. Imaging Studies

1. CT scanning and MRI—CT scanning is quite useful in identifying the extent of bony erosion and dilatation of the fallopian canal. In addition, it delineates whether the tumor mass impinges upon the ossicles. An MRI scan with gadolinium contrast is superior for defining the extent of the tumor within the cerebellopontine angle and the parotid gland (Figure 65–5). The tumor has an intermediate signal intensity on both T1- and T2-weighted MRI.

It can be difficult to differentiate between an acoustic neuroma and a facial nerve schwannoma within the IAC. However, facial nerve schwannomas typically follow the course of the facial nerve. They extend into the temporal bone, involving the geniculate ganglion and horizontal portion of the facial nerve within the middle ear. In contrast, acoustic neuromas stop at the fundus, which is the distal portion of the IAC.



▲ **Figure 65–5.** Facial nerve schwannoma. Axial view, T1-weighted image MRI with gadolinium contrast demonstrates an enhancing tumor of the left IAC (arrow) that extends anteriorly to the geniculate ganglion (arrowhead).

2. Audiometry—Audiometry often demonstrates conductive hearing loss. The ipsilateral acoustic reflex may have elevated thresholds or show abnormal decay functions.

Differential Diagnosis

The differential diagnosis of a facial nerve schwannoma in the cerebellopontine angle and IAC includes vestibular schwannoma, meningioma, and epidermoid cyst. If the tumor involves the geniculate ganglion or the intratemporal facial nerve, the differential diagnosis includes cholesteatoma, paraganglioma, and geniculate hemangioma. If a parotid mass is palpable, all types of benign and malignant parotid tumors are within the differential diagnosis. For any patient with unilateral peripheral facial palsy, both idiopathic Bell's palsy and Ramsey–Hunt syndrome should be included in the differential diagnoses.

Treatment

A. Nonsurgical Measures

These tumors are extremely slow growing and typically cause slowly progressive facial nerve palsy. Observation is the treatment of choice until the facial nerve palsy is substantial (House–Brackmann Grade 4 or greater) or symptoms of brainstem compression occur.

B. Surgical Measures

Because surgical excision requires resection of the involved segment of the nerve and grafting of the facial nerve, a significant postoperative facial nerve deficit is to be expected. After nerve grafting or hypoglossal-facial nerve transfer has been performed, the best facial nerve function that can be expected is a House–Brackmann Grade 3. The surgical approach depends on the precise location of the tumor. If the tumor is limited to the IAC and cerebellopontine angle, a retrosigmoidal or middle cranial fossa approach can be used to try to preserve hearing. Typically, the middle fossa approach allows better exposure of the facial nerve as it lies on the superior aspect of the nerves within the IAC. If hearing has already been lost, a translabyrinthine approach allows the best exposure of the complete length of the facial nerve. If the facial nerve schwannoma is limited to the middle ear or mastoid, a postauricular tympanomastoidectomy approach can be used. Although this approach does not allow exposure of the IAC, complete exposure from the geniculate ganglion to the parotid gland can be obtained.

Tumor removal involves transecting the facial nerve on either side of the schwannoma. If only a small segment of

the nerve is involved, the nerve may be mobilized out of its canal and repaired primarily. Otherwise, a nerve graft either from the great auricular nerve or the sural nerve can be grafted between the segments. If the proximal portion of the facial nerve is involved at the brainstem, nerve grafting may be impossible and a hypoglossal-facial nerve transposition can be performed.

Prognosis

After the initial diagnosis, close follow-up is warranted with a serial MRI, CT scan, or both to determine whether there is evidence of tumor growth. As long as symptoms are stable, these tumors can be followed. If surgical excision is required, routine eye care is needed until facial nerve function returns. This may require the use of artificial tears and Lacri–Lube (a nighttime eye lubricant), a protective eye shield, or the placement of a gold weight in the upper eyelid. Patients may also have conductive or sensorineural hearing loss that needs to be managed accordingly.

Marzo SJ, Zender CA, Leonetti JP. Facial nerve schwannoma. *Curr Opin Otolaryngol Head Neck Surg*. 2009;17(5):346–350. [PMID: 19561500] (The management of facial nerve tumors.)

Thompson AL, Aviv RI, Chen JM, et al. Magnetic resonance imaging of facial nerve schwannoma. *Laryngoscope*. 2009;119(12):2428–2436. [PMID: 19780031] (Imaging characteristics of facial nerve tumors.)

GENICULATE HEMANGIOMAS

General Considerations

Hemangiomas are benign tumors of blood vessels. They are the most common tumor of infancy and typically resolve spontaneously by the time the child is 5 to 6 years old. Within the temporal bone, hemangiomas have a predilection for the geniculate ganglion of the facial nerve. These are different from typical hemangiomas in that they are not associated with pediatric patients. They are usually identified in middle-aged adults.

Pathogenesis

Geniculate hemangiomas arise directly from the geniculate ganglion. The bony floor of the middle cranial fossa is dehiscent over the tumor in nearly all cases. The tumor can extend superiorly into the middle cranial fossa but typically remains extradural. It can also track distally along the distal portion of the facial nerve but does not extend beyond the horizontal segment. Geniculate hemangiomas usually do not extend proximally into the IAC; however, hemangiomas can arise primarily within the IAC, which similarly do not extend to the geniculate ganglion.

Clinical Findings

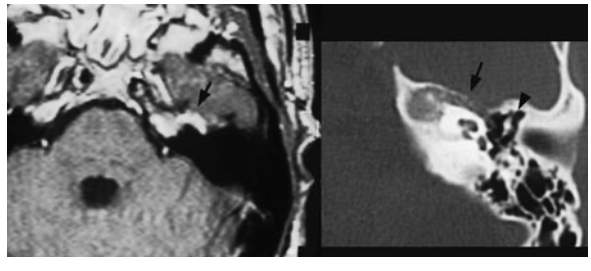
A. Symptoms and Signs

The most common presenting symptom of geniculate hemangiomas is slowly progressive facial paralysis. Rarely, a patient may present with a rapid onset of facial paralysis. Although a patient may have a geniculate hemangioma without facial paralysis, it would be unusual to diagnose this lesion without this symptom. Facial paralysis may simulate Bell's palsy (idiopathic facial paralysis), with improvement in facial function with steroid treatment; however, the facial palsy recurs as the effect of the steroids wears off.

Facial twitch and spasm can be identified in patients with tumors compressing the facial nerve and have been reported in patients with geniculate hemangiomas. Hearing loss is typically conductive owing to impingement of the tumor on the ossicular mass in the middle ear. These tumors usually do not erode the otic capsule and do not affect the IAC; therefore, sensorineural hearing loss is unusual. Patients may complain of symptoms related to compression of the greater superficial nerve, including either epiphora or dry eye. On physical exam, the patient may present with a red mass behind the eardrum and the Weber and Rinne tuning fork tests suggest a conductive hearing loss in that ear.

B. Imaging Studies

CT scans demonstrate a soft tissue density in the area of the geniculate ganglion with bony dehiscence and erosion of the floor of the middle cranial fossa around the geniculate ganglion (Figure 65–6). Classically, there may be intratumoral calcifications or bone spicules within the tumor, which are diagnostic for a hemangioma. However, the absence of calcium within the tumor does not rule out a hemangioma.



A B

▲ **Figure 65–6.** Geniculate hemangioma. **(A)** Axial view, T1-weighted image MRI with gadolinium contrast demonstrates an enhancing lesion in the vicinity of the geniculate ganglion (arrow). **(B)** CT scan of the temporal bone demonstrates an expansile lesion with moderate bone erosion (arrow). There are characteristic calcium flakes within the tumor. The malleus and incus are also identified as a landmark (arrowhead).

MRI is useful in delineating the intracranial extent of the tumor. It enhances intensely with gadolinium contrast. On T1-weighted images without contrast, the tumor has the same density as brain tissue; on T2-weighted images, the tumor is bright.

Differential Diagnosis

The differential diagnosis of a geniculate lesion includes facial nerve schwannomas, meningioma, metastases, cholesteatomas, cholesterol granulomas, and mucoceles.

Treatment

A. Nonsurgical Measures

These lesions demonstrate slow but progressive growth. Observation can be considered in an older or debilitated patient in whom surgical risks are felt to be too great.

B. Surgical Measures

Surgical excision is the treatment of choice for most patients with these tumors since they clearly grow and cause worsening symptoms. Although they are next to the facial nerve, they usually do not infiltrate the nerve nor do they extend intradurally. Surgery often permits complete tumor resection with minimal impact on the facial nerve function. However, large tumors can affect final facial nerve outcomes. The best surgical strategy is via a middle cranial fossa approach, with care to identify the interface between the tumor and the dura during the initial elevation of the dura off the floor of the middle cranial fossa. The tumor can usually be delicately microdissected from the geniculate ganglion with facial nerve preservation.

Prognosis

Surgical excision is curative. There have been no recurrence rates reported.

Isaacson B, Telian SA, McKeever PE et al. Hemangiomas of the geniculate ganglion. *Otol Neurotol*. 2005;26:796–802. [PMID: 16015187] (Hemangiomas infiltrate the facial nerve.)

MALIGNANT HEMATOLOGIC DISORDERS

1. Leukemia

Leukemia is the production of an abnormally high number of white blood cells that deposit in various organs and sites within the body. The temporal bone is one site that occasionally becomes infiltrated, typically within the marrow of the petrous apex. Involvement of the middle ear cleft and mastoid can also occur; however, it is unusual for leukemic infiltrates to involve the inner ear or the facial nerve. Patients with leukemia are immunosuppressed and are highly prone to developing acute otitis media. Hemorrhage into the middle ear can also occur. Up to 32% of patients with leukemia have otologic symptoms, usually due to eustachian tube dysfunction with resultant middle ear effusion and conductive hearing loss. Obstruction of the eustachian tube can occur along its length or at its opening to the nasopharynx at the adenoid bed. A solid tumor known as a granulocytic sarcoma or chloroma is occasionally noted with myelogenous leukemia. This is a localized concentration of neoplastic granulocytic cells that begins within the marrow of the petrous apex.

CT scanning demonstrates a lytic lesion, and MRI shows the mass to have low-signal intensity on T1-weighted images and intermediate intensity on T2-weighted images. It enhances moderately with contrast. The treatment for leukemic infiltrates, granulocytic sarcoma, or both is based on systemic chemotherapy; there is no need for surgical treatment of this disease. Occasionally, a myringotomy is useful to drain fluid out of the middle ear cleft and for culture of the middle ear effusion if infection is suspected. Very rarely, a mastoidectomy is required if coalescent mastoiditis has developed or for biopsy purposes.

2. Lymphoma

Lymphoma can infiltrate the marrow spaces of the temporal bone, typically within the petrous apex. Like patients with leukemia, these patients can have eustachian tube dysfunction or hemorrhage into the middle ear with resultant middle ear effusion and conductive hearing loss. It is unusual to see destruction of the inner ear or facial nerve in this group of patients. The treatment of the disease is systemic chemotherapy and radiation therapy.

3. Plasmacytoma

The head and neck are the most common sites of an extramedullary plasmacytoma (ie, plasmacytoma arising anywhere outside of the bone marrow). Lesions usually involve the Waldeyer ring, which includes the tonsils, adenoids, and lymphoid tissue along the base of tongue. Very rarely, extramedullary plasmacytomas may involve the temporal bone, usually within the middle ear and mastoid air cells. Patients with this lesion present with eustachian tube dysfunction, middle ear effusion, and conductive hearing loss. Occasionally, a middle ear mass is identified. Surgery may be required to perform a biopsy, but once the diagnosis has been made, it is important to search for disseminated disease suggestive of multiple myeloma (found in 31% of patients with extramedullary plasmacytoma). This includes staging CT scans and a bone marrow biopsy.

The treatment for a solitary extramedullary plasmacytoma is based on radiation therapy alone. Debulking surgery is not generally recommended; however, limited resection with preservation of the facial nerve and inner ear can be performed during the biopsy. It is not recommended to perform a radical resection because this is not thought

to improve outcomes. The 5-year survival rate is 69% for patients with isolated extramedullary plasmacytomas of the head and neck. If disseminated plasmacytoma or multiple myeloma is identified, chemotherapy is usually recommended in combination with radiation therapy.

LANGERHANS CELL HISTIOCYTOSIS

ESSENTIALS OF DIAGNOSIS

- Chronic otitis media, otorrhea, and an aural polyp in a child.

General Considerations

Langerhans cell histiocytosis is a proliferation of cells that arise from the bone marrow and are found circulating within the blood and lymph nodes and at junctional areas between the body and the outside environment (eg, along epithelial and endothelial surfaces). The role of normal histiocyte function is to present antigens to both T cells and B cells to initiate an immune response.

Other terms for Langerhans cell histiocytosis include histiocytosis X, eosinophilic granuloma, Hand–Schüller–Christian disease, and Letterer–Siwe disease. All of these diseases have now been categorized as Langerhans cell histiocytosis, and the latter terms are no longer used.

Langerhans cell histiocytosis is typically a disease of children, although it can occur at any age. There are three standard presentations. Localized Langerhans cell histiocytosis (Group 1) often occurs in children between the age of 5 and 9 and presents as a single bony lesion. Multifocal Langerhans cell histiocytosis (Group 2) typically occurs in children between the age of 2 and 5 and presents with two or more osseous, cutaneous, or soft tissue lesions with or without endocrine abnormalities. Disseminated Langerhans cell histiocytosis (Group 3) is found throughout the entire body in association with vital organ dysfunction. These patients are under 2 years of age.

Pathogenesis

The cause of Langerhans cell histiocytosis is unclear. Current theories suggest that it may represent an immune dysfunction that is either primary or secondary to an external stimulus, such as an infection. In addition, it may represent a low-grade type of lymphoma. Langerhans cells appear as mononuclear cells under light microscopy. With electron microscopy, Langerhans cells display the characteristic Birbeck granule or X-body. This is a rod-shaped structure that contains a central striated line and often expands at one end to form a shape similar to a tennis racket.

Clinical Findings

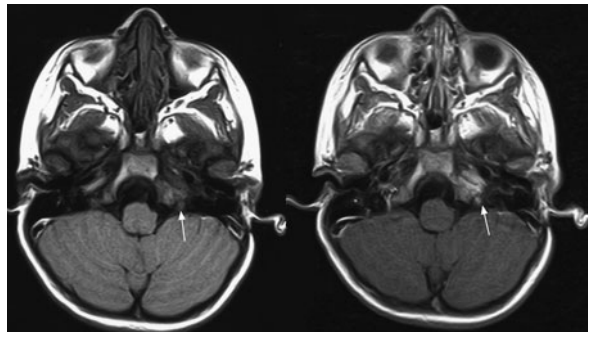
A. Symptoms and Signs

The most common presenting symptoms of Langerhans cell histiocytosis include a swelling of the skull (45%), cervical adenopathy (25%), cephalic rash (20%), and otorrhea (20%). Within the temporal bone, the disease often masquerades as otitis media, mastoiditis, and otorrhea that fail to resolve with antibiotic therapy. Conductive hearing loss is often noted, and an aural polyp may be realized during the physical exam. Indeed, Langerhans cell histiocytosis should be considered in all children with aural polyps and chronic otitis media. Facial nerve paralysis, vertigo, dysequilibrium, tinnitus, and sensorineural hearing loss are rare.

Patients with disseminated Langerhans cell histiocytosis are quite sick and present with failure to thrive, fever, and extensive systemic involvement. There may also be cervical lymphadenopathy and cutaneous manifestations. These patients may have anemia and bleeding diatheses if the hematopoietic system is involved. A common site of central nervous system involvement is the pituitary stalk. Thus, it is extremely common for patients to present with diabetes insipidus (polyuria and polydipsia). This can also manifest as growth hormone deficiency, hypothyroidism, and diminished sex hormone function.

B. Imaging Studies

Plain radiographs of the skull often reveal multiple lytic skull lesions. CT scanning reveals a soft tissue mass with diffuse irregular bone destruction. The lesions have intermediate intensity on T1-weighted imaging and high intensity on T2-weighted MRI (Figure 65–7). They enhance moderately



A B

▲ **Figure 65–7.** Langerhans cell histiocytosis. Axial views, T1-weighted MRI without **(A)** and with **(B)** gadolinium contrast demonstrate a subtle, mildly enhancing lesion in the petrous apex of the temporal bone and lateral clivus (arrow). There is no bony destruction.

with gadolinium contrast. One should always look for other central nervous system lesions of Langerhans cell histiocytosis, especially in the pituitary stalk. . A bone scan can also be useful in identifying any other sites of involvement throughout the body.

Differential Diagnosis

Langerhans cell histiocytosis mimics many disorders. Chronic otitis media, aural polyps, cholesteatoma, external otitis, and coalescent mastoiditis are common inflammatory diseases with similar presenting symptoms. Other tumors of the temporal bone, including rhabdomyosarcoma, chondrosarcoma, adenocarcinoma, Ewing sarcoma, osteosarcoma, and metastasis, also mimic Langerhans cell histiocytosis. Lymphoma, leukemia, and plasmacytoma are uncommon lesions of the temporal bone that may also simulate this disorder as well.

Treatment

A. Nonsurgical Measures

1. Radiation therapy—Low-dose radiation therapy may be used if adequate curettage is not feasible for localized or multifocal Langerhans cell histiocytosis and is commonly used in patients with disseminated Langerhans cell histiocytosis.

2. Chemotherapy—Patients with disseminated Langerhans cell histiocytosis require both chemotherapy and radiation. The most common chemotherapeutic regimen is a combination of corticosteroids, vincristine or vinblastine, and methotrexate. Response rates vary widely and depend on the presence or absence of organ dysfunction.

B. Surgical Measures

The surgical management of Langerhans cell histiocytosis involves diagnostic biopsy and curettage. Conservative curettage is indicated, and there is no need for radical resection of the lesion. In particular, the inner ear, the ossicles, and the facial nerve should be carefully preserved. Surgical treatment is usually all that is required for patients with localized or multifocal disease.

Prognosis

Patients with localized disease can be treated equally well with either curettage or low-dose radiation therapy; their survival rate is 95–100%. Patients with multifocal disease also have a good survival rate, ranging from 65% to 100%. Patients with disseminated disease re treated with a combination of radiation therapy and chemotherapy. Their survival rate is quite poor and varies from 0% to 75%.

Cochrane LA, Prince M, Clarke K. Langerhans' cell histiocytosis in the paediatric population: presentation and treatment of head and neck manifestations. *J Otolaryngol.* 2003;32:33. [PMID: 12779259] (review article.)

Imashuku S, Kinugawa N, Matsuzaki A et al. Japan LCH Study Group. Langerhans cell histiocytosis with multifocal bone lesions: Comparative clinical features between single and multisystems. *Int J Hematol.* 2009 Nov;90(4):506–512. Epub 2009 Sep 25. [PMID: 19779766]

OTHER RARE NEOPLASMS

1. Chondrosarcoma

General Considerations

Chondrosarcomas are thought to arise from cartilage rests left within the skull base after endochondral ossification during embryogenesis. Although theoretically these tumors can occur anywhere within the temporal bone, usually they are found at the petroclival junction around the foramen lacerum. They are very slow-growing tumors. Pathologically, they are usually well or moderately differentiated tumors, although poorly differentiated tumors have been reported.

Clinical Findings

Clinically, patients may present with pulsatile tinnitus, hearing loss, headaches, diplopia, facial numbness, and dysphagia, depending on the tumor location. Radiographic findings usually demonstrate an expansile mass at the petroclival junction with bony erosion on CT. There may be small areas of calcification within the tumor, referred to as a "popcorn" pattern. The tumor has intermediate intensity on T1-weighted MRI and high intensity on T2-weighted MRI. The lesion also enhances heterogeneously with gadolinium contrast, although some tumors are quite avascular and may demonstrate only minimal enhancement throughout. The differential diagnosis includes chordoma, osteosarcoma, fibrosarcoma, meningioma, and paraganglioma.

Treatment & Prognosis

The mainstay of therapy is surgical excision. Microsurgical total tumor removal can usually be achieved via the middle fossatranspetrous approach with removal of the bone of the petrous apex medial to the cochlea (Kawase triangle) to expose the petroclival junction (see Figure 65–2). Alternately, an infratemporal fossa approach (Fisch Type B or C) or a combined subtemporalretrosigmoidal approach (see Figure 65–3) may be used. Postoperative radiation therapy, often delivered via proton beam, appears to improve patient prognosis. The 5-year survival rate is 40% to 90%.

2. Chordoma

General Considerations

Chordomas arise from remnant cells of the primitive notochord, an embryonic structure important during the embryologic development of the central nervous system, spinal cord, and vertebral bodies. Pathologically, chordomas are

gelatinous tumors filled with vacuolated stellate cells in a background of glycoprotein matrix. Within the skull base, the predominant site where chordomas originate is the midline clivus. As the tumor grows and erodes the surrounding bone, it may extend anteriorly into the sphenoid sinus and nasopharynx, laterally into the cavernous sinus and temporal bone, and posteriorly to compress the brainstem. It is uncommon for chordomas to extend intradurally.

Clinical Findings

Presenting symptoms most commonly include headache and diplopia (palsy of CN III, IV, or VI), although any cranial nerve can be affected, depending on tumor extension. CT scanning reveals an expansile lesion of the midclivus with bone destruction. MRI demonstrates the tumor to be multilobular and to have intermediate signal intensity on T1-weighted images and high intensity on T2-weighted images. There is strong contrast enhancement with gadolinium, although this may be heterogeneous if there are cystic areas within the tumor filled with mucin. The differential diagnosis includes chondrosarcoma, osteosarcoma, fibrosarcoma, meningioma, and paraganglioma.

Treatment

Microsurgical total tumor removal is the goal of therapy; however, this is difficult because of the location of the tumor and the proximity of vital vascular structures (eg, internal carotid arteries, the circle of Willis, and the cavernous sinus) and neurologic structures (eg, CN II, III, IV, V, VI, the brainstem, and the pituitary gland). If the tumor is only in the midline and is extradural, an anterior approach is used. This may be performed through two routes: (1) by traversing the sinuses and resecting the tumor through an opening in the posterior wall of the sphenoid sinus or nasopharynx, or (2) via a transoral approach and tumor resection through the posterior pharyngeal wall. CSF leak through contaminated oral or nasal passageways can be a serious complication of these anterior approaches. If the tumor extends laterally or intradurally, a lateral approach should be used. Lateral approaches include an infratemporal fossa approach (Fisch Type B or C), a middle fossa-transpetrous approach with removal of the anterior petrous apex (Kawase triangle) (see Figure 65–2), or a combined subtemporal-retrolabyrinthine approach (see Figure 65–3).

Prognosis

Postoperative radiation therapy appears to reduce recurrence rates. Although metastases are distinctly uncommon, tumor seeding of the wound during surgery can happen with aggressive chordomas. The natural history of this disease is local recurrence with eventual mortality. The 5-year survival rate ranges widely from 35% to 85%, depending on the amount of tumor removal achieved at surgery.

3. Meningioma

General Considerations

Meningiomas arise from arachnoidal cap cells associated with arachnoid villi. Within the posterior cranial fossa, these tumors can be found along the dura anywhere from the sigmoid sinus (posteriorly) to the cavernous sinus (anteriorly). Similar to schwannomas, meningiomas are usually sporadic, but they are also associated with neurofibromatosis Type II. Although most meningiomas are benign, 5% have malignant cell characteristics as well as a tendency for early and aggressive recurrence. Meningiomas usually grow slowly by expanding into the cerebellopontine angle or along the Meckel cave (around the gasserian ganglion). However, any posterior fossa meningioma also has the potential to invade the temporal bone.

Clinical Findings

A. Symptoms and Signs

Patients with meningiomas may present with hearing loss from tumor expansion into the IAC, the inner ear (sensorineural loss), or the middle ear (conductive loss). Jugular foramen syndrome, which includes dysphagia, vocal cord paralysis, and shoulder weakness, may be present if the tumor infiltrates cranial nerves IX, X, and XI of the jugular foramen.

B. Imaging Studies

On CT scan, meningiomas demonstrate hyperostosis of the adjacent bone and calcification within the tumor on CT scan. The tumors have intermediate intensity on both T1-and T2-weighted MRI. They enhance strongly with contrast and show a characteristic "dural tail," with enhancement of the dura bordering the tumor mass because of its infiltration within the tumor; this finding is a key diagnostic difference between meningioma and schwannoma. Flow voids may be noted on larger tumors, and occasionally angiography with embolization is useful as a preoperative measure to reduce blood loss during a planned surgery.

Treatment

The treatment of meningiomas includes observation with serial MRI, stereotactic radiation, and surgery. In a younger patient with a larger tumor, surgery is usually recommended, whereas in an older patient with minimal symptoms, observation or radiation should be considered. Surgical resection depends on the tumor location but often requires a retrosigmoidal or combined subtemporal-retrolabyrinthine approach (see Figure 65–3). Although the complete resection of these infiltrative tumors is nearly impossible, a good subtotal resection, sparing vital neurovascular structures, is adequate. If the tumor recurs, further resection or radiation therapy can be performed.

4. Intralabyrinthine Schwannoma

General Considerations

In general, vestibular schwannomas are usually found within the IAC. However, they can arise anywhere Schwann cells are present, which extends from the oligodendrogliocyte-Schwann cell junction (the Obersteiner–Redlich zone) near the porus acousticus to the hair cells of the inner ear.

Clinical Findings

A. Symptoms and Signs

Patients with a vestibular schwannoma arising within the inner ear labyrinth have symptomatology similar to those with a vestibular schwannoma arising within the IAC. Vague imbalance, unilateral tinnitus, and asymmetric hearing loss are the common presenting symptoms.

B. Imaging Studies

Imaging features include an enhancing mass within the inner ear on gadolinium contrast T1-weighted MRI, which simulates acute labyrinthitis. However, the absence of fluid density within the inner ear on T2-weighted MRI is what differentiates these two processes. Of note, the bone of the otic capsule is usually not expanded by the tumor. Indeed, these tumors continue to grow by slowly filling the entire labyrinth before bone erosion occurs. These tumors are quite small and easily missed if not looked for carefully.

Treatment

If the only symptom is mild sensorineural hearing loss, the treatment is usually observation. Surgical resection requires labyrinthectomy and results in profound hearing loss in the affected ear. If chronic dysequilibrium develops, surgical excision by a transcochlear approach (through both the vestibular labyrinth and the cochlea) is warranted.

5. Schwannomas of the Jugular Foramen, Jacobson Nerve, & Arnold Nerve

General Considerations

Besides seventh and eighth cranial nerve schwannomas, schwannomas can also arise from other nerves that pass through the temporal bone. Cranial nerves IX, X, and XI run from the brainstem through the jugular foramen and down into the neck. These nerves are located medial to the jugular vein at the skull base. Jacobson nerve is a branch of cranial nerve IX that runs along the promontory of the middle ear, supplying sensation and parasympathetic fibers to the parotid gland. Arnold nerve is a branch of cranial nerve X that carries fibers that supply sensory innervation to the ear canal.

Clinical Findings

Patients with a jugular foramen schwannoma present with dysphagia, hoarseness due to vocal cord paralysis, and shoulder weakness. A middle ear mass may also be noted. Patients with a schwannoma of Jacobson or Arnold nerves present with conductive hearing loss and have a bulging, white middle ear mass on otoscopy. Like all schwannomas, these tumors are smooth and gently erode the surrounding bone. They enhance on gadolinium contrast MRI.

Treatment

Treatment is surgical resection. Schwannomas of the lower cranial nerves require a transtemporal approach to the jugular foramen, like the Fisch Type A approach (see Figure 65–2**A**) or transjugular craniotomy, although often the facial nerve does not require rerouting and the ear canal does not need to be closed off, preserving hearing.

6. Rhabdomyosarcoma

General Considerations

Rhabdomyosarcoma is the most common soft tissue sarcoma in children, accounting for 5–15% of all childhood cancers. The average age at presentation is 4.4 years.

Clinical Findings

A. Symptoms and Signs

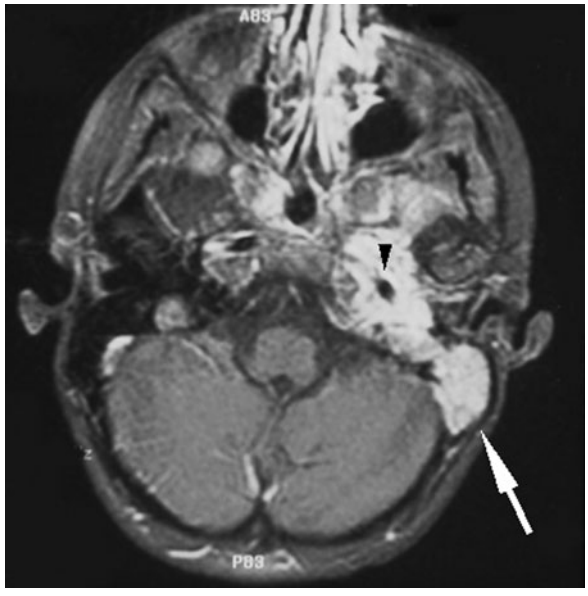
Rhabdomyosarcoma involving the temporal bone presents as chronic otitis media recalcitrant to antibiotic therapy. Otorrhea, earache, and an aural polyp are commonly noted. This disease process is highly aggressive. Local destruction of surrounding bone can produce either conductive or sensorineural hearing loss. Facial nerve paralysis can manifest if the mastoid or middle ear is involved with tumor. If the petrous apex is involved, facial numbness, diplopia, or both can be exhibited owing to involvement of cranial nerves V and VI. Extension of tumor to the IAC and cerebellopontine angle can also develop.

B. Imaging Studies

CT scanning demonstrates an enhancing soft tissue mass with bony destruction. MRI shows an intermediate-intensity mass on T1-weighted imaging and a high-intensity mass on T2-weighted images (Figure 65–8). The lesion enhances with gadolinium contrast.

Treatment & Prognosis

Initially, a biopsy of the temporal bone mass must be performed, which may require a mastoidectomy through a postauricular incision if no aural polyp is available to biopsy. Treatment is based upon chemotherapy and external beam



▲ **Figure 65–8.** Rhabdomyosarcoma. Axial view, T1-weighted image MRI with gadolinium contrast demonstrates a large enhancing tumor involving the entire temporal bone (arrow) and surrounding the internal carotid artery (arrowhead).

radiation therapy. There are five histologic subtypes of rhabdomyosarcoma: (1) pleomorphic (5%), (2) alveolar (20%), (3) embryonal (55%), (4) botryoid (5%), and (5) mixed. The botryoid and pleomorphic subtypes have a favorable prognosis, the embryonal subtype has an intermediate prognosis, and the alveolar and mixed subtypes have an unfavorable prognosis. The prognosis gets worse if distant metastases develop.

7. Osteosarcoma

Osteosarcoma is extremely rare within the temporal bone. It presents as a rapid, painful swelling of the bone and is most often found in patients between the age of 10 and 30. Imaging characteristics depend on the amount of osteoblastic and osteolytic activity of the tumor. An enhancing soft tissue mass may be present. If the tumor has osteoblastic components, concentric rings are usually seen, termed as "onion skinning." The treatment is surgical resection followed by chemotherapy and radiation therapy. Patients have a 5-year survival rate of 9%.

8. Fibrosarcoma

More than half of all fibrosarcomas are diagnosed within the first year of life, with less than 2% occurring in the head and neck. This tumor may appear as a soft tissue tumor within the temporal bone with local bony destruction. Treatment is surgical resection. Often, preoperative chemotherapy can be attempted to reduce the tumor mass, permitting a more conservative resection. The prognosis is good, with 5-year survival rates of 84–92%.

9. Hemangiopericytoma

Hemangiopericytoma is a malignant vascular neoplasm arising from the contractile cells around blood vessels, the "pericytes of Zimmerman." These mesenchymal tumors arise within the musculoskeletal system and rarely may arise within the middle ear cleft. Pathologically, sheets of spindle-shaped tumor cells with numerous vascular channels are noted. Treatment is based upon complete surgical resection, with consideration of postoperative radiation. Metastases occur in about 50% of cases, predominantly to the lung, bones, and liver.

10. Adenoma

Middle ear adenomas are rare tumors that arise from the middle ear mucosa. Patients with these neoplasms present with conductive hearing loss because the mass compresses the ossicular chain. Examination reveals a middle ear mass that enhances on gadolinium contrast MRI. An aural polyp may also be noted. The differential diagnosis includes glomus tympanicum tumors and schwannomas of the facial, Jacobson, or Arnold nerve. Treatment is middle ear exploration and resection. These are benign tumors with minimal propensity for malignant degeneration.

11. Endolymphatic Sac Neoplasms (Papillary Adenocarcinoma)

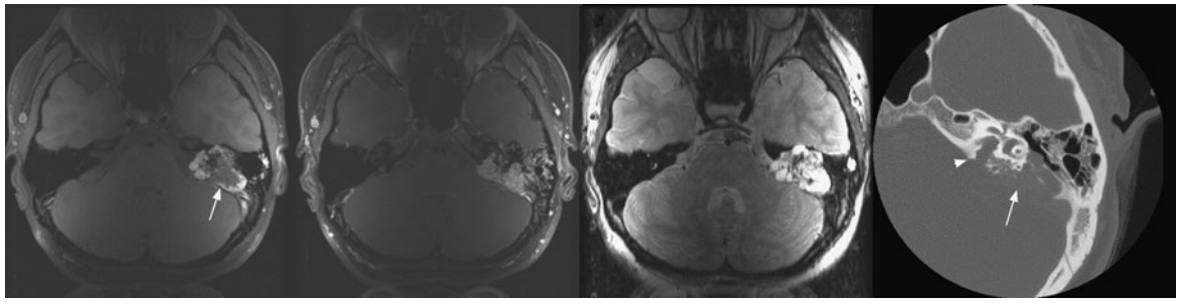
General Considerations

Endolymphatic sac tumors are extremely uncommon and are most often identified in young patients with von Hippel–Lindau disease, an autosomal dominant disease with multiple central nervous system and retinal hemangioblastomas, renal cell carcinoma, pancreatic cysts, and islet cell tumors. Von Hippel–Lindau disease is caused by germline mutations of the tumor suppressor gene located on chromosome 3p25. Isolated endolymphatic sac tumors can occur as well. Tumors arise from the cuboidal epithelium of the endolymphatic sac and are low-grade adenocarcinomas, with both papillary and cystic areas. They are highly vascular. The hallmark of these tumors is that they invade the inner ear and infiltrate bone, including the otic capsule.

Clinical Findings

A. Symptoms and Signs

The aggressive, infiltrative behavior of these tumors leads to the primary symptoms of sensorineural hearing loss, pulsatile



▲ **Figure 65–9.** Endolymphatic sac tumor. Axial views. **(A)** T1-weighted MRI demonstrates an infiltrative tumor of the posterior temporal bone (arrow) with some areas of low intensity (representing tumor) and some areas of high intensity (representing proteinaceous fluid). **(B)** The addition of gadolinium contrasts makes the entire tumor of high signal intensity. **(C)** T2-weighted MRI demonstrates high signal intensity. **(D)** CT scan of the temporal bone demonstrates significant bony destruction of both the mastoid air cells and the otic capsule bone (arrow). The IAC (arrowhead) is infiltrated with tumor.

tinnitus, imbalance, and facial nerve paralysis. Physical examination may demonstrate a reddishpurple middle ear mass on otoscopy that originates from the mastoid.

B. Imaging Studies

CT and MRI demonstrate an enhancing mass based in the posterior cranial fossa with erosion of the posterior face of the temporal bone and the otic capsule (Figure 65–9). The signal intensity on T1- and T2-weighted images without contrast is heterogeneous because of areas of mucin collection with variable protein and fluid content. Small tumors may only be detectable as erosion of the endolymphatic duct.

▶ Treatment

Treatment is complete surgical excision, usually via a transcochlear approach with obliteration of the middle ear and mastoid and with closure of the external auditory canal. The dura of the posterior and possibly the middle cranial fossa also need to be resected. If the disease extends intradurally, this also needs to be removed. Close follow-up of these patients is indicated, reserving the use of radiation therapy for unresectable, recurrent disease.

12. Carcinoma

Carcinoma arising primarily within the temporal bone is rare. However, the mucosa of the middle ear may dedifferentiate into carcinoma, including squamous cell carcinoma and adenocarcinoma. Patients with squamous cell carcinoma originating from the middle ear have a high likelihood of having had a long history of chronic otitis media, suggesting that squamous metaplasia with subsequent chronic inflammation may underlie the etiology of the tumor. More commonly, patients have squamous cell carcinoma that originated from the skin of the ear canal and has grown medial to the tympanic membrane, invading the temporal bone. These tumors present in middle-aged adults as a painful, chronically draining ear. An aural polyp or external auditory canal lesion may be noted. These patients are usually treated with a temporal bone resection, parotidectomy, and neck dissection. A free flap or regional myocutaneous flap may be needed to close a soft tissue defect. Postoperative radiation therapy is usually given.

13. Metastatic Disease

▶ General Considerations

The most common primary sites of malignant growth that spreads to the temporal bone are the breasts (25%), the lungs (11%), the kidneys (9%), the stomach (6%), the bronchus (6%), and the prostate (6%). The most common route of metastasis to the temporal bone is via hematogenous spread. The most common site of disease metastatic to the temporal bone is the petrous apex (33%), and the second most common is the IAC (16%).

▶ Clinical Findings

A. Symptoms and Signs

Growth of the lesion may interfere with eustachian tube function, producing middle ear effusion and conductive hearing loss. The facial nerve and inner ear may become infiltrated as well. The most common symptoms

of metastasis to the temporal bone are hearing loss (60%), facial paralysis (50%), and vertigo (30%). Commonly, these symptoms are overshadowed by other systemic symptoms because temporal bone metastases occur late in the disease process. Meningeal carcinomatosis can also occur, producing headache, altered mental status, and cranial neuropathy. Concurrent brain metastasis can be found in 26% of patients.

B. Imaging Studies

CT scanning usually reveals an osteolytic lesion, although breast and prostate metastatic lesions may demonstrate new bone growth consistent with osteoblastic activity. MRI reveals an intermediate signal intensity on T1-weighted images and a high signal intensity on T2-weighted images. The lesion enhances brightly with gadolinium contrast. A bone scan can be quite useful in making the diagnosis of metastasis.

Treatment & Prognosis

Treatment for temporal bone metastasis is directed toward palliative care. The prognosis for these patients is universally poor. External-beam radiation therapy or radiation therapy can be offered to the patient with symptomatic temporal bone metastasis.

Butman JA, Kim HJ, Baggenstos M, et al. Mechanisms of morbid hearing loss associated with tumors of the endolymphatic sac in von Hippel–Lindau disease. *JAMA*. 2007;;298(1):41–48. [PMID: 17609489]

Oghalai JS, Buxbaum JL, Jackler RK et al. Skull base chondrosarcoma originating from the petroclival junction. *Otol Neurotol*. 2005;26:1052. [PMID: 16151358] (Review of chondrosarcoma.)

Sbeity S, Abella A, Arcand P et al. Temporal bone rhabdomyosarcoma in children. *Int J Pediatr Otorhinolaryngol*. 2007;71(5):807–814. Epub 2007 Mar 8. [PMID: 17346806]

Neurotologic Skull Base Surgery

66

Robert K. Jackler, MD

Although in widespread use, the term "skull base surgery" is somewhat of a misnomer. Only a minority of such procedures are undertaken to expose lesions actually located primarily within the skull base. Most procedures are conducted to expose deep-seated intracranial lesions situated either adjacent to the brainstem (eg, midbrain, pons, or medulla) or beneath the cerebral cortex. Previously, many such tumors were approached via simple openings in the calvaria, which require vigorous and often injurious degrees of brain retraction.

The fundamental principle in transbasal craniotomy is removal of the skull base bone to minimize the need for brain retraction. Although current techniques represent a major enhancement in our ability to control inaccessible tumors while minimizing morbidity, they are not panaceas. For example, experience has shown that these procedures are far more suitable for benign lesions (eg, meningiomas, schwannomas, and paragangliomas) and even for low-grade malignant growths (eg, chordomas and chondrosarcomas) than for high-grade malignant lesions (eg, squamous cell carcinoma, adenocystic carcinoma, and soft tissue sarcomas). Currently, more emphasis is placed on the preservation of function, especially cranial nerves, than on the necessity for radical resection in every case. The value of neurophysiologic nerve monitoring for motor nerves within the surgical field has become well established. In the developmental years of skull-base surgery, two-stage procedures were common. More recently, single-stage procedures have become preferred in most centers, even for tumors with sizable intra- and extracranial components, as well as those involving multiple cranial fossae. Computerized imaging modalities provide localizing information that guides the surgeon around vital structures and helps to enable thorough tumor removal.

Jackler RK. *Atlas of Skull Base Surgery and Neurotology.* Theime, 2009

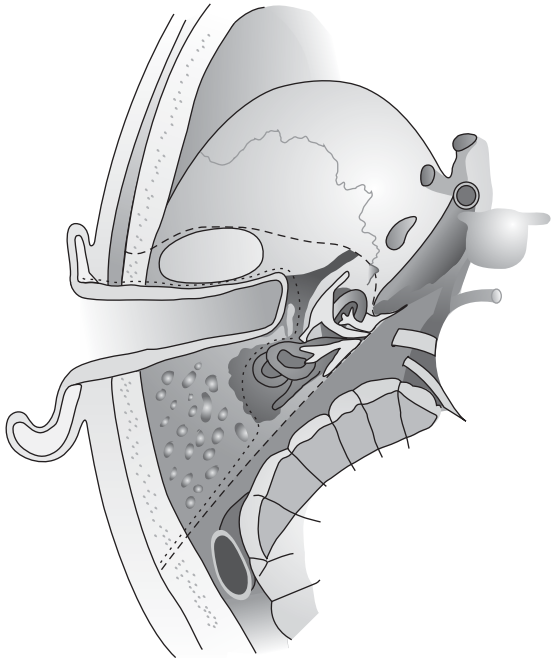
APPROACHES TO CRANIAL BASE LESIONS

TEMPORAL BONE

Temporal bone resection is a fairly radical operation conducted for malignant disease, particularly squamous cell carcinoma originating in the external auditory canal. Some other indications include adenomatous tumors, such as the aggressive papillary adenocarcinoma of the endolymphatic sac and those arising in salivary tissue (eg, adenocystic carcinoma). In most cases, the lateral portion of the temporal bone housing the ear canal is removed en bloc (Figure 66–1). The posterior margin consists of the dural lining of the petrous pyramid, which is exposed via mastoidectomy. The anterior margin often includes some or all of the parotid gland and, at times, the mandibular condyle and the temporomandibular joint (Figure 66–2).

Most surgeons remove more deeply involved regions (eg, the cochlea, semicircular canal, and internal auditory canal) piecemeal, using a high-speed drill as resection en bloc risks injury to the internal carotid artery. In advanced lesions, the resection can be carried medially to the internal carotid artery, but its resection is seldom justified. After resection of the condyle, exenteration of the pterygoid muscles, including the third division of the trigeminal nerve to the level of the pterygoid plates, may be accomplished in deeply penetrating lesions. As a general rule, if the facial nerve works preoperatively, a diligent effort should be made to preserve it, although this is not always feasible and engraftment may be needed.

Reconstruction of the defect needs to anticipate the need for radiation therapy. Leaving an open cavity increases the risk of osteoradionecrosis. For this reason, the external auditory meatus is typically sewn shut. A rotation flap of temporalis muscle is often desirable to reinforce the closure with well-vascularized tissue. Regional (eg, pectoralis or trapezius) or even free (rectus abdominis) flaps may be needed for closure in cases where auriculectomy has been required.



▲ **Figure 66–1.** The degrees of temporal bone resection. The solid lines demarcate the so-called sleeve resection of the soft tissue of the canal. This is an insufficient approach to malignant tumors of the region. The dotted lines depict subtotal temporal bone resection. The dashed lines illustrate total temporal bone resection. (Reprinted with permission of Jackler RK.)

Dean NR, White HN, Carter DS et al. Outcomes following temporal bone resection. *Laryngoscope.* 2010;120(8):1516–1522. [PMID: 20641083]

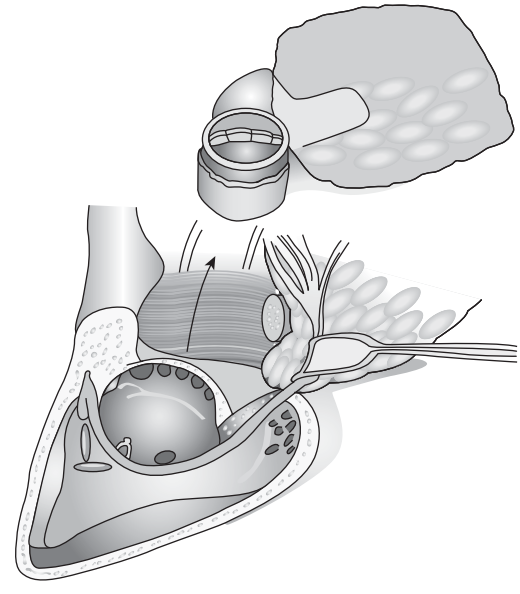
Gidley PW, Roberts DB, Sturgis EM. Squamous cell carcinoma of the temporal bone. *Laryngoscope.* 2010;120(6):1144–1151. [PMID: 2051303]

Smith JE, Ducic Y, Adelson RT. Temporalis muscle flap for reconstruction of skull base defects. *Head Neck.* 2010;32(2):199–203. [PMID: 19557763]

PETROUS APEX, PETROCLIVAL JUNCTION, & FORAMEN LACERUM

1. Petrous Apicotomy

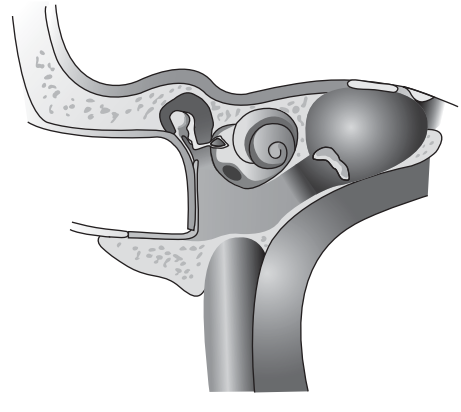
The majority of procedures conducted for disease in the petrous apex involve creation of a narrow drainage pathway that circumnavigates the inner ear. Such procedures, which are usually carried out to drain petrositis or cholesterol granulomas, are best-termed petrous apicotomy (Figure 66–3). In the subcochlear route, a channel is excavated along the floor of the external auditory canal and the hypotympanum,



▲ **Figure 66–2.** Temporal bone resection with a specimen, en bloc, including the external auditory canal, the mandibular condyle, and a portion of the parotid gland. (Reprinted with permission of Jackler RK.)

which traverses the narrow window between the cochlea, the carotid genu, and the dome of the jugular bulb.

An alternate pathway is the infralabyrinthine approach, conducted between the posterior semicircular canal and the jugular bulb, immediately behind the descending portion of the facial nerve. However, because most apical cysts are located anteriorly medial to the cochlea, the infralabyrin-



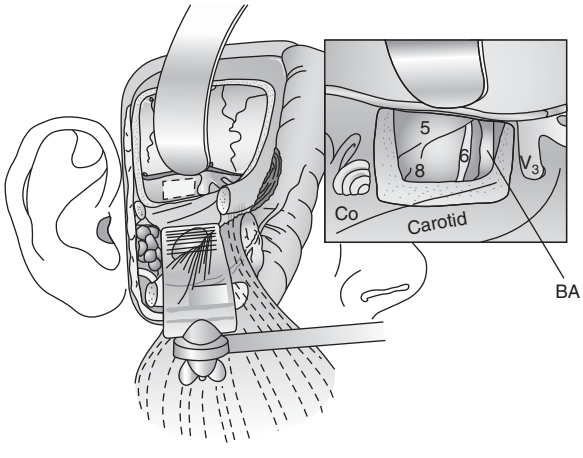
▲ **Figure 66–3.** Petrous apicotomy is a narrow drainage opening created circumventing the inner ear to drain an apical fluid collection (cholesterol granuloma or infection). (Reprinted with permission of Jackler RK.)

thine route is deeper, more difficult, and creates a less adequate drainage portal. Apical cysts which extend medial to the carotid artery can sometimes be marsupialized onto the nose via an endoscopic transsphenoidal approach.

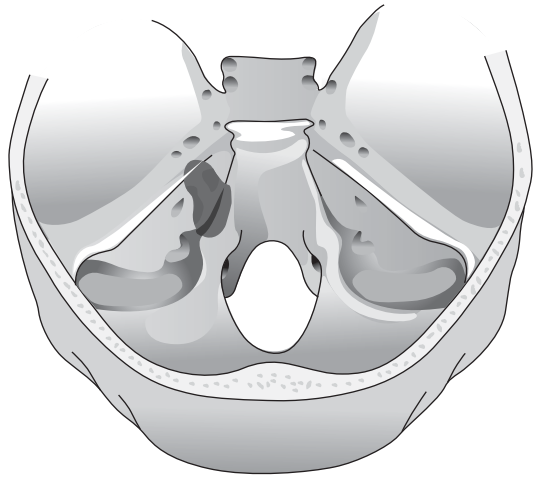
Jacob CE, Rupa V. Infralabyrinthine approach to the petrous apex. *Clin Anat.* 2005;18(6):423. [PMID: 1601561]
Leung R, Samy RN, Leach JL et al. Radiographic anatomy of the infracochlear approach to the petrous apex for computer-assisted surgery. *Otol Neurotol.* 2010;31(3):419–423. [PMID: 20084044]
Zanation AM, Snyderman CH, Carrau RL et al. Endoscopic endonasal surgery for petrous apex lesions. *Laryngoscope.* 2009;119(1):19–25. [PMID: 19117306]

2. Petrous Apicectomy

Petrous apicectomy, the formal removal of the petrous apex, is conducted for neoplasms of the apex and petroclival junction. It is conducted via a low subtemporal craniotomy, which exposes the anterior face of the petrous pyramid (Figure 66–4). Anatomically, the resection is limited inferiorly by the horizontal portion of the internal carotid artery, laterally by the cochlea and internal auditory canal, and medially by Meckel cave and the trigeminal nerve. Exposing the infratemporal fossa beneath the internal carotid artery requires downfracture and subsequent repair of the zygomatic arch. The characteristic tumor of this region is the chondrosarcoma of the petroclival junction, which arises in the cartilaginous section of the foramen lacerum



▲ **Figure 66–4.** Petrous apicectomy is the surgical resection of the petrous apex and is carried out through a subtemporal exposure of the ventral surface of the petrous pyramid. Note the transapical view of the superior aspect of the cerebellopontine angle. Downward displacement of the zygomatic arch is optional. BA, basilar artery; Co, cochlear. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–5.** Chondrosarcoma of the petroclival junction arising from the cartilage of foramen lacerum. (Reprinted with permission of Jackler RK.)

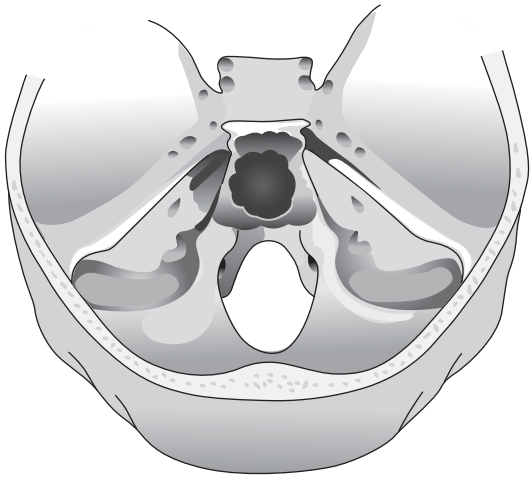
(Figure 66–5). Although it is not often necessary, apicectomy is sometimes used for the resection of cholesterol granulomas that have proven recalcitrant to drainage procedures.

Oghalai JS, Buxbaum JL, Jackler RK et al. Skull base chondrosarcoma originating from the petroclival junction. *Otol Neurotol.* 2005;26(5):1052. [PMID: 16151358]
Sanna M, Dispenza F, Mathur N et al. Otoneurological management of petrous apex cholesterol granuloma. *Am J Otolaryngol.* 2009;30(6):407–414. [PMID: 19880030]

CLIVUS

The clivus is not a bone in and of itself, but is rather a region composed of the dorsal part of the sphenoid bone and the portion of the occipital bone located anterior to the foramen magnum. The clivus, which, in Latin, means *slope*, spans from the posterior clinoid to the anterior margin of the foramen magnum. Adjacent to its dorsal surface is the entire brainstem and the vertebrobasilar system. The subject of clival tumors falls into two categories: (1) intrinsic tumors (especially chordomas) and (2) meningiomas arising from the dural lining of its dorsal surface.

Chordomas arise from notochordal remnants in the midline of the skull base (Figure 66–6). Initially, they grow to fill the clival marrow compartment but later erode its cortical plate to spread intradurally. This brings them into contact with the brainstem, which may be compressed posteriorly. Intrinsic clival lesions, which remain extradural, are approached anteriorly via either a **transsphenoethmoidal** or **transoral approach.** The transsphenoethmoidal approach is well suited for lesions of the mid and upper clivus, whereas



▲ **Figure 66–6.** Chordoma of the clivus with intracranial involvement due to breaching of the dorsal clival surface. (Reprinted with permission of Jackler RK.)

the transoral approach is preferred when lower clival and craniovertebral junction exposure is needed. Recently, endoscopic techniques are increasingly used in surgery of clival tumors.

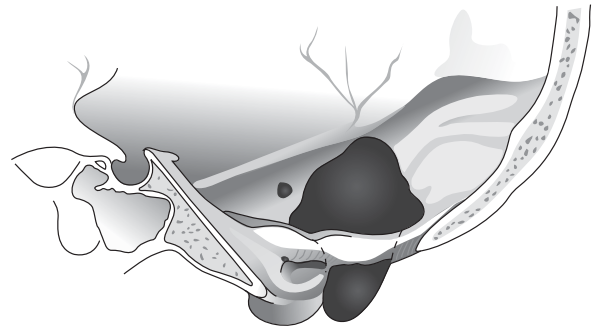
Morera VA, Fernandez-Miranda JC, Prevedello DM et al. "Far-medial" expanded endonasal approach to the inferior third of the clivus: the transcondylar and transjugular tubercle approaches. *Neurosurgery.* 2010;66(6):211–219; discussion 219–220. [PMID: 20489508]

Singh H, Harrop J, Schiffmacher P et al. Ventral surgical approaches to craniovertebral junction chordomas. *Neurosurgery.* 2010;66(3):96–103. [PMID: 20173533]

de Notaris M, Cavallo LM, Prats-Galino A, et al. Endoscopic endonasal transclival approach and retrosigmoid approach to the clival and petroclival regions. *Neurosurgery.* 2009;65(6):42–50; discussion 50–2. [PMID: 19935001]

JUGULAR FORAMEN

The jugular foramen is traversed by the jugular vein and the three lower cranial nerves (CN IX, the glossopharyngeal nerve; CN X, the vagus nerve; CN XI, the accessory nerve). The vertical segment of the facial nerve lies immediately lateral to the jugular foramen, presenting one of the classic challenges in cranial base surgery. The dome of the jugular bulb approaches the hypotympanic portion of the middle ear. Three tumor types predominate in tumors of this region: (1) glomus jugulare tumors, (2) meningiomas, and (3) lower cranial nerve schwannomas. These may remain confined to the cranial base, but most often possess a component in the upper neck, posterior cranial fossa, or both (Figure 66–7).

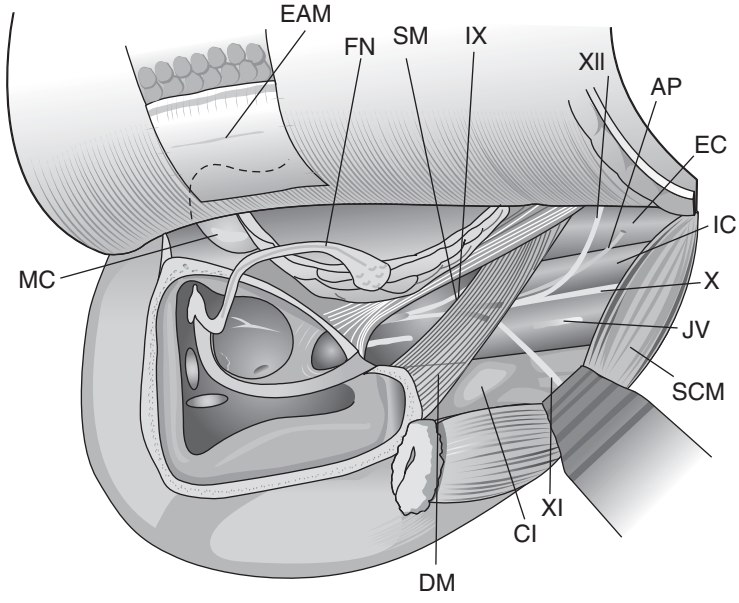


▲ **Figure 66–7.** Jugular foramen tumor with intracranial, foraminal, and extracranial component. (Reprinted with permission of Jackler RK.)

The jugular foramen approach begins control of the great vessels in the upper neck (Figure 66–8). Exposure of the foramen itself commences with a mastoidectomy and decompression of the bony covering of the sigmoid sinus. After skeletonization of the descending fallopian canal, the lateral aspect of the jugular foramen is exposed. Tumor resection commences after connecting the skull base and neck dissection followed by proximal and distal occlusion of the jugular vein (Figure 66–9).

Traditionally, many surgeons rerouted the facial nerve anterior to obtain unobstructed access to the jugular foramen. However, this frequently leads to transient palsy, which does not always recover to normal. More recently, a **fallopian bridge** technique has gained popularity. In this procedure, the facial nerve remains in situ, and microdissection is carried out around it (Figure 66–10). Some surgeons use facial nerve rerouting selectively when encasement of the carotid artery necessitates obtaining augmented anterior exposure.

Meningiomas and glomus tumors both have a proclivity for growing proximally into the sigmoid sinus and distally into the jugular view. Meningiomas and schwannomas are also more likely to involve the neural plane containing cranial nerves IX–XI, although these structures may certainly become involved with larger paragangliomas as well. To reduce blood loss and facilitate orderly microdissection, preoperative embolization is usually conducted. Tumor removal is conducted piecemeal, with resection of involved segments of the sigmoid–jugular system (typically occluded from disease) as required. Although preservation of the stout cranial nerves in the neck is usually readily accomplished, the multiple fine neural branches of the jugular foramen region can be a challenge to preserve when infiltrated by tumor. In such cases, meticulous microdissection, guided by neurophysiologic monitoring, can sometimes be rewarded by preservation of part or all of the lower nerve branches.

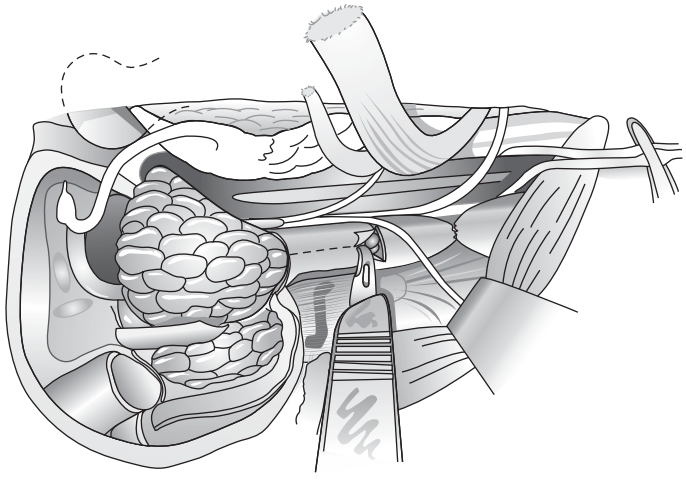


▲ **Figure 66–8.** Surgical exposure of the jugular foramen region after mastoidectomy, anterior rerouting of the facial nerve, and upper-neck dissection. MC, mandibular condyle; EAM, closed external auditory meatus; FN, facial nerve; SM, styloid muscle; IX, glossopharyngeal nerve; DM, digastric muscle; C1, the transverse process of C1; XI, accessory nerve; XII, hypoglossal nerve; AP, ascending pharyngeal artery; EC, external carotid artery; IC, internal carotid artery; X, vagus nerve; JV, jugular vein; SCM, sternocleidomastoid muscle. (Reprinted with permission of Jackler RK.)

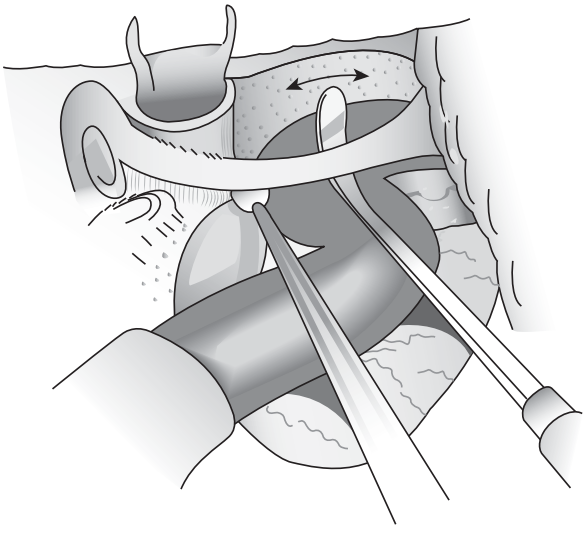
The removal of jugular foramen tumors can often be accomplished with preservation of the auditory apparatus. Resection of the middle ear and ear canal with closure of the meatus is necessary under two circumstances: (1) extensive destruction of the ear canal and (2) substantial involvement of the carotid genu (Figure 66–11). Intradural penetration of jugular foramen tumors will be discussed with transjugular craniotomy.

Borba LA, Araújo JC, de Oliveira JG et al. Surgical management of glomus jugulare tumors: A proposal for approach selection based on tumor relationships with the facial nerve. *J Neurosurg.* 2010;112(1):88–98. [PMID: 19425885].

Fayad JN, Keles B, Brackmann DE. Jugular foramen tumors: Clinical characteristics and treatment outcomes. *Otol Neurotol.* 2010 Feb;31(2):299–305. [PMID: 19779386]



▲ **Figure 66–9.** Large glomus jugulare tumor with retrograde spread into the sigmoid sinus and distal involvement of the lumen of the jugular vein. The hypotympanum is extensively eroded. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–10.** Fallopian bridge approach to the jugular foramen, leaving the descending facial nerve in situ. (Reprinted with permission of Jackler RK.)

Fukuda M, Oishi M, Saito A et al. Long-term outcomes after surgical treatment of jugular foramen schwannoma. *Skull Base.* 2009;19(6):401–408. [PMID: 20436841]

Roche PH, Mercier P, Sameshima T et al. Surgical anatomy of the jugular formen. *Adv Tech Stand Neurosurg.* 2008;33:233–63. [PMID: 18383816]

Sanna M, Bacciu A, Falcioni M et al. Surgical management of jugular foramen meningiomas: A series of 13 cases and review of the literature. *Laryngoscope.* 2007;117(10):1710–1719.

INFRATEMPORAL FOSSA

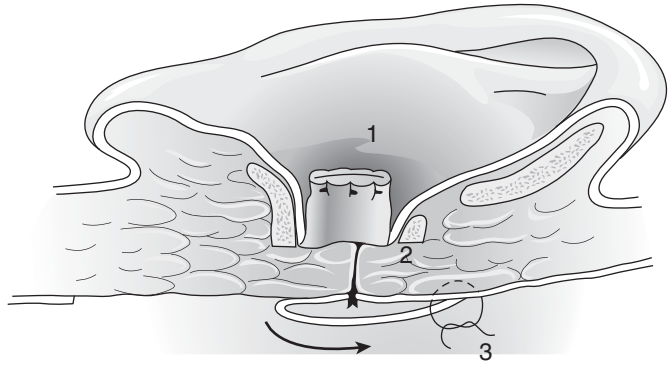
The infratemporal fossa is not a well-demarcated anatomic compartment but rather the region of the upper neck that lies beneath the temporal bone and the sphenoid wing. Within it are the jugular vein, the carotid artery, the styloid process, the third division of the trigeminal nerve, the eustachian tube, the pterygoid muscles and their associated bony plates, and a rather impressive venous plexus. Laterally, the infratemporal fossa is defended by the mandible (condyle and ramus) and the zygomatic arch. Medially, it is bounded by the nasopharynx and the lateral wall of the sphenoid sinus. As previously mentioned, jugular foramen tumors often involve the superficial portion of the infratemporal fossa in proximity to the great vessels. Tumors involving the deeper regions include trigeminal schwannomas in the vicinity of the foramen ovale and penetrating malignant neoplasms such as those from the deep lobe of the parotid gland and ear. The most common tumor involving the deep aspect of the infratemporal fossa is nasopharyngeal carcinoma.

Lesions involving the lateral portion of the infratemporal fossa, such as glomus jugulare tumors, are approached via a postauricular incision and include some degree of temporal bone surgery. More anteriorly situated lesions are approached preauricularly, often with access gained through downfracture of the zygomatic arch and either downward displacement or resection of the condyle. When necessitated by penetration of the skull base, the exposure can be combined with middle fossa craniotomy. Resection of the glenoid fossa and division of V3 is needed to expose Meckel cave and the cavernous sinus from this perspective. A reasonably functional pseudoarthrosis usually forms after resection of the glenoid. In one commonly used system of nomenclature, the various depths of infratemporal fossa dissection are referred to as approaches A, B, and C (Figures 66–12 and 66–13).

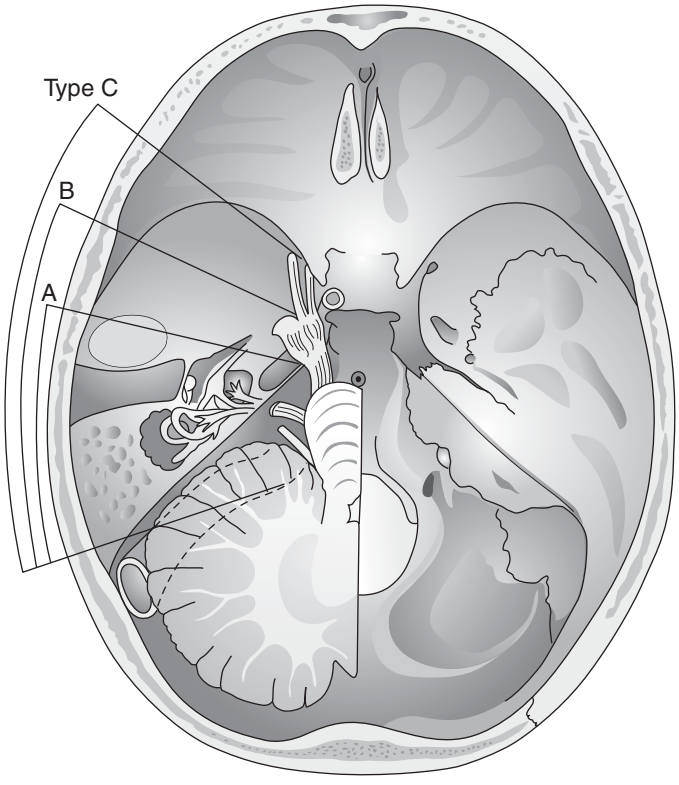
TRANSBASAL APPROACHES TO INTRACRANIAL NEOPLASMS

INTERNAL AUDITORY CANAL & CEREBELLOPONTINE ANGLE

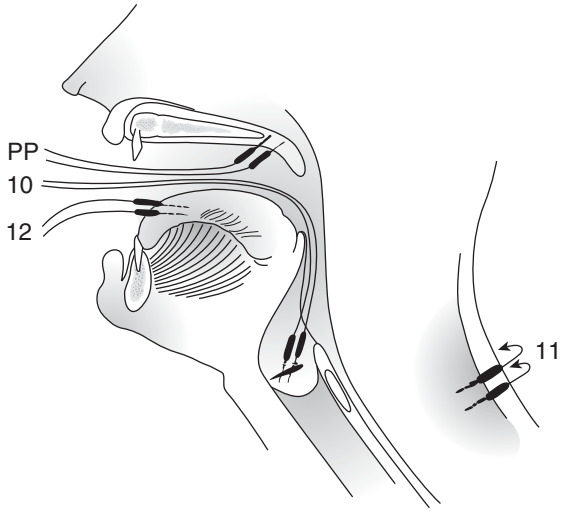
Surgery of tumors of the internal auditory canal (IAC) and cerebellopontine angle (CPA) is a central issue to neurotology. Some of the complex issues in this involved subject



▲ **Figure 66–11.** Ear canal closure is carried out with a meticulous three-layer technique to withstand cerebrospinal fluid pressure, if necessary. **(1)** everted canal skin; **(2)** subcutaneous tissue; **(3)** periosteum. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–12. I**nfratemporal fossa approaches types A, B, and C (after Fisch). (Reprinted with permission of Jackler RK.)

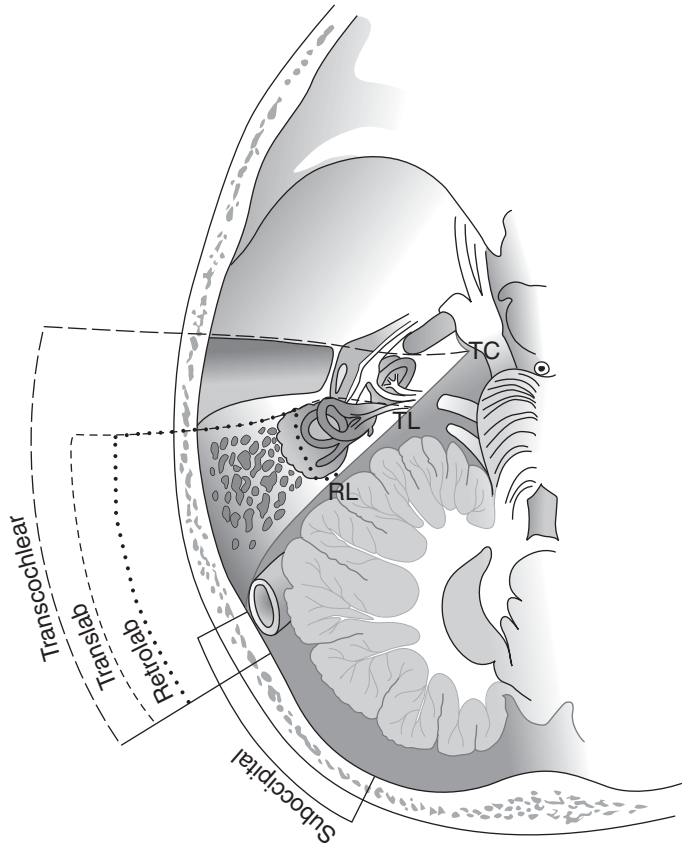


▲ **Figure 66–13.** Neurophysiologic monitoring of the lower cranial nerves in jugular foramen surgery. 10, vagus nerve; 11, accessory nerve; 12, hypoglossal nerve; PP, pharyngeal plexus. (Reprinted with permission of Jackler RK.)

are considered, in greater depth, in the chapter that discusses vestibular schwannomas (see Chapter 56, Vestibular Disorders). A decision among the three approaches in widespread use (translabyrinthine, retrosigmoidal, and middle fossa) depends on a number of variables such as size, shape, anatomic location, and pathologic type of tumor, as well as status of hearing (Figure 66–14).

1. Retrosigmoidal Approach

The retrosigmoidal approach is a classic means of exposing the CPA (Figures 66–15, 66–16, and 66–17). It provides wide access to the CPA from the tentorium to the foramen magnum. Although not relevant in vestibular schwannoma surgery, the retrosigmoidal approach provides enhanced access to the inferior region of the CPA when compared with the translabyrinthine approach. The opening is created by removing the calvaria immediately behind the sigmoid and below the transverse sinus. Retraction of the cerebellar hemisphere brings the CPA into view. Access to the IAC is obtained by drilling off its posterior bony lip. Approximately the medial two thirds of the IAC can be exposed without violating a portion of the inner ear. Thus, when the fundus of the canal is involved, direct exposure of the deepest portion



▲ **Figure 66–14.** Overview of posterior fossa approaches to the cerebellopontine angle: retrosigmoidal, retrolabyrinthine, translabyrinthine, and transcochlear. (Reprinted with permission of Jackler RK.)

of the tumor in the IAC precludes an attempt at hearing conservation. The primary disadvantage of the retrosigmoidal approach is a higher incidence of persistent headache when compared with the translabyrinthine or middle fossa approaches. Although still used routinely as a hearing conservation method in many centers, comparison data show that the middle fossa approach appears to be more successful in this regard, at least for tumors with modest-sized components within the CPA.

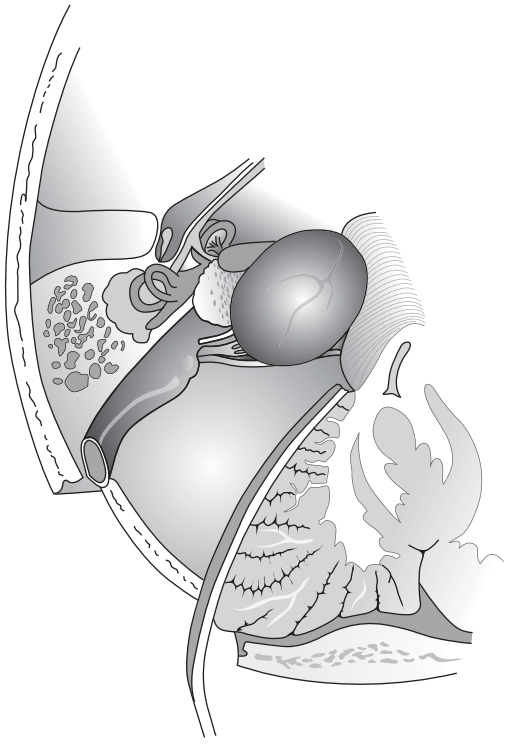
2. Translabyrinthine Approach

The translabyrinthine approach provides direct exposure of the CPA through the petrous pyramid, the shortest route from the surface (Figures 66–18 and 66–19). When properly performed, it provides excellent exposure of the lateral aspect of the pons and upper medulla. Exposure of the CPA is bounded superiorly by the tentorium cerebelli and inferiorly by the limitation imposed by the sigmoid sinus and jugular bulb. Because the opening provided by petrosectomy alone is fairly narrow, the exposure is augmented by removing the bone overlying the sigmoid sinus and a variable degree of retrosigmoidal posterior fossa dura (depending on the amount of posterior fossa exposure required). After mastoidectomy and decompression of the sigmoid sinus, removal of the semicircular canals brings into view the bone surrounding the IAC. Excavations around the IAC place it into high relief so that it is fully accessible for microsurgical dissection.

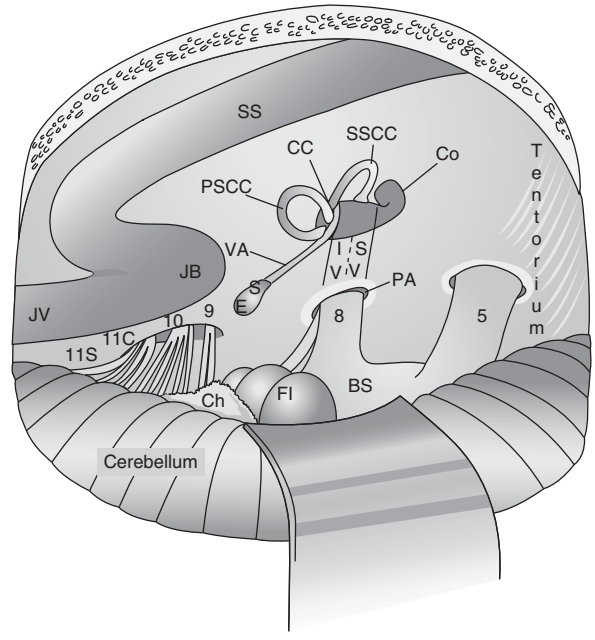
The translabyrinthine approach is primarily used for vestibular schwannomas, although it has some role in posterior fossa meningioma surgery as well. Since a portion of the inner ear is removed during the craniotomy, in most centers, this approach is used either for CPA tumors associated with poor hearing or for patients in whom hearing preservation is not a realistic option.

3. Middle Fossa Approach

The middle fossa approach provides exposure to the IAC from above and limited access to the CPA (Figure 66–20). Most centers do not use this approach for tumors exceeding approximately 1.5 cm in CPA diameter. After removal of an approximately 3.0 cm by 3.0 cm plate of calvaria above the ear, the temporal lobe is elevated extradurally off the petrous



▲ **Figure 66–15.** Overview of the retrosigmoidal approach from an axial perspective. Note the removal of the posterior lip of the internal auditory canal. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–16.** Operative view of the cerebellopontine angle via the retrosigmoidal approach. JV, jugular vein; JB, jugular bulb; 11S, spinal root of accessory nerve; 11C, cranial root of accessory nerve; 10, vagus nerve; 9, glossopharyngeal nerve; ES, endolymphatic sac; VA, vestibular aqueduct; PSCC, posterior semicircular canal; CC, common crus; SSCC, superior semicircular canal; Co, cochlea; IV, inferior vestibular nerve; SV, superior vestibular nerve; PA, porus acusticus; Ch, choroids plexus; Fl, flocculus; BS, brainstem; 7, facial nerve; 8, audiovestibular nerve; 5, trigeminal nerve. (Reprinted with permission of Jackler RK.)

floor. With the exposure maintained through a specially designed retractor, the bone is removed from the superior aspect of the IAC. Wide excavation of the petrous apex and the region of the porus acusticus provides limited access to the CPA from above. The primary advantage of the middle fossa approach is its superior ability to preserve hearing. The primary disadvantage is the inconvenient location of the facial nerve on the superior surface of the tumor that must be manipulated to a greater degree and thus has a higher rate of temporary postoperative dysfunction.

Baumann I, Polligkeit J, Blumenstock G et al. Quality of life after unilateral acoustic neuroma surgery via middle cranial fossa approach. *Acta Otolaryngol.* 2005;125(6):585. [PMID: 16076706]

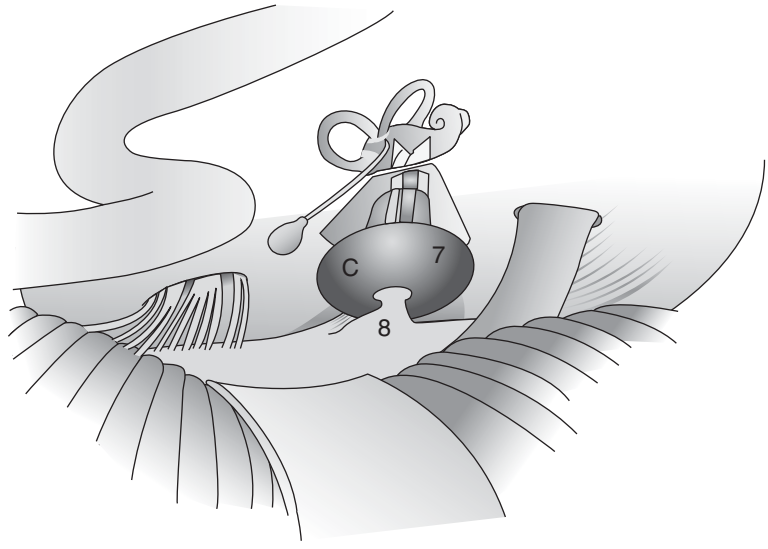
Ciric I, Zhao JC, Rosenblatt S,et al. Suboccipital retrosigmoid approach for removal of vestibular schwannomas: Facial nerve function and hearing preservation. *Neurosurgery.* 2005;56(3):560; discussion 560. [PMID: 15730582]

Pellet W, Moriyama T, Thomassin JM. Translabyrinthine approach for vestibular schwannomas: Operative technique. *Roche PH, Prog Neurol Surg.* 2008;21:73–78. [PMID: 18810201]

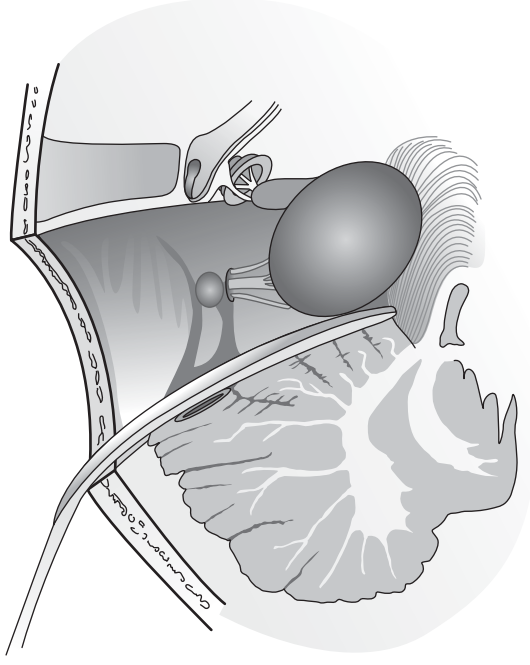
Shiobara R, Ohira T, Inoue Y et al. Extended middle cranial fossa approach for vestibular schwannoma: Technical note and surgical results of 896 operations. *Prog Neurol Surg.* 2008;21:65–72. [PMID: 18810200]

INTRACRANIAL ASPECTS OF THE JUGULAR FORAMEN

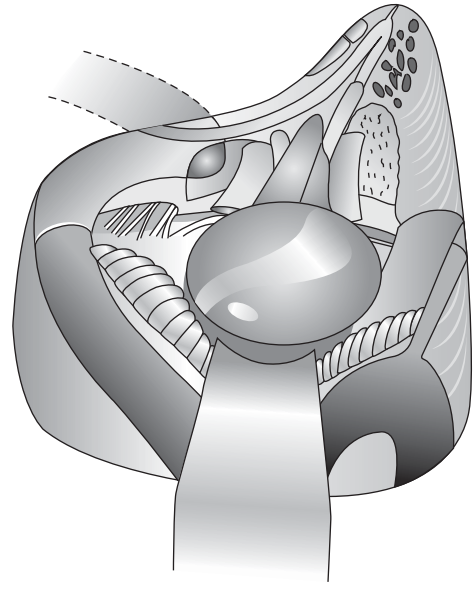
Meningiomas, schwannomas, and paragangliomas frequently extend intracranially. Meningiomas and schwannomas originate in the intracranial compartment, whereas glomus tumors spread posteriorly from their skull base component via either the neural portion of the foramen or by penetrating the posterior surface of the jugular bulb or sigmoid sinus. In the past, these tumors were commonly approached with a multistage procedure in which the skull base and neck component were removed separately from the intracranial



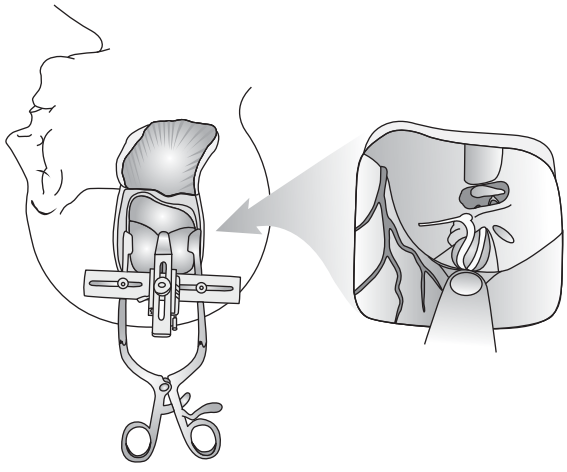
▲ **Figure 66–17.** Retrosigmoidal approach to a small vestibular schwannoma that extends only partly down the internal auditory canal. Note that the inner ear overlies the lateral one third of the internal auditory canal. C, cochlear nerve; 7, facial nerve; 8, audiovestibular nerve. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–18.** Overview of the translabyrinthine approach from an axial perspective. Note that the craniotomy extends from the posterior edge of the external auditory canal to a distance behind the sigmoid sinus, which is posteriorly displaced. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–19.** Translabyrinthine approach to a mediumsized vestibular schwannoma. Note the deviation and splaying of the facial nerve on the anterior surface of the tumor. (Reprinted with permission of Jackler RK.)



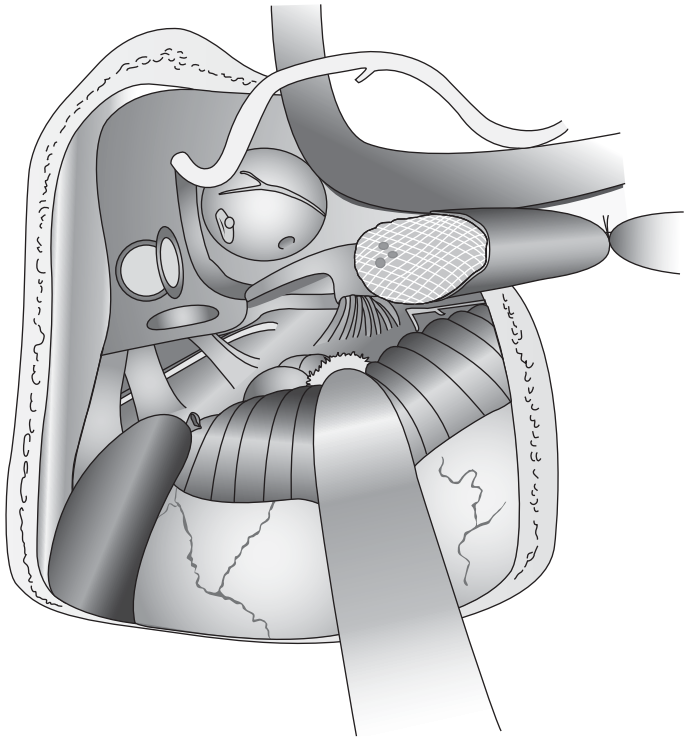
▲ **Figure 66–20.** Middle fossa approach to the internal auditory canal and cerebellopontine angle. (Reprinted with permission of Jackler RK.)

portion. The current trend is toward a single-stage removal via a **transjugular craniotomy.** This procedure involves the creation of a posterior fossa craniotomy through resection of the sigmoid sinus and jugular bulb, both of which have usually been occluded by tumor growth (Figures 66–21 and 66–22). This maneuver provides direct visualization of the intracranial aspect of the jugular foramen, including the lower nerve roots emanating from the lateral aspect of the medulla.

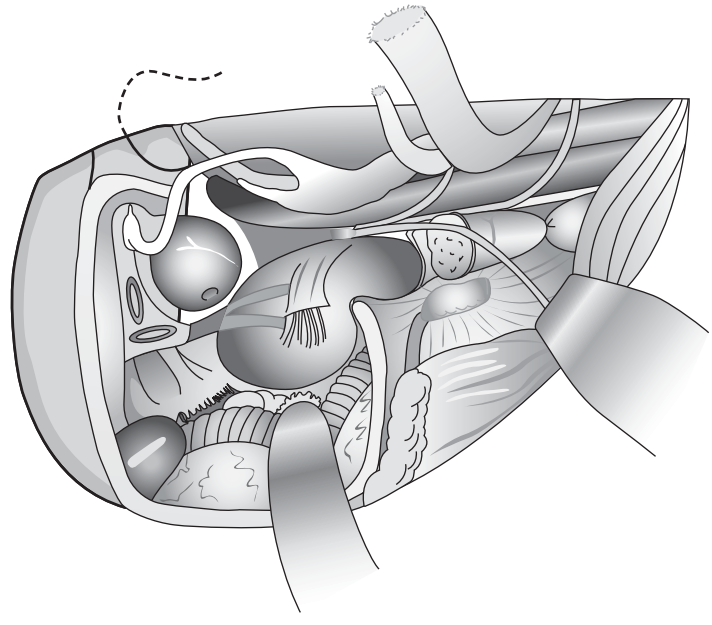
Some tumors, especially meningiomas, but occasionally lower cranial nerve schwannomas as well, are largely intracranial with little or no foraminal involvement. In such cases, a retrosigmoidal approach is appropriate. It is possible, from this perspective, to drill open the introitus of the intracranial aspect of the jugular foramen from above.

Oghalai JS, Leung MK, Jackler RK. Transjugular craniotomy for the management of jugular foramen tumors with intracranial extension. *Otol Neurotol.* 2004;25(4):570; discussion 579. [PMID: 15241237]

Sanna M, Bacciu A, Falcioni M et al. Surgical management of jugular foramen meningiomas: A series of 13 cases and review of the literature. *Laryngoscope.* 2007;117(10):1710–1719. [PMID: 17690614]



▲ **Figure 66–21.** Transjugular craniotomy is conducted through resection of the sigmoid-jugular system (usually occluded preoperatively by tumor growth). This affords an excellent view of the intracranial aspect of the jugular foramen nerves as well as the lateral aspect of the pons and upper medulla. Note that although the facial nerve is rerouted in this illustration, this is not necessary in most cases. (Reprinted with permission of Jackler RK.)



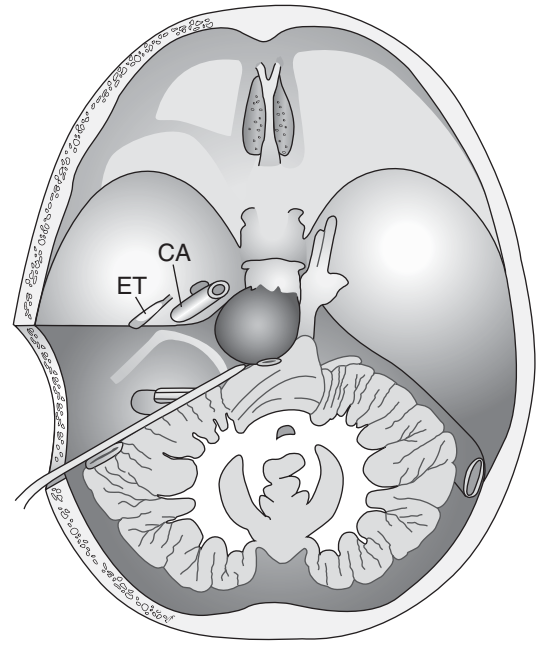
▲ **Figure 66–22.** A jugular foramen schwannoma as visualized through a transjugular craniotomy. (Reprinted with permission of Jackler RK.)

THE VENTRAL SURFACE OF THE BRAINSTEM

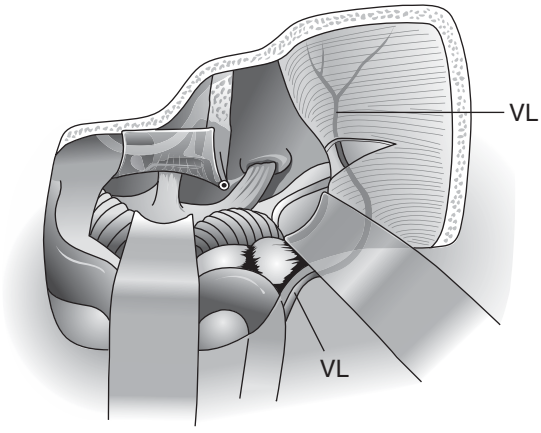
1. Transcochlear Approach

In the past, lesions situated anterior to the brainstem were considered to be unresectable. Typical tumors of the region include clival meningiomas and chordomas that had broken through the posterior surface of the clivus to become intradural. **Radical petrosectomy**, also known as the transcochlear approach, is one method used to expose this inaccessible region (Figure 66–23). This procedure entails complete rerouting of the facial nerve, which results in a complete paralysis that recovers only partially and with synkinesis; sacrifice of the entire inner ear; closure of the external auditory meatus and eustachian tube; and skeletonization of the intrapetrous carotid artery. After removal of the apical petrous bone, petroclival junction, and even the lateral aspect of the clivus, an excellent view of the ventral surface of the pons and upper medulla is obtained with minimal brain retraction. Although this method affords excellent exposure, it is associated with high morbidity, including ipsilateral deafness and permanent facial nerve dysfunction. In recent years, this aggressive technique has become increasingly supplanted by the so-called combined approach craniotomies.

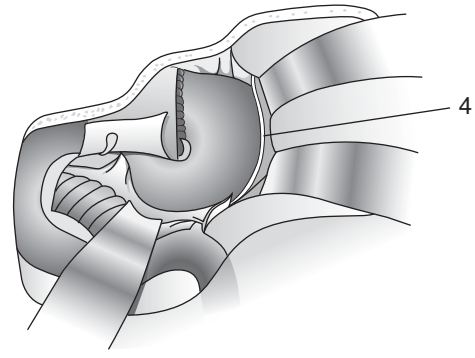
De la Cruz A, Teufert KB. Transcochlear approach to cerebellopontine angle and clivus lesions: Indications, results, and complications. *Otol Neurotol.* 2009;30(3):373–380. [PMID: 19318889]



▲ **Figure 66–23.** Transcochlear approach to a prepontine tumor. The anterior limits are the eustachian tube, which has been obliterated with bone wax and the carotid artery. Note that the facial nerve has been rerouted. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–24.** Combined retrolabyrinthine-subtemporal craniotomy with access to the lateral aspect of the pons and midbrain. Note the preservation of the semicircular canals and endolymphatic sac. The posterior and middle cranial fossae have been made confluent by division of the tentorium. The vein of Labbé is noted on the temporal lobe and joining the transverse sinus. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–25.** Combined retrolabyrinthine-subtemporal craniotomy for a meningioma with substantial components in both the middle and posterior cranial fossae. Note the trochlear nerve (4) on the superior surface of the tumor. (Reprinted with permission of Jackler RK.)

Sincoff EH, McMenomey SO, Delashaw JB Jr. Posterior transpetrosal approach: Less is more. *Neurosurgery.* 2007;60(2 Suppl 1). [PMID: 17297365].

2. Retrolabyrinthine-Subtemporal Approach

In the combined retrolabyrinthine-subtemporal approach (also called simply the **petrosal approach**), a limited presigmoid petrosectomy is combined with a subtemporal opening (Figures 66–24 and 66–25). The two fossae are connected by division of the tentorium. This affords a wide exposure of the lateral aspect of the midbrain, pons, and medulla. This versatile approach has become the heavily used option in modern neurotology for a wide range of tumors in and around the brainstem. Although exposure is limited in the inferior reaches of the CPA by the sigmoid sinus and jugular bulb, superiorly it readily exposes the cavernous sinus. A partial (retrolabyrinthine) petrosectomy is usually chosen as this approach allows for hearing preservation. In lesions predominantly involving the anterior midline, a greater degree of petrosectomy (eg, translabyrinthine or even transcochlear) may be needed. During a combined-approach craniotomy, care must be taken in elevation and retraction of the posterior temporal lobe to avoid injury to the vein of Labbé. Injury to this bridging vein may result in a venous infarct of the temporal-parietal cortex.

Behari S, Tyagi I, Banerji D et al. Postauricular, transpetrous, presigmoid approach for extensive skull base tumors in the petroclival region: The successes and the travails. *Acta Neurochir (Wien).* 2010 Oct;152(10):1633–1645.

Bambakidis NC, Gonzalez LF et al. Combined skull base approaches to the posterior fossa. *Neurosurg Focus.* 2005;19:1. [PMID: 16122215]

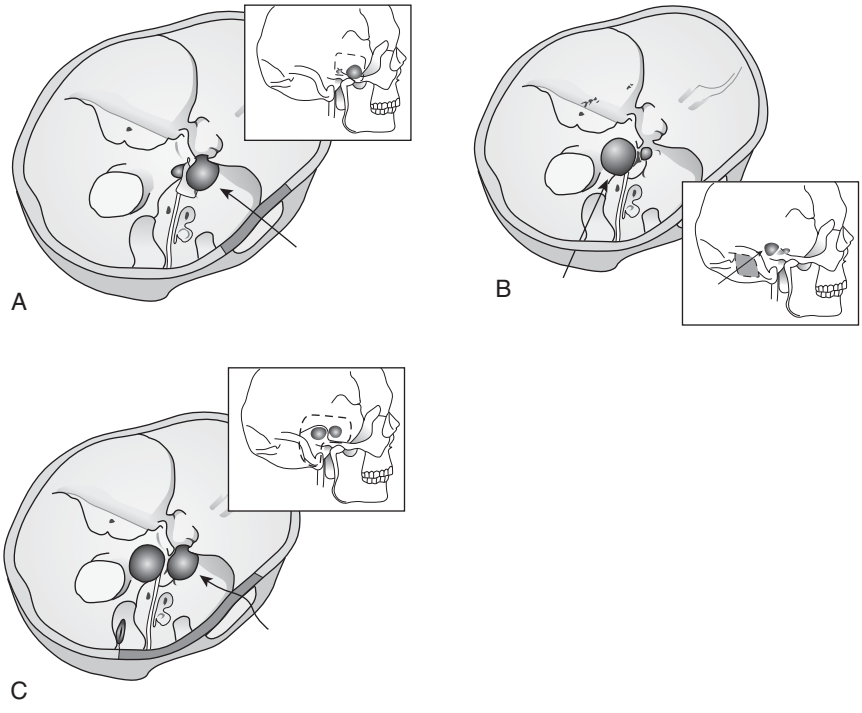
MECKEL CAVE

Meckel cave, also known as the cavum trigeminale, overlies the petroclival junction. Traversing it is the semilunar ganglion of the fifth cranial nerve (the trigeminal nerve). In close relationship, anteromedially is the cavernous sinus. Posteriorly, its mouth opens into the superior aspect of the CPA. The oculomotor nerves IV and VI are in the immediate vicinity of the roof of Meckel cave. Because of the rich representation of arachnoid granulations in this region, meningiomas are especially prevalent. The second most common lesion is trigeminal schwannoma.

The optimal surgical exposure of Meckel cave depends upon whether the tumor is dominantly in the middle fossa, posterior fossa, or bilobed (Figure 66–26**A–C**). Middle fossa lesions are approached via a subtemporal craniotomy. Posterior fossa lesions are exposed via a standard retrosigmoidal approach, modified, when necessary, by drilling open the posterior aspect of the Meckel cave. In current practice, a bilobed lesion with substantial components in both posterior and middle cranial fossae is addressed by a single opening that connects both fossa (retrolabyrinthine-subtemporal).

Danner C, Cueva RA. Extended middle fossa approach to the petroclival junction and anterior cerebellopontine angle. *Otol Neurotol.* 2004;25(5):762. [PMID: 15354008]

Koerbel A, Kirschniak A, Ebner FH et al. The retrosigmoid intradural suprameatal approach to posterior cavernous sinus: Microsurgical anatomy. *Eur J Surg Oncol.* 2009;35(4):368–372. [PMID: 18378110]



▲ **Figure 66–26.** Surgery for tumors of Meckel cave. **(A)** Middle fossa predominant lesions are approached subtemporally. **(B)** Posterior fossa predominant lesions are approached retrosigmoidally. **(C)** Bilobed lesions are exposed via a combined craniotomy. (Reprinted with permission of Jackler RK.)

Zhang L, Yang Y, Xu S et al. Trigeminal schwannomas: A report of 42 cases and review of the relevant surgical approaches. *Clin Neurol Neurosurg.* 2009;111(3):261–269. [PMID: 19081670]

FORAMEN MAGNUM & CRANIOVERTEBRAL JUNCTION

The exposure of posterior lesions of foramen magnum presents relatively little challenge. Extradural lesions located ventral to the craniovertebral junction are usually approached transorally (eg, lower clival chordoma or odontoid displacement upward). Intradural lesions in this ventral location, such as meningiomas, require a sterile approach from a lateral perspective. The far lateral (transcondylar) approach has been devised for just such cases (Figure 66–27; see also Figure 66–26). After a retrosigmoidal craniotomy and removal of the posterior ring of the foramen magnum, the posterior margin of the jugular foramen is skeletonized. Working beneath the jugular foramen, the cerebellum is elevated extradurally while a variable portion of the occipital condyle is removed. Usually, adequate exposure is obtained following the removal of approximately half of the condyle. Additional condylar resection may lead to instability that requires the insertion of hardware for stabilization. Resection of the tumor ventral to the medulla and upper spinal cord is carried out between the lower cranial nerve roots and the upper spinal roots.

Karam YR, Menezes AH, Traynelis VC. Posterolateral approaches to the craniovertebral junction. *Neurosurgery.* 2010;66(3):135–140. [PMID: 20173516]

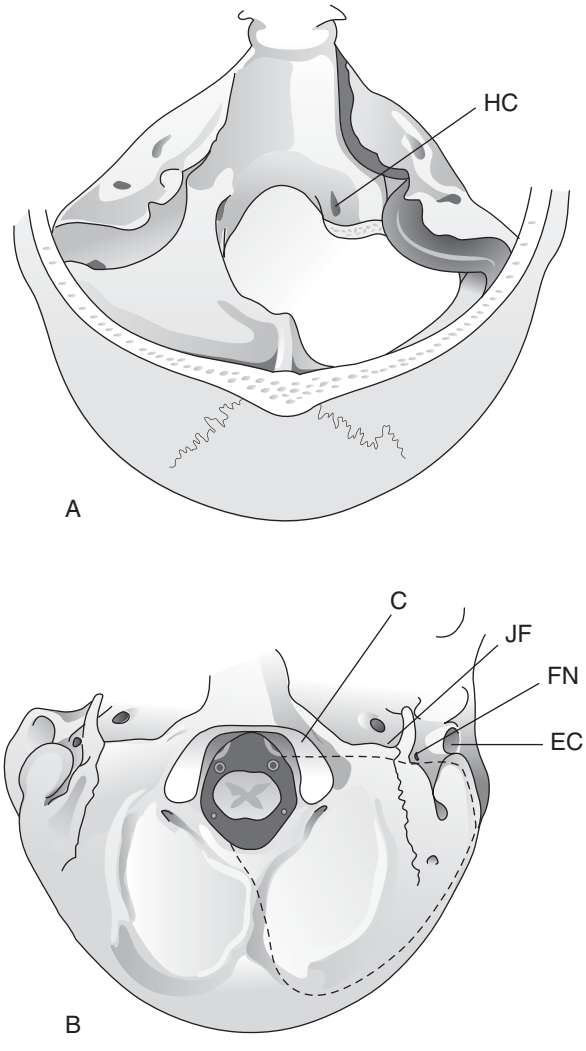
Sen C, Shrivastava R, Anwar S et al. Lateral transcondylar approach for tumors at the anterior aspect of the craniovertebral junction. *Neurosurgery.* 2010;66(3):104–112. [PMID: 20173511]

Suhardja A, Agur AM, Cusimano MD. Anatomical basis of approaches to foramen magnum and lower clival meningiomas: Comparison of retrosigmoid and transcondylar approaches. *Neurosurg Focus.* 200315;14(6):9. [PMID: 15669794]

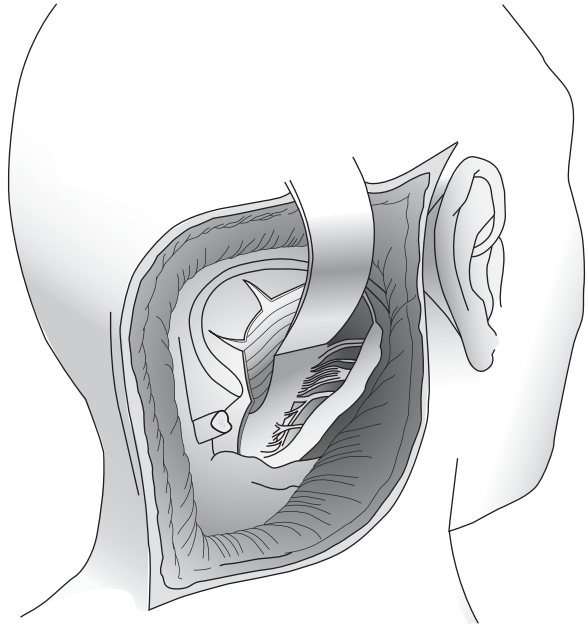
VERTEBROBASILAR LESIONS

Neurotologic cranial base approaches have a role in the exposure of aneurysms of the posterior circulation. The **subtemporal transapical approach**, similar to that used for an apical petrosectomy (noted previously), was initially devised as a means of both exposing basilar tip aneurysms and establishing proximal control of the intrapetrous carotid (see Figure 66–4). Through the window created in the petrous apex, access is provided to the upper basilar artery. The transcochlear approach is capable of providing access for midbasilar artery aneurysms. Similarly, the transcondylar approach has use in approaching vascular lesions in the region of the vertebrobasilar junction.

Kumar CR, Vannemreddy P, Nanda A. Far-lateral approach for lower basilar artery aneurysms. *Skull Base.* 2009;19(2):141–149. [PMID: 19721770]



▲ **Figure 66–27.** Bone removed via the far lateral (transcondylar) approach to the foramen magnum as seen from above **(A)** and below **(B)**. HC, hypoglossal canal; C, condyle; JF, jugular foramen; FN, facial nerve; EC, ear canal. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–28.** Surgical view of the far lateral approach to a ventrally situated meningioma in the foramen magnum region. Note that tumor resection must be conducted through a veil of lower cranial nerves. (Reprinted with permission of Jackler RK.)

MENINGOCELES & ENCEPHALOCELES

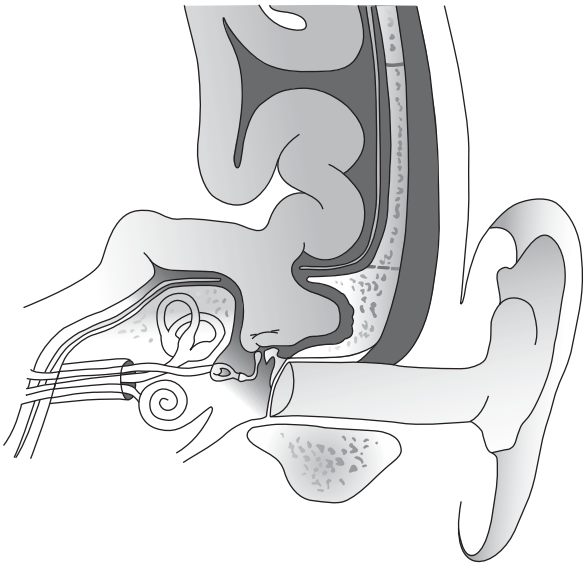
Defects in the dura of the roof of the petrous pyramid may occur spontaneously or following trauma or may arise as a consequence of long-standing elevated intracranial pressure. The thin bone of the tegmen overlying the mastoid or middle ear is most frequently breached. The petroclival junction is a site where congenital meningoceles may occur. Postsurgical defects after mastoid surgery commonly involve the herniation of brain tissue (encephaloceles). The operative approach to such defects is generally from above, with repair of the temporal floor defect with fascia and, when a substantial defect exists, reinforcement with a plate of bone (Figures 66–28 and 66–29). In extensive lateral defects, the temporalis muscle may be rotated to augment the repair (Figure 66–30).

Sanna M, Fois P, Russo A et al. Management of meningoencephalic herniation of the temporal bone: Personal experience and literature review. *Laryngoscope.* 2009;119(8):1579–1585. [PMID: 19479744]

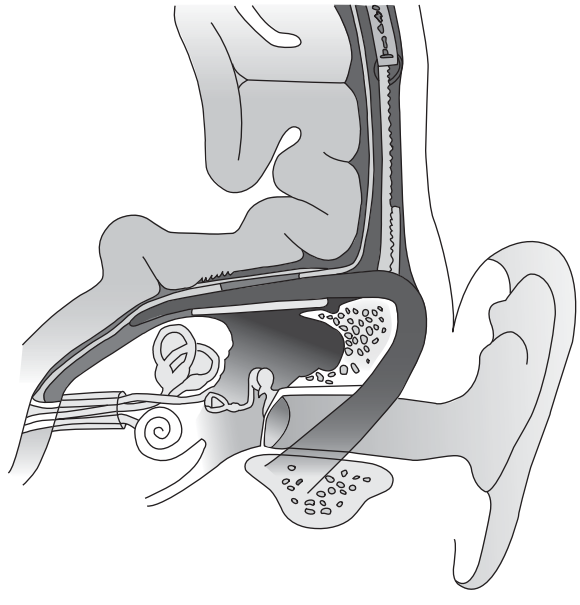
RECONSTRUCTION OF THE CRANIAL BASE

CLOSURE OF DEFECTS

Free adipose tissue, usually harvested from the anterior abdominal wall or iliac crest region, is the mainstay of skull base defect obliteration. Local rotation flaps, such as those fashioned using the temporalis muscle or pericranium, are useful supplements for minor soft tissue deficits. More substantial deficits require the use of either regional rotation flaps, such as the pectoralis major or trapezius myocutaneous flaps, or microvascular free flaps, such as the rectus abdominis.



▲ **Figure 66–29.** Encephalocele of the tegmen tympani. (Reprinted with permission of Jackler RK.)



▲ **Figure 66–30.** Multilayer repair of a large tegmen defect with fascia (intradural), bone (spanning the skull base defect), and inward rotation of the temporalis muscle. (Reprinted with permission of Jackler RK.)

Stow NW, Gordon DH, Eisenberg R. Technique of temporoparietal fascia flap in ear and lateral skull base surgery. *Otol Neurotol.* 2010;31(6):964–967. [PMID: 20517170]

CEREBROSPINAL FLUID RHINORRHEA & OTORRHEA

Aside from cranial nerve neuropathy, cerebrospinal fluid (CSF) leakage is the most prevalent morbidity in cranial base surgery. These surgeries frequently violate pneumatic tracts that ultimately connect to the middle ear and, from there, via the eustachian tube to the nasopharynx. Methods in common use to discourage CSF leak include packing the craniotomy defect with adipose tissue and sealing transected cell tracts with bone wax or other obliterative material. Despite diligent efforts at preventing this complication, CSF rhinorrhea occurs in about 10% of CPA surgeries, regardless of operative technique used, and an even higher percentage of more major skull base resections. Jugular foramen tumors that possess both intracranial and upper-neck components are particularly prone to formation of large pseudomeningoceles. This risk can be minimized by avoiding both the opening of unnecessary tissue planes and multilayer closure of the neck tissues. Meticulous hemostasis is important to avoid the need for a cervical drain.

One reason for this persistent incidence is the frequency of transient postoperative CSF hypertension brought about by the impaired resorptive function of arachnoid granulations. Management of CSF leakage includes fluid restriction, medication to reduce CSF production (eg, acetazolamide [Diamox] at 250 mg qid), and CSF diversion via a lumbar subarachnoid drain. Although most CSF leaks halt with such conservative management, a small percentage of skull base surgeries require secondary operative intervention. The most common remedial procedure is obliteration of the eustachian tube.

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Goddard JC, Oliver ER, Lambert PR. Prevention of cerebrospinal fluid leak after translabyrinthine resection of vestibular schwannoma. *Otol Neurotol.* 2010;31(3):473–477. [PMID: 20084041]

Implantable Middle Ear Hearing Devices

67

Betty S. Tsai, MD & Steven W. Cheung, MD

GENERAL CONSIDERATIONS OF IMPLANTABLE HEARING DEVICES

SOCIETAL FACTORS

Hearing loss is a common disability among adults. In the aging population, 25% of individuals between age 65 and 74 and 50% of individuals age 75 and older have hearing problems. Overall, approximately 30 million adults in the United States have moderate-to-severe sensorineural hearing loss. For this group, acoustic amplification (a conventional hearing aid) is an important rehabilitative strategy that often restores hearing to a serviceable level.

Despite the potential benefits of acoustic amplification, many hearing-impaired patients do not accept hearing aids. Some common complaints about hearing aids include feedback annoyance, ear canal discomfort, stigma of wearing an external appliance, and psychological rejection. It is estimated that only 20% of individuals within the United States who may benefit from a hearing aid own one. Only half of those who own a hearing aid use their device on a long-term basis.

ADVANTAGES OF IMPLANTABLE HEARING DEVICES

The search for alternatives to conventional hearing aids motivated the development of implantable hearing devices that deliver sound energy more directly to middle and inner ear structures. This design eliminates many of the disadvantages of conventional hearing aids. Implantable hearing devices endeavor to deliver more natural sound quality, increase gains across the frequency spectrum, reduce feedback, improve comfort and cosmesis, and eliminate ear canal occlusion. Although the chapter is mainly devoted to implantable middle ear hearing devices (IMEHDs), a bone-anchored hearing aid (BAHA) is a common implantable alternative to the conventional hearing aid and is briefly discussed.

IMPLANTATION-RELATED RISKS

Risks associated with middle ear device implant surgery include sensorineural hearing loss, ossicular chain disruption, facial nerve injury, external canal laceration, and cerebrospinal fluid leak. Beyond surgical risks, other considerations associated with implantable hearing devices are higher costs compared with conventional hearing aids, incompatibility with magnetic resonance imaging (MRI), and uncertain need for future explantation (ie, device removal) and reimplantation. Nevertheless, emerging technologies in IMEHDs are very exciting for both patients and care providers.

Perioperative risks associated with BAHA surgery include cerebrospinal fluid leak and wound problems surrounding the osseointegrated implant. The most common long-term complication is skin overgrowth over the abutment, as common as one in five patients, and has been shown to correlate with incomplete skin graft survival in the early postoperative period. However, an important distinguishing feature of the BAHA from all middle ear implants is that it is safe in MRI scanners with forces up to 9.4 T. Because of its minimal risks, the BAHA has become a popular alternative for those with conductive and sensorineural hearing losses and cannot tolerate or use hearing aids.

HEARING DEVICE COMPONENTS

An IMEHD is a device that converts acoustic energy to mechanical energy and delivers it to a vibratory structure in the middle ear. The basic components of an IMEHD consist of an **acoustic signal detector** (receptor), a **transmission link,** and an **actuator** that vibrates the ossicular chain (effector). The two basic transducer types used to drive the ossicular chain are electromagnetic and piezoelectric systems. **Electromagnetic fields** generated by induction coils can put magnets into oscillatory motion. **Piezoelectric transducers** are generally ceramic materials that vibrate in response to applied electrical energy. The general design of an IMEHD consists of separate receptor and effector limbs.

For semi-implantable devices, the receptor limb is an external, removable component that houses the microphone, the speech processor, and the power supply. It is held in a stable position relative to the fixed internal component across the scalp interface by using a centering magnet. Acoustic information is transferred from the external receptor component to the internal effector system through radiofrequency coupling. For totally implantable devices, the receptor and effector limbs are completely internalized; there is no external component. Transcutaneous technologies are used to power and replenish energy to the internal batteries. The effector limb of implantable hearing devices differs in the location of ossicular chain stimulation. The sites of contact are the incus head, body, and lenticular process, and the stapes superstructure.

The BAHA consists of a titanium post that is osseointegrated in the postauricular region. Attached to the post is a sound processor that contains a microphone. The microphone picks up sound and the processor sends vibrations to the post to stimulate the cochlea via bone conduction.

ACOUSTIC, IMAGING, AND OTHER DEVICE CONSIDERATIONS

Acoustic considerations for IMEHDs relate to increased stiffness and mass loading of the ossicular chain, which may result in a deepening of the existing hearing loss. Because middle ear mechanics may be impacted by all IMEHDs, normal middle ear function is a strict criterion in selecting patients for implantation. Ossicular chain stiffness is increased when there is a rigid coupling between the device and the ossicles. Mass loading is increased when an effector component is attached to the incus or the stapes.

Currently, none of the IMEHDs is compatible with MRI. Unforeseen clinical problems in the future might warrant device explantation for diagnostic and therapeutic interventions. Once an IMEHD is implanted, electrocautery cannot be used in surgical procedures because electrical discharges might damage the device. Electromagnetic interference from other environmental sources might possibly interact with IMEHDs in unknown ways. Device-related uncertainties include life span of IMEHDs, output protection safeguards to prevent noise-induced hearing loss, hermitic seal dependability to reduce device failure rates, ease of upgrade from a semi- to a fully implantable model, and performance capacity to accommodate progressive hearing loss.

SPECIFIC IMPLANTABLE MIDDLE EAR HEARING DEVICES

The semi-implantable Vibrant Soundbridge® (Med-El, Innsbruck, Austria), the totally implantable Envoy Esteem™ (Envoy Medical, Minneapolis, MN), and the totally implantable Carina™ (Otologics LLC, Boulder, CO) devices featured in this section are examples of innovative IMEHD technologies. The Vibrant Soundbridge® is currently the only FDA-approved device within the United States and is also available in Europe. The Envoy Esteem, a totally implantable device, has recently been recommended for approval by an advisory panel to the FDA in the United States. It is currently available in many European countries as well as Brazil, Iran, and India. The Carina™ is currently undergoing Phase II FDA trials in the United States.

VIBRANT SOUNDBRIDGE

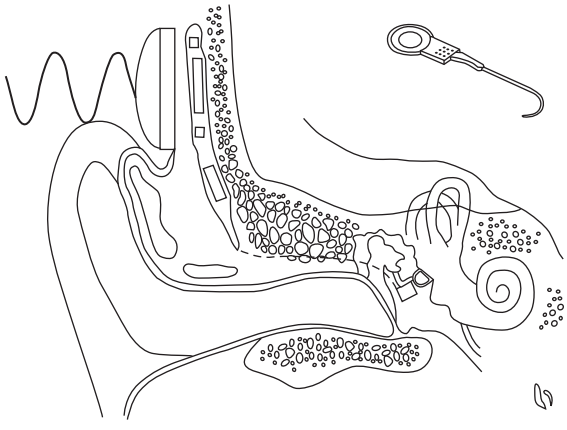
The Vibrant Soundbridge is a semi-implantable device that uses an electromagnetic effector to drive the ossicular chain. The external component is the audio processor, and the internal component is the surgically implanted vibrating ossicular prosthesis. The audio processor houses the microphone, the speech processor, and the battery. The vibrating ossicular prosthesis (Figure 67–1) contains the radiofrequency link, the demodulator, and the ossicular stimulator—the floating mass transducer—which is attached to the incus lenticular process with a titanium clip. The floating mass transducer is an electromagnetic effector with a magnet housed within an induction coil.

Implantation & Candidate Criteria

The surgical procedure consists of a mastoidectomy with a facial recess approach to place the floating mass transducer onto the lenticular process. After a 2-month period of healing, the device is activated. The speech processor delivers electronically controlled currents to drive the floating mass transducer into vibratory motion. Candidates for implantation are adults (≥18 years) with a moderate-to-severe sensorineural hearing loss and speech discrimination scores >50%. Recent studies have also shown that placement of the floating mass transducer either directly on the round window membrane or on the stapes in the absence of the incus have promising results, suggesting that this is an alternative form of hearing amplification for patients with otosclerosis and aural atresia.

Testing

For the Vibrant Soundbridge Phase III FDA study, statistically significant improvements in average functional gain on the order of 10–15 dB across the frequency spectrum were reported. Mass loading of the incus did not adversely affect hearing in a clinically significant manner. Subjects reported improved satisfaction and performance; they preferred the Vibrant Soundbridge to a heterogeneous group of conventional hearing aids. Occlusion and feedback were virtually eliminated. Of note, aided speech recognition was compa-



▲ **Figure 67–1.** The med-El Vibrant Soundbridge semi-implantable device. The external audio processor receives and processes sounds. Signals are transmitted to the internal vibrating ossicular prosthesis (inset, right) via radiofrequency coupling. The floating mass transducer, which is attached to the incus lenticular process with a titanium clip, vibrates the stapes.

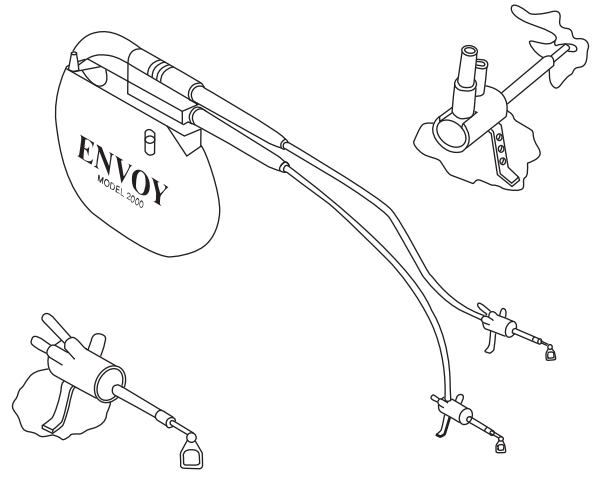
rable between the Vibrant Soundbridge and conventional hearing aids.

Safety

The trial also demonstrated acceptable safety. Most patients did not have a significant change in residual hearing (ie, change in pure-tone average <10 dB). However, a small percentage of patients (4% or 2 of 53 patients) experienced a 12–18 dB decrease in residual hearing. Other adverse effects have been reported during the U.S. trial. There were six device failures; these devices were successfully reimplanted after the manufacturer revised the product. One subject had a disconnection of the floating mass transducer; the device was successfully reimplanted.

ENVOY ESTEEM™

The Envoy Esteem™ is a totally implantable hearing device that uses piezoelectric transducers. A major design challenge of totally implantable hearing devices is the management of mechanical and acoustic feedback. By necessity, receptor (sensor) and effector (driver) limbs of the system are in close proximity. At high output levels by the effector limb, feedback may occur because the sensor detects the output signal. This results in feedback oscillation. The Envoy system addresses this difficult problem by segregating the receptor and effector limbs through controlled ossicular discontinuity. The device has now received FDA approval and is available in the United States.



▲ **Figure 67–2.** The Envoy totally implantable device. Sensor and driver limbs connect to the processor with detachable pins. The sensor is affixed to the incus body with bone cement. Note that the distal incus lenticular process is shortened to segregate sensor and driver vibrations (inset, upper right). The driver is also attached to the stapes capitulum with bone cement (inset, lower left). (Reproduced with permission of Envoy Medical Corporation, St. Paul, MN.)

Implantation & Candidate Criteria

The surgical procedure is a mastoidectomy with a facial recess approach to vaporize the distal 2–3 mm of the incus lenticular process with a laser (Figure 67–2). Bone cement is used to stabilize the sensor and driver to the mastoid and to affix the device tips to the incus body and stapes capitulum. When incoming sounds vibrate the native drum, the incus head is set in motion. The sensor tip, which is firmly attached to the incus head, deflects the piezoelectric transducer. Electrical signals are generated and transmitted to the speech processor. Outflow electrical signals from the processor guide the movements of the driver tip, which is transmitted to the stapes. Candidates for the Envoy device implantation are adults (≥18 years) with a mild-to-severe sensorineural hearing loss and speech discrimination scores ≥60%.

Phase I Testing and Safety Data

For the Envoy Esteem™ Phase I FDA study in seven patients, five of seven perceived benefit over their best-fit hearing aid at the 2-mo activation period. Two of the five patients who ultimately experienced benefit required revision surgery after initial implantation because immediate benefit was insufficient. In the original cohort of seven patients, three were explanted owing to infection or patient request.

Functional gain with the Esteem™ was similar to hearing aids. Cochlear reserve in study patients appeared to be preserved following Esteem™ implantation, whereas air conduction thresholds for frequencies greater than 1 kHz were increased by 10–20 dB at 12 months after implantation. Device modifications were implemented prior to Phase III trial.

OTOLOGICS CARINA™

Initially developed as a semi-implanatable device, the Otologics Carina™ device is now a fully implantable device that incorporates a microphone, speech processor, battery, and transducer into a prosthesis. The microphone, located under the postauricular skin, amplifies sound and converts acoustic signals to electrical signals that are transmitted to the transducer. Thereafter, the ossicular stimulator vibrates the ossicles. The subcutaneous battery is charged daily with a radiofrequency coil that is placed over the implant site. The implant is programmable and the volume can be adjusted with a remote control that sits over the implant.

Implantation & Candidate Criteria

The surgical procedure is a modified atticotomy that exposes the body of the incus and the head of the malleus. A mounting plate with a retaining ring is affixed to the mastoid cortex with self-tapping screws that allows the electronics capsule to be secured. A laser is used to create a hole in the midbody of the incus. The transducer is mounted to the retaining ring with its probe tip is advanced into the hole of the incus. Electrical stimulation of the transducer translates into mechanical stimulation of the ossicular chain. After a 6- to 8-week healing period, the device can be activated. Candidates for the Otologics device are similar to that for the Envoy Esteem.

Phase I Testing and Safety Data

A study of 20 implanted patients demonstrated that although their conventional hearing aids had slightly better pure-tone averages and monaural word recognition scores, patients preferred hearing with the Carina™, noting improved quality of sound, improved ability to hear soft sounds, comfort, and ability to use the device in noisy conditions. Complications included implant extrusion in three of the patients, requiring explantation in two, increased charging times in seven patients, resulting in two no longer using their implants, and loss of external communication with the implant, making it unable to be charged. It was also noted that at 6 months after implantation, there was decreased usage of the implant secondary to decreased speech perception. It is believed that this is a result of the migration of the microphone and processors. Since this trial, modifications to the device to address these issues have been made as it enters Phase II testing.

BONE-ANCHORED HEARING AIDS

While it is not an implantable middle ear device, the BAHA (Cochlear Corporation, Sydney, Australia) is an FDA-approved implant for patients with conductive hearing loss, mixed hearing loss, or unilateral sensorineural hearing loss who cannot tolerate or have limited benefits from conventional air conduction hearing aids. Traditional bone conduction hearing aids require the use of a head band to secure the transducer to the head. With the BAHA, not only is the band no longer required but also the coupling between the transducer and the microphone is significantly better, as much as by 10–15 dB. Disadvantages of the BAHA include a higher cost and requirement of a surgical procedure. However, the improvement in hearing and communication has made the BAHA an appealing option for certain groups of patients with hearing loss.

Implantation & Candidate Criteria

The surgical procedure consists of creating thin skin flap, about the thickness of a full-thickness skin graft. A titanium abutment is installed into the temporal bone and the thin skin flap with a center hole is draped over the implant. The wound is then allowed to heal for 3–4 months for osseointegration to take place.

The BAHA was originally indicated for patients with a conductive or mixed hearing loss with a conductive component >30 dB. Patients with chronically draining ears despite vigorous treatment, bilateral congenital aural atresia, and conductive loss in the only hearing ear have been the primary beneficiaries. More recently, patients with single-sided deafness have been shown to benefit from the BAHA.

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Haynes DS, Young JA, Wanna GB et al. Middle ear implantable hearing devices: An overview. *Trends Amplific*. 2009;13(3):206.
House JW, Kutz JW. Bone-anchored hearing aids: Incidence and management of postoperative complications. *Otol Neurotol.* 2007;28(2):213.
Jenkins HA, Atkins JA, Horlbeck D et al. Otologics fully implantable hearing system: Phase I trial 1-year results. *Otol Neurotol.* 2008;29(4):534.
Ko WH, Zhu WL, Kane M, Maniglia AJ. Engineering principles applied to implantable otologic devices. *Otolaryngol Clin North Am*. 2001;34(2):299.
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We would like to acknowledge Kenneth C.Y. Yu, MD for his contribution to this chapter in the previous editions of CDT.

68 Cochlear Implants

Michael B. Gluth, MD,
Colin L.W. Driscoll, MD, &
Anil K. Lalwani, MD

An absence or disturbance of cochlear hair cells causes most cases of deafness. This defect in normal cochlear function, specifically, in the transduction of a mechanical acoustic signal into auditory nerve synaptic activity, represents a broken link in the delicate chain that constitutes the human sense of hearing. Cochlear implants afford an artificial means to bypass this disrupted link via direct electric stimulation of auditory nerve fibers.

Although current technological and scientific boundaries preclude the artificial transduction of sound by using the exact native cochlear patterns of synaptic activity at the level of each individual residual auditory nerve fiber, knowledge of these native patterns has aided the development of cochlear implants by allowing the processing of speech into novel synthetic electronic codes that contain the key features of spoken sound. By using these codes to systematically regulate the firing of intracochlear electrodes, it is possible to convey the timing, frequency, and intensity of sound. Cochlear implants have progressively evolved with increasing complexity and elegance from an experimental concept to a proven tool used in the management of patients with sensorineural hearing loss (SNHL). Worldwide, the number of implants is rapidly increasing. As with many other technology-driven medical treatment modalities, recent innovations in microcircuitry and computer science are continuing to drive the performance profiles of cochlear implants to new heights.

COCHLEAR IMPLANT SYSTEMS HARDWARE

Currently, three separate corporations manufacture multichannel implant systems that are commercially available and approved by the FDA for use in both adults and children. Although expensive, multiple studies have demonstrated that the cost-utility of cochlear implantation is excellent and that it compares well with other common medical interventions.

All modern implant systems function by the use of the same basic components including a microphone, a speech processor, and an implanted receiver–stimulator (Figure 68–1).

Microphone & Receiver-Stimulator

Sound is first detected by a microphone (usually worn on the ear) and converted into an analog electrical signal. This signal is then sent to an external processor where, according to one of a number of different processing strategies, it is transformed into an electronic code. This code, a digital signal at this point, is transmitted via radiofrequency through the skin by a transmitting coil that is held externally over the receiver–stimulator by a magnet. Ultimately, this code is translated by the receiver–stimulator into rapid electrical impulses distributed to electrodes on an array implanted within the cochlea (Figures 68–2 through Figure 68–5).

Speech Processor

Current generations of speech processors are smaller in size and are continuously being redesigned to improve functionality, comfort, and cosmesis. Most adults and older children wear ear-level processors (behind-the-ear processors). Processors worn on the belt, clipped to clothing, or incorporated into small packs (body-worn processors) are still preferred for very young children as well as some adults (Figures 68–6 through Figure 68–8). Entirely implantable devices are under development.

SPEECH PROCESSING

The literature uses the term *speech processing*, but this component may be more aptly termed **sound processing**, because the manipulations are not limited to speech only. In fact, a greater focus is now on enhancing the quality of all sound and specifically an effort to improve music

▲ **Figure 68–1.** Schematic depiction of how cochlear implant systems operate. 1. Sound is detected by an external microphone. 2. This signal is directed to an external sound processor. 3. Once processed, a digital electronic code is sent by a transmitting coil situated over the receiver–stimulator via radiofrequency through the skin. 4. The receiver–stimulator delivers electronic impulses to electrodes on a coil located within the cochlea according to whichever strategy is being used by the processor. 5. Electrodes electrically stimulate spiral ganglion cells and auditory nerve axons.

appreciation. No matter what processing strategy is used, part of this process must include both amplification (ie, gain control) and compression. Since the deaf ear responds to electrical stimulation with a dynamic response in the range of 10–25 dB, processing must compress the signal to fit within this narrow range. How to best convert sound into an electrical signal is being actively investigated.

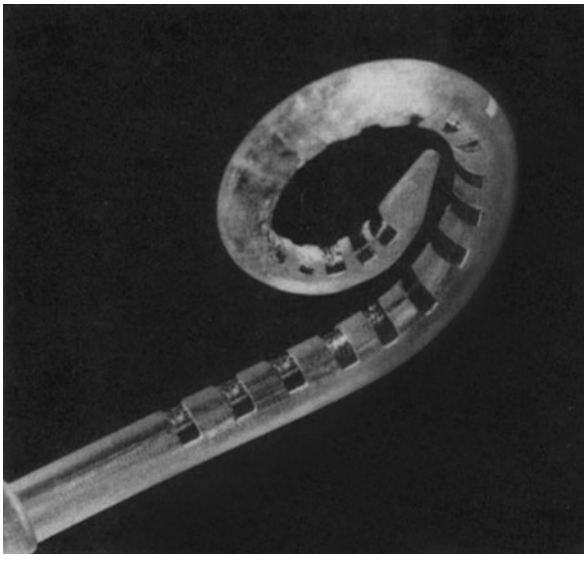
Electrical Stimulation Strategies

A. Multichannel Strategies

Some of the earliest multichannel strategies, known as analog filter bank strategies (**continuous analog**), channel speech through multiple frequency-dependent filters and deliver distinct outputs of sinusoidal analog signals directly to separate electrodes. Other so-called feature extraction strategies (F0, F1 and F0, F1, F2) work by rapidly drawing out frequency-based details that are considered to be the most essential in speech recognition; these include both fundamental frequency and vowel formants. Disbursement of this key information is accomplished through pulsatile signals having rates synchronous to the fundamental frequency and a tonotopic order that is derived from formants.

B. Pulsatile Stimulation

Modern adaptations of direct analog strategies have sought to overcome the problem of channel interaction or "spill-over" that readily occurs when adjacent electrodes are simultaneously stimulated with continuous analog signals. The result of such efforts has led to the development of a strategy, **continuous interleaved sampling**, that delivers very rapid noncontinuous pulsatile stimulation over multiple filtered channels.



▲ **Figure 68–2.** The nucleus contour advance curled electrode array. (Image courtesy of the Cochlear Corporation, Sydney, Australia.)

C. Spectral Analysis

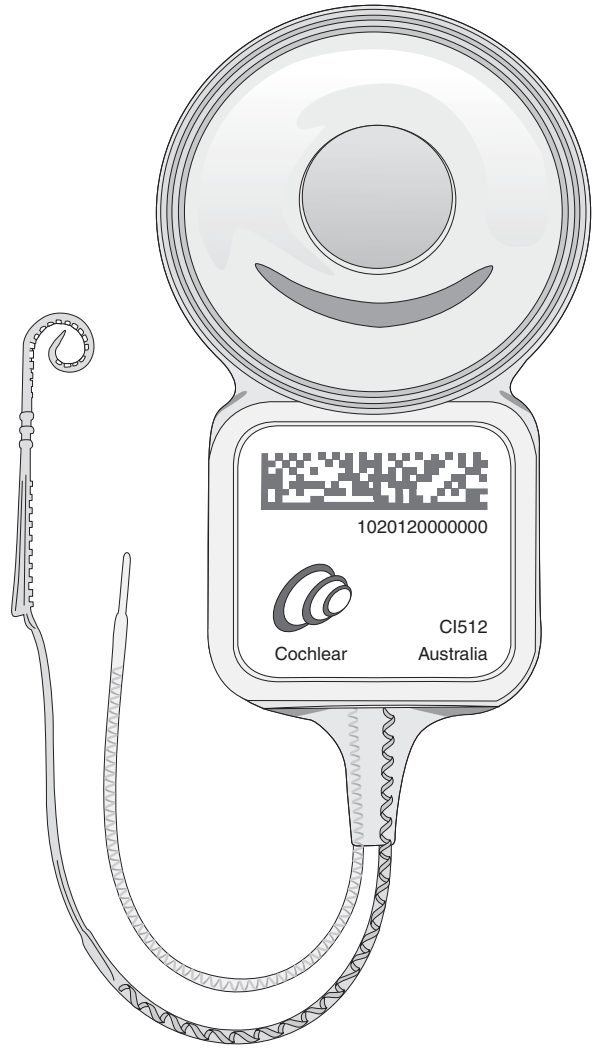
In addition, newer high-rate spectral analysis strategies, **SPEAK** (**sp**ectral p**eak**) and **ACE** (**a**dvanced **c**ombination **e**ncoders), for example, determine 6–10 spectral maxima for each input signal. Other newer approaches such as "n-of-m" strategies (n = filters, m = channels) are constantly undergoing innovation and refinement with the goal of combining the theoretical advantages of each type of system while incorporating ever-progressing new technologies.

Neural Responses

In speech processing, consideration is given to the incoming acoustic signal; in addition, actual neural responses (**neural response telemetry**, **neural response imaging**, or **auditory** nerve **response telemetry**) to stimulation may be measured and accounted for in the formulation of a neural stimulation scheme. By measuring evoked action potentials from specific electrodes, it is possible to predict the needed amplitudes for each channel of the speech processor. Some audiologists find this information particularly helpful when programming very young children.

Cheng AK, Rubin HR, Powe NR et al. Cost-utility analysis of the cochlear implant in children. *JAMA.* 2000;284:850. [PMID: 10938174] (Cost-utility in children is favorable.)

Cheng AK, Niparko JK. Cost-utility of the cochlear implant in adults: a meta-analysis. *Arch Otol Head Neck Surg.* 1999;125:1214. [PMID: 10555692] (Cost-utility of cochlear implantation in adults shown to be in line with many other common medical and surgical modalities.)



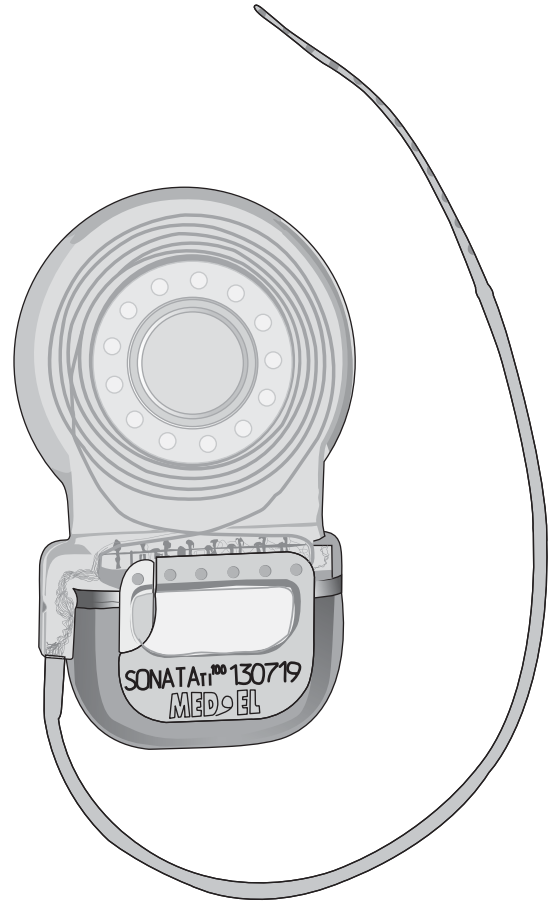
▲ **Figure 68–3.** The nucleus CI512 cochlear implant. (Image courtesy of the Cochlear Corporation, Sydney, Australia.)

SELECTION & EVALUATION OF PATIENTS

AUDIOLOGICAL ASSESSMENT

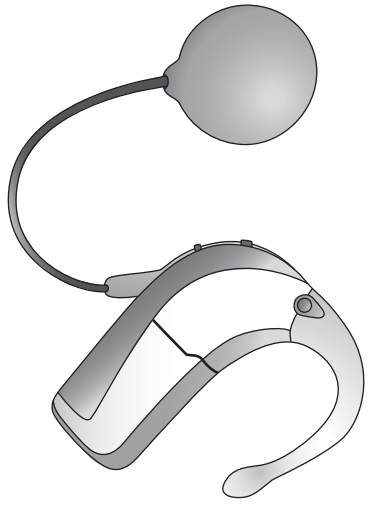
Candidacy for cochlear implantation relies heavily on the audiological evaluation. Although the audiometric criteria continue to change, the goal remains the same—identify those patients in whom the implant is likely to provide better hearing. Because of device improvements, the ability to hear with an implant has dramatically improved over time. Therefore, the accepted audiometric criteria for implanta-

▲ **Figure 68–4.** The advanced bionics HiResolution™ 90K implant. (Image courtesy of the Advanced Bionics Corporation, Sylmar, California).



▲ **Figure 68–5.** The Med El Sonata™ TI100 cochlear implant. (Image courtesy of the Med-El Corporation, Innsbruck, Austria.)

▲ **Figure 68–6.** The nucleus 5 sound processor with wireless remote assistant for programming. (Image courtesy of the Cochlear Corporation, Sydney, Australia.)



▲ **Figure 68–7.** The advanced bionics Harmony™ speech processor. (Image courtesy of the Advanced Bionics Corporation, Sylmar, California.)

tion have expanded to include patients with more residual hearing. Some of these patients, having quite useful low-tone hearing in the setting of middle- and high-frequency deficits, may now be classified as having "**partial deafness**." Hybrid or short electrode devices have been developed to allow the preservation of the native low-frequency hearing, thus the patient would combine electric (cochlear implant) and acoustic (hearing aid) hearing in the same ear.

For adults in the United States, candidacy is based on sentence recognition test scores (eg, **Hearing-in-Noise Test** or Arizona Biomedical Sentences) with properly fitted hearing aids. Scores of 60% or less are generally needed to establish candidacy.

In children undergoing an evaluation for cochlear implantation, it is first necessary to establish a hearing threshold. This may include otoacoustic emissions, auditory brainstem response testing, auditory steady-state responses, and behavioral testing. A hearing aid trial can then be initiated and speech and language development assessed. Input is elicited from audiologists, parents, teachers, and speech and language pathologists. The cochlear implant team then assimilates the information and a determination is made regarding the child's progress with amplification and suitability for implantation.

OTOLOGICAL ASSESSMENT

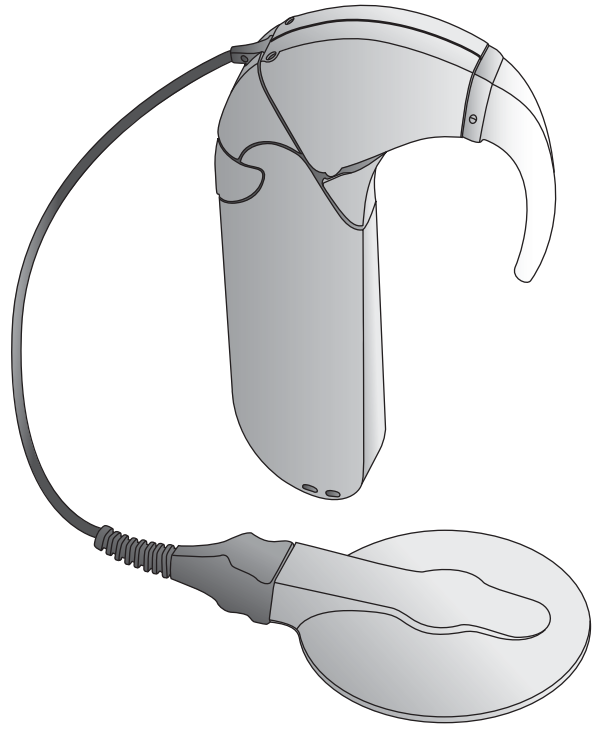
A thorough otological history and physical examination are obtained as part of the preimplantation assessment and include an investigation into the etiology of the hearing loss. (For a thorough discussion of the evaluation of SNHL in adults and children, see Chapter 52, Sensorineural Hearing Loss.)

Otitis Media and Eustachian Tube Dysfunction

In pediatric patients, it is important to ascertain whether there is a history of recurrent ear infections, pressure equalization (PE) tube placement, or other otological surgeries. Patients with acute otitis media should be both treated with appropriate conventional antibiotics and demonstrated to be clear of infection before proceeding with surgery. For patients with a chronic middle ear effusion or recurrent acute otitis media, myringotomy with PE tube placement may be considered. Cochlear implants can safely coexist with PE tubes, although, ideally, patients would have an intact tympanic membrane at the time of surgery.

Chronic Otitis Media

For adult implant recipients, an intact tympanic membrane is preferred. Accordingly, patients with a tympanic membrane perforation, a chronic draining ear, or cholesteatoma



▲ **Figure 68–8.** The Med El Opus 2™ sound processor with wireless fine-tuner. (Image courtesy of the Med-El Corporation, Innsbruck, Austria.)

often require other surgical procedures before implantation. For patients with long-dormant chronic ear disease and a modified radical cavity, it is not uncommon to combine cochlear implantation, closure of the ear canal, and obliteration of the mastoid cavity and middle ear into a single surgical procedure. Patients with active chronic ear disease processes, however, are better served with initial conventional otological surgery with cochlear implantation delayed until the ear is stable.

Cochlear Patency

When deafness is a result of meningitis or cochlear otosclerosis, special attention is required preoperatively to account for the possibility of cochlear soft tissue obstruction or ossification. Cochlear patency is best evaluated with MRI. CT scanning should demonstrate cochlear ossification; however, obliteration due to fibrosis and the presence of soft tissue can be best assessed with a T2-weighted MRI. When the cochlea appears to be actively undergoing obliteration, the surgeon may wish to implant quickly, assuming that hearing is not expected to be recovered.

Cochlear and Vestibular Malformations

The specific type and severity of malformation presents a unique set of challenges to the implant surgeon. Preoperative imaging is invaluable in planning surgery, choosing the most appropriate electrode array and avoiding complications. Incomplete device insertion, cerebrospinal fluid leak, facial nerve injury, vestibulopathy, and poorer hearing outcomes are all more common in the setting of malformations.

General Medical Considerations

It is important to be aware of individuals at particular risk of infection or surgical site complications during the implant workup process. Pertinent nonotological medical conditions to consider are previously irradiated surgical field, immunodeficiency, poorly controlled diabetes mellitus, tobacco use, malnutrition, a prominent history of allergic hypersensitivity reactions, or widespread dermatological disease.

Vestibular Evaluation

A vestibular evaluation, including at least electronystagmography, while not required preoperatively can be helpful in selecting the ear for implantation and for assessing the risk of postoperative balance problems. Although the risk of losing balance function in the ear being implanted is low with current minimally traumatic surgical technique, if function was lost and the contralateral ear already lacked function, the resulting balance problems can be devastating, particularly in elderly adults. Patients with an existing balance problem or suspicion for unilateral or bilateral vestibular hypofunction should undergo preoperative testing.

RADIOLOGICAL ASSESSMENT

Radiological assessment for cochlear implantation typically consists of fine-cut CT scanning and/or MRI of the temporal bone. CT is preferred to delineate the detailed bony anatomy of the labyrinth, which may include evidence of cochlear ossification, abnormal facial nerve course, or congenital abnormalities. In patients in whom soft tissue detail is required, as in a patient with an elevated suspicion of central pathology or when cochlear patency is in question, MRI with and without gadolinium plus high-resolution T2-weighted images may prove to be valuable. The modification of MRI pulse sequences, such as fast-spin echo, and the development of new coils are leading to continuously improving resolution of the inner ear and internal auditory canal. Specifically, MRI can now allow reliable imaging of the internal auditory canal contents and afford confirmation of the presence of an auditory nerve. The Michel deformity (ie, congenital cochlear agenesis) and absence of the auditory nerve, which may be present with the narrow internal auditory canal malformation or in the setting of auditory neuropathy, are the two absolute contraindications to cochlear implantation that may be found on radiological assessment.

CANDIDACY

General Considerations

In addition to meeting audiometric and medical criteria, the basic evaluation of cochlear implant candidates involves analyzing multiple other factors (Table 68–1). The goals of the evaluation are (1) to determine whether the patient is

Table 68–1. General Criteria for Cochlear Implant Candidacy.

Children
Bilateral severe-to-profound hearing loss
Lack of auditory development with a proper binaural hearing aid trial as documented by objective testing or a parental questionnaire (for very young children)
Properly aided open-set word recognition scores <20–30% in children capable of testing
Suitable auditory developmental education plan
Lack of medical contraindication, with cochlea and auditory nerve present
Adults
Bilateral severe-to-profound hearing loss
Limited benefit from conventional hearing aids
Sentence (Hearing-in-Noise Test or Arizona Biomedical Sentences) recognition scores <60%
Lack of medical contraindication, with cochlea and auditory nerve present
Realistic expectations

likely to benefit from the implant, (2) to establish realistic expectations concerning the outcome, and (3) to assess the needs and expectations of the patient, the patient's family, or both. Not all patients who meet audiometric and medical criteria are appropriate implant candidates. There must be grounded expectations as well as a firm commitment to follow through with the necessary postimplantation rehabilitation and programming.

Patients with Other Cognitive or Developmental Disorders

A unique group of individuals requiring careful consideration are with hearing loss and other developmental and cognitive deficits. Historically, children with cerebral palsy or children with other conditions in addition to hearing loss were denied implantation. It is now clear, however, that many of these patients are very good candidates. In fact, if a hearing disability can be ameliorated with a cochlear implant, other disabilities (eg, a learning disability) may become less pronounced or more manageable. In contrast, in a child with very severe developmental issues and a poor prognosis for cognitive development, a cochlear implant may simply be another burden and not result in an improved quality of life.

Timing of Implantation

The timing of implantation is very important. Earlier implantation in children generally yields more favorable results, and many centers routinely implant children under 12 months of age. In engaging this pursuit, complex questions arise with regard to how early children should undergo cochlear implantation in order to optimize eventual developmental outcomes. Although the answers to all these questions have yet to be definitively answered, success in progressively younger patient populations is driving the age of implant recipients lower. Early implantation essentially limits how far behind the child is in language development. Likewise, adults do better with a shorter duration of deafness. It has been shown that outcomes in adults over age 80 rival those in young adults. Excellent results can be obtained in older children and adults with long-term deafness, but expectations for the outcome should be modified.

IMPLANT SELECTION

All three currently available devices are excellent, and rarely there are strong reasons to prefer one to another. The hearing outcomes seem to be similar regardless of the device, thereby indicating that patient factors are more important than the device variations. There are a few clinical situations that may influence the physician to favor one device over another. For example, a device with MRI compatibility or a removable magnet may be the best type to implant in a patient who will need future MRI scans. Some companies have multiple electrode configurations that are useful in an obliterated or malformed cochlea. To avoid unwanted facial nerve stimulation in the setting of cochlear otosclerosis, a perimodiolar electrode array may be preferable. Finally, multiple family members or friends may have implants, and being able to share experiences and tips is facilitated if the devices are the same.

SURGICAL CONSIDERATIONS & GENERAL TECHNIQUES

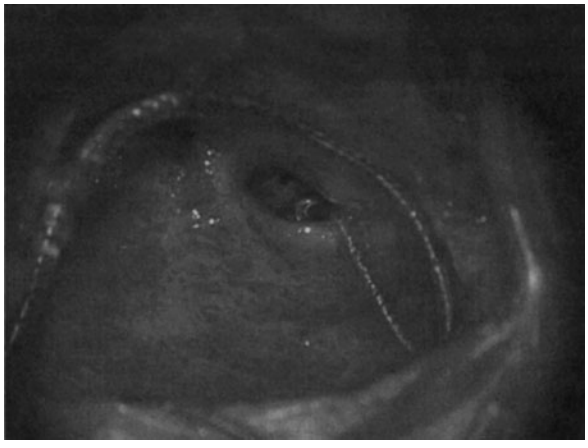
SURGERY

Implant Location

Surgery is performed under a general anesthetic without muscle relaxation to allow for facial nerve monitoring. The device location is marked out with the use of templates. It is important to place the internal device far enough posteriorly so that the processor that is placed behind the ear does not lie against it and render the underlying skin at risk. In an effort to avoid the complications associated with a skin flap breakdown, it is imperative to plan the skin incision in order to provide adequate exposure while both preserving tissue viability and avoiding the placement of a suture line directly over implanted hardware. The location of prior incisions should be taken into account. Most surgeons use a postauricular incision that may be extended slightly more superiorly than what might be typically used in a routine ear surgery. The current devices can be placed through a 3–4 cm cosmetically acceptable incision. In children, the scar is less likely to widen with head growth if it is located only in the postauricular area and does not extend up into the scalp. Due diligence should be rendered in manipulating the tissues of the skin flap to assure minimal trauma.

Mastoidectomy & Cochleostomy

After the initial incision, the periosteum is elevated from the mastoid and a mastoidectomy is performed. The facial recess is opened to gain access to the middle ear—specifically to the promontory, the round window niche, and the stapes (Figure 68–7). The chorda tympani nerve is preserved and the incus buttress can be left in place. According to the shape and size of the particular device chosen, a well may be drilled posterior to the mastoid cavity in the cortex to harbor the receiver–stimulator package. In children, this dissection is often carried down to the dura so that the device can be recessed. This better protects the device from trauma and is more cosmetically appealing. In adults, because of thicker bone, the device can be adequately recessed by removing bone to the inner table of the skull. The device can be placed in a tight subperiosteal pocket or secured by various means such as suture.

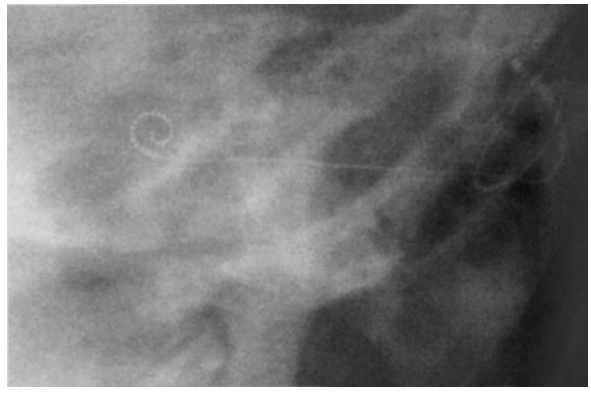


▲ **Figure 68–9.** The basal turn of the cochlea is approached via drilling out the facial recess. The coiled electrode array is inserted into a cochleostomy that is fashioned 1 mm anterior and inferior to the round window.

After the device is seated, a cochleostomy is then made inferior to the round window membrane with a goal of affording access to the scala tympani (Figure 68–9). Principles of minimally traumatic surgery should be employed in all cases in an effort to preserve structure and function. These atraumatic techniques include elements such as a more inferiorly based cochleostomy site to assure wide clearance of the osseous spiral lamina, minimizing access of bone dust or blood into the cochlea, avoiding suctioning of perilymph, slowing methodical electrode array insertion, and utilizing adjuvants such as corticosteroids and/or lubricants. Following successful insertion, small pieces of fascia or periosteum are used to carefully seal around the cochleostomy.

Hearing Preservation

Preservation of residual hearing is possible with a full insertion of a standard electrode array when minimally traumatic surgical technique is utilized, but with current techniques it cannot be reliably achieved. Hearing preservation, and thus electroacoustic stimulation are best obtained by implanting a shortened electrode that does not extend into and disturb the apical cochlear neural elements. Because these devices are quite small and flexible, residual hearing can be preserved in more than 90% of patients at the time of surgery. Unfortunately, there is the potential for delayed hearing loss, typically in the first 3–6 months, the etiology of this remains unknown and is actively being investigated. A direct round window membrane incision may be favored over cochleostomy by some surgeons for its potential to be less traumatic.



▲ **Figure 68–10.** Postoperative x-ray image of a cochlear implant. Note the spiral coil within the cochlea.

Intraoperative Electrical Tests

Depending on the device and the availability of audiology support, intraoperative electrical tests can be performed to confirm the proper functioning of the device. Evoked potentials and stapedial reflexes can be measured, which may be particularly helpful in programming with young children. Finally, if cochlear nerve action potentials can be recorded and a stapedial reflex is elicited, the surgeon can be quite confident that the device is indeed in the cochlea. After wound closure, a Stenver's view x-ray can be obtained for further confirmation of the device location and for reference in the case of future trauma or device migration (Figure 68–10). Patients may be discharged from the hospital on the same day, or they may spend one night in the hospital.

SPECIAL CIRCUMSTANCES

Cochlear Ossification

When cochlear ossification is encountered, various approaches may be used to ultimately attain satisfactory electrode placement. Often the obliteration involves only the first few millimeters of the basal turn, which can be removed with a drill or other small instruments. In these cases, the device can then be fully inserted. A preoperative MRI can usually predict this situation. For more extensive disease, other options exist such as partial electrode insertion, insertion into the scala vestibuli, or other more elaborate drill-out approaches. Split electrodes (ie, two distinct electrodes) have been designed so that one electrode can be partially inserted in the scala tympani and the second can be inserted in the scala vestibuli or further along the scala tympani.

Cochlear Malformation

Cochlear malformations provide another surgical challenge. Everything from finding the cavity to inserting and stabilizing the electrode may be problematic. Fortunately, specifically designed electrodes are available to facilitate implantation. A CSF leak should be anticipated and may require plugging the eustachian tube and packing the middle ear. Additionally, electrode insertion under fluoroscopic guidance may be of benefit.

Bilateral Implantation

The benefits of bilateral cochlear implantation have been studied in adults and children. Specifically, improvements in sound localization and speech understanding in noise have been noted. Bilateral implantation can be performed sequentially, and staged months apart or simultaneously in one operation. For children who are implant candidates, it is routine in many large centers to proceed with bilateral simultaneous implantation, even in children under 12 mo of age.

Adunka OF, Pillsbury HC Buchman CA. Minimizing intracochlear trauma during cochlear implantation. *Adv Otorhinolaryngol.* 2010:67:96. [PMID: 19955726]. (Highlights the importance or cochleostomy site selection in avoiding intracochlear trauma during cochlear implant surgery.)

INITIAL STIMULATION & DEVICE PROGRAMMING

After the patient has healed from surgery, usually in 1–4 weeks, the device hardware is fully engaged and programmed. The initial programming is often done over 2–3 days. There are a myriad of variables that can be adjusted to improve the sound quality. After the first day, most adults report that speech sounds like static or voices sound either like "Donald Duck" or sound metallic in character. Amazingly, without any changes to the device, over the next 24 hours the sound quality improves. The brain somehow manages to adapt to the signal. This learning by the brain occurs mostly within the first 3–6 months, after which the rate of improvement in sound quality slows. Most adults have programming sessions two to four times in the first year, then annually or as needed.

Children (particularly infants) are more difficult to program because of the lack of a consistent feedback regarding volume and clarity. Objective intraoperative measurements are helpful in estimating hearing thresholds and comfort levels. It is obviously very important to not provide too much gain. Children are seen more frequently for programming. Programming is critical to the success of the device, and experienced audiologists are able to achieve better outcomes than less-experienced audiologists.

INTRAOPERATIVE & POSTOPERATIVE COMPLICATIONS

Cochlear implantation requires a surgical procedure under general anesthesia and therefore carries some risk. In particular, risks such as those encountered when removing a cholesteatoma or performing any surgery for chronic ear pathology do exist, including wound infection, facial nerve injury, taste disturbance, tinnitus, and balance problems. Overall, the complication rate of cochlear implantation has been reported as being 5–10%.

Wound Infection

The frequency of cochlear implant site wound complications and cochlear implant infections have been reported to range from 4.5% to 11.2% and 1.7% to 4.1%, respectively. Collectively, these comprise the largest subset of cochlear implant-related complications. It should be noted that implant site wound complications such as flap necrosis or dehiscence often lead to the development of infection and vice versa; thus, from the standpoint of prevention and treatment, these need to be considered together.

In general, cochlear implant infections come in two broad categories. By far, the most common type involves the postauricular soft tissues including the suture line, flap, and/or hardware itself consisting of cellulitis and/or abscess. Often these originate from a focus of scalp pressure necrosis caused by dynamic contact with an external object (including an excessively strong magnet) or by spread from a nearby infected cutaneous lesion. The second type of cochlear implant infection involves a bout of acute otitis media.

In the rare event that an implant recipient would present with a severe systemic or life-threatening infectious complication such as a brain abscess or unstable meningitis, immediate device explantation and surgical debridement are required. Fortunately, extreme complications are rare and most cases can be safely managed with intravenous antibiotics and local wound care.

Most uncomplicated cases of acute otitis media can be treated promptly on an outpatient basis with oral antibiotics and close follow-up to confirm a complete response to therapy, with more aggressive inpatient treatment reserved for those unresponsive to conservative treatment and those with negative risk factors such as a major congenital cochlear anomaly. The pathogens causing acute otitis media in the implanted patient population are the same usual pathogens encountered in the nonimplanted population.

In cases of infection unresponsive to prolonged culture-directed intravenous antibiotic therapy, hardware explantation may be required. It has been hypothesized that bacterial biofilms may play a role in some cases of implant infections and that the presence of a biofilm will render infection essentially impossible to clear with antibiotic medications and local wound care in many of these cases. During explantation, most surgeons advocate leaving the electrode array

within the cochlea to prevent the development of obliterative soft tissue and/or new bone formation, thereby facilitating subsequent reimplantation.

Facial Nerve Injury

Facial nerve injury has been reported which may not be surprising because of the wide array of aberrant anatomy potentially encountered in this unique patient population. The anticipation of an abnormal nerve location and the use of intraoperative facial nerve monitoring should result in very few cases of temporary or permanent nerve injury.

Taste Disturbance

Drilling a posterior tympanostomy via the facial recess requires surgical negotiation of the chorda tympani nerve. At times, especially when the facial recess is poorly pneumatized or when round window visualization is otherwise poor, trauma to the chorda tympani nerve and associated taste disturbance may occur. This typically resolves by 6 mo but may be permanent in 2–3% of cases.

Tinnitus

Patients need to understand that the residual hearing in the ear with the implant may be lost and that a hearing aid may be of no benefit. Cochlear trauma from device insertion not only results in a loss of hearing but also may lead to or exacerbate tinnitus. When encountered in this setting, tinnitus typically lessens in time and often markedly improves after device programming.

Vestibular Dysfunction

Breaching the confines of the inner ear may also result in vestibular dysfunction with temporary, or more rarely permanent, balance difficulty. A patient who suffers an acute vestibulopathy should be provided vestibular rehabilitation therapy to maximize recovery. Benign paroxysmal positioning vertigo may occur in the postoperative setting and can be treated in standard fashion.

Device Failure

Although the implanted device has no moving parts to wear out, there are still instances of electronic malfunction or failure due to trauma. In fact, device failure is one of the most common postoperative complications. Most devices can be explanted and a new device is reimplanted without compromising performance.

Risk of Meningitis

The risk of meningitis in implant recipients has been scrutinized. Patients with inner ear malformations have a higher risk of meningitis pre- and postoperatively unrelated to the cochlear implantation. The role of the electrode design and its impact on the risk of meningitis has also been investigated and it is accepted that a particular historical design led to an increased risk. The Centers for Disease Control and Prevention has specific recommendations for vaccination of adult and pediatric implant candidates and recipients.

Calhoun CD, Slattery WH, Luxford WM. Postoperative infection in cochlear implant patients. *Otol Head Neck Surg.* 2004:131:109.
Hoffman RA, Cohen NL. Complications of cochlear implant surgery. *Ann Otol Rhinol Laryngol.* 1995;166:420–422.
Yu KCY, Hegarty JL, Gantz BJ et al. Conservative management of infections in cochlear implant recipients. *Otol Head Neck Surg.* 2001;125:66.

ASSESSMENT OF OUTCOMES

Subjective Measurements

Cochlear implantation, not long ago viewed as experimental, is now a proven treatment for SNHL in properly selected patients. Adult implant recipients with positive outcomes have seen benefits as far-reaching as a restored capability to communicate on the telephone (attained by roughly 60% of adult recipients) and the ability to converse without the necessity of lip-reading. More modest outcomes have included the improved reception of environmental sounds and augmented lip-reading capabilities. Other selected benefits that have been described include the treatment of tinnitus, the improvement of preimplantation depression, and a perceived overall improvement in the quality of life (reported to be as high as 96% of recipients in one report).

Rarely, in medicine, there is a procedure that has such a profoundly positive impact on the quality of life. Successful cochlear implantation is extremely rewarding for implant team members and patients alike. Yet, it is essential to stress that the outcomes seen with cochlear implantation vary widely both within given patient populations and among differing groups. Multiple factors have been shown to have a bearing on the degree of benefit obtained from implantation (Table 68–2). Although these factors are helpful in anticipating performance levels, additional unaccounted-for dynamics, which are difficult to gauge and recognize, do exist and account for about 50% of the variance in performance.

Objective Measurements

A. Open-Set Sentence and Word Recognition Scores

More specific objective measures in postlingual deafened adults following implantation include an evaluation of both open-set sentence and word recognition scores. Various reports have documented open-set sentence recognition scores of 60–70% and word recognition scores of 30–50%.

Table 68–2. Factors Generally Associated with Better Outcomes in Cochlear Implantation (Listed in Random Order).

Adults and Children
Shorter duration of deafness
Better preoperative word or sentence recognition (or both)
Lip-reading ability
Higher intelligence quotient
Better preoperative residual hearing
Optimized implant technology and processing strategy
Cause of deafness (eg, meningitis associated with poor outcomes)
Intact, nonossified cochlea
Additional Factors in Children
Younger age at implantation
Motivated family assistance
Higher socioeconomic status
Oral preoperative education
Oral education rehabilitation program as opposed to *total communication*

Note that patient variability, evolving inclusion criteria, and ever-changing technological innovations render the objective analysis between various implant systems and processing strategies quite difficult. Overall, average performance continues to improve.

B. Measurements for Pediatric Patients

In children, results seem to have greater variability and are more difficult to measure.

1. Mainstream schooling—A common goal (and one that has been frequently attained) for implant recipients in the very young pediatric population is to achieve communication abilities sufficient to allow enrollment in mainstream schooling by the second grade. In fact, an especially high number of children who have received an implant before age 3 have been known to eventually achieve age-appropriate speech recognition and production, with the most frequent success coming in the subset of patients who are younger than 18 months when they receive the implant.

2. Word understanding—The objective markers of pediatric outcomes in postlingual deafened children (the minority of deaf children) include word understanding test scores 3 years after implantation that are documented to reach as high as 100%. The prelingual deafened child, who represents the majority of pediatric deaf patients, has shown to make slower and more variable improvements over a longer time span, including reported progress at up to 8 years after implantation. As previously alluded to, evidence seems to indicate that children do better if implantation is undertaken at the youngest possible age with the best outcomes usually obtained in children less than 2 years old.

Chmiel R, Sutton L, Jenkins H. Quality of life in children with cochlear implants. *Ann Otol Rhinol Laryngol.* 2000;185:103. [PMID: 11140975] (Quality of life gauged to be significantly better in children with cochlear implants.)

Franz DC. Pediatric performance with the Med-El Combi 40+ cochlear implant system. *Ann Otol Rhinol Laryngol.* 2002;189:66. [PMID: 12018352] (Good outcomes in children with the Med-El Combi 40+.)

Gantz BJ, Hansen MR, Turner CW et al. Hybrid 10 clinical trial: preliminary results. *Audiol Neurotol.* 2009;14(1):32. [PMID: 19390173]. (Good outcomes and a high rate of hearing preservation with the Iowa Hybrid-S device for "partial deafness" implantation.)

Geers A, Brenner C, Nicholas J et al. Rehabilitation factors contributing to implant benefit in children. *Ann Otol Rhinol Laryngol.* 2002;189:127. [PMID: 12018339] (Children and family nonverbal IQ, implant characteristics, and educational variables each account for variability in the outcomes in pediatric implantation.)

Geers AE, Nicholas J, Tye-Murray N et al. Effects of communication mode on skills of long-term cochlear implant users. *Ann Otol Rhinol Laryngol.* 2000;185:89. [PMID: 11141021] (Results in children using an oral–auditory communication mode are superior to total communication.)

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Anatomy, Physiology, & Testing of the Facial Nerve

69

Lawrence R. Lustig, MD &
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FACIAL NERVE ANATOMY

The facial nerve is directly and indirectly involved in numerous pathological conditions affecting the temporal bone, ranging from infection to neoplasia. In each instance, a solid understanding of its complex anatomy is crucial to the physician's ability to both diagnose and treat disorders of the facial nerve.

EMBRYOLOGY

Intratemporal Development

The facial nerve (Figure 69–1) begins its development near the end of the first month of gestation, when the acousticofacial primordium, giving rise to both the facial and acoustic nerves, develops adjacent to the primordial inner ear, the otic placode. The geniculate ganglion, which arises from the second branchial arch, develops early in the second month of the gestation. Adjacent to the developing geniculate ganglion, the acousticofacial primordium differentiates into a caudal and a rostral trunk. The caudal trunk progresses into the mesenchyme of the second branchial arch, becoming the main trunk of the facial nerve. The rostral branch becomes associated with the first arch, eventually developing into the chorda tympani nerve, providing taste to the anterior two-thirds of the tongue. This development partially explains the close association of the chorda tympani with the facial nerve.

Both the geniculate ganglion and the nervus intermedius, arising from the second branchial arch, form independently of the motor division of the seventh nerve. During the sixth week of gestation, the motor division of the facial nerve establishes its position in the middle ear between the membranous labyrinth (an otic placode structure) and the developing stapes (a second arch structure). The nerve then passes into the mesenchyme of the second arch. During this time, the chorda tympani nerve becomes associated with the trigeminal nerve, which will carry the chorda tympani on its way to the tongue via the lingual nerve. The greater superficial petrosal nerve, which carries preganglionic parasympathetic fibers toward the pterygopalatine ganglion, also develops during this time period.

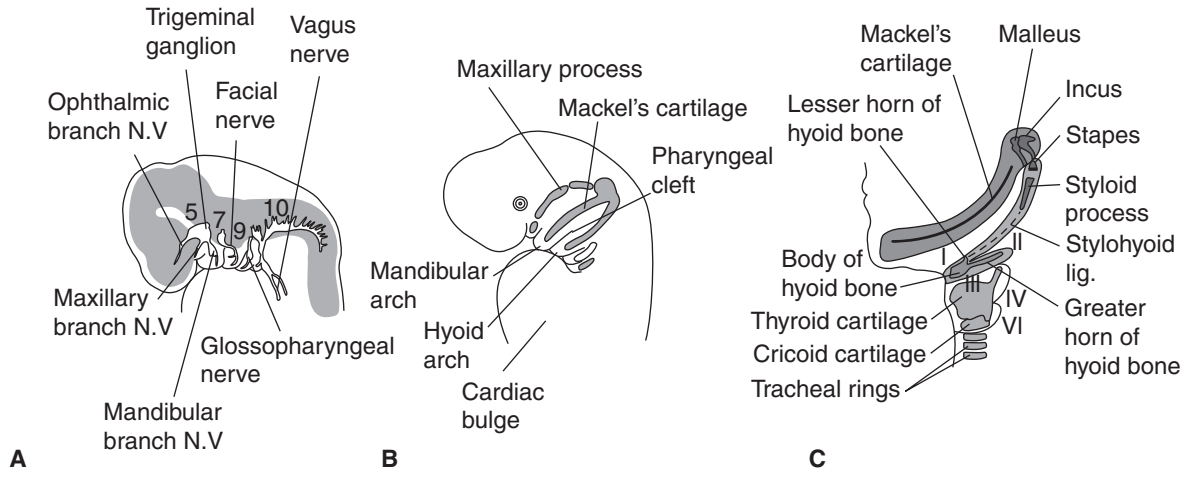
Most of the anatomic relationships of the facial nerve are established by the end of the second gestational month. Although the fallopian canal, the bony canal that transmits the facial nerve through the temporal bone, begins its development in the fifth gestational month, it is not complete until several years after birth. The incomplete development of this canal is though to be responsible for the natural dehiscences that may contribute to facial palsies that are associated with childhood otitis media.

Extratemporal Development

During the sixth gestational week, the extratemporal portion of the facial nerve begins development. By the end of the second gestational month, all five divisions of the extratemporal nerve—the temporal, zygomatic, buccal, mandibular, and cervical branches—are present. Over the third month, the nerve becomes enveloped by the parotid gland. The facial muscles (Figure 69–2), developing independently, are formed at 7–8 week gestation and must be innervated by the distal facial nerve branches or else will degenerate. By the end of the third gestational month, a majority of the facial musculature is identifiable and functional.

Postnatal Development

At birth, the facial nerve is located just beneath the skin near the mastoid tip, as it emerges from the temporal bone. This nerve is thus placed at risk when a postauricular incision is made in a young child, as is often done for ear surgery. As the mastoid tip forms and elongates during childhood, the facial nerve assumes its more medial position. Individual axons of the facial nerve also undergo myelination until the age of 4 years, an important consideration during electrical testing of the nerve during this time period.

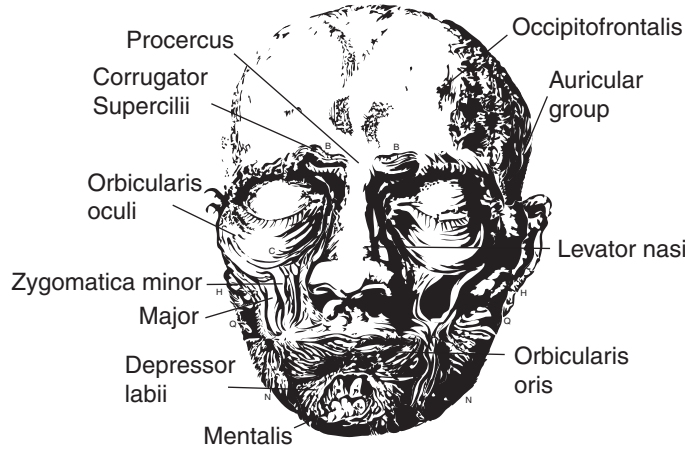


▲ **Figure 69–1.** A schematic illustration demonstrating the embryology of the facial nerve. **(A)** The location of the primitive facial nerve in the developing embryo is shown in relation to other important nerves in the head and neck. **(B)** The location of the second branchial arch giving rise to the main trunk of the facial nerve is shown in relation to the other branchial arches. **(C)** Other derivatives of the second branchial arch are shown and help explain the complex innervation pattern of the facial nerve. (Reproduced with permission from Langman J & Sadler TW, *Langman's Medical Embryology,* 5th ed. Williams and Wilkins: Baltimore, MD; 1985.)

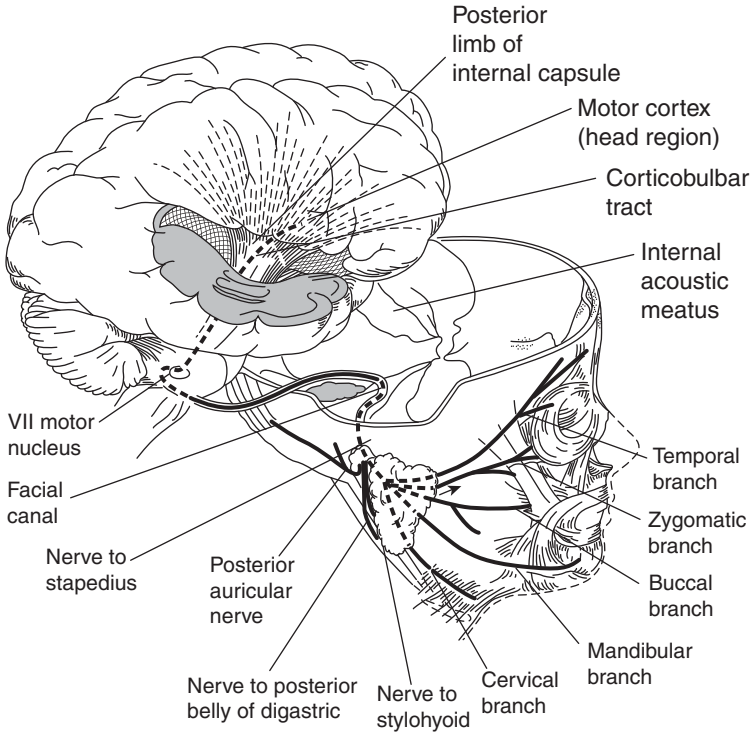
CENTRAL NEURONAL PATHWAYS

Supranuclear Pathways

The primary somatomotor cortex of the facial nerve is located in the precentral gyrus, corresponding to Brodmann areas 4, 6, and 8. It is from this region that the complex voluntary motor functions of the facial nerve, such as facial expression, are controlled (Figure 69–3). Neural projections from this area combine into fascicles of the corticobulbar tract during their descending course through the internal capsule. These neural projections continue through the pyramidal tracts within the basal pons. In the caudal portion of the pons, most of the facial nerve fibers cross the midbrain to reach the contralateral facial nucleus. A small number of facial nerve fibers innervate the ipsilateral facial nucleus, a majority of which are destined for the temporal branch of the nerve. This distinction becomes important when the



▲ **Figure 69–2.** An adaptation of Sir Charles Bell's classic illustration of the muscles of facial expression, with the muscles labeled. (Reproduced with permission from Bell C, *Essays on the Anatomy of Facial Expression,* 2nd ed. Murray; 1824.)



▲ **Figure 69–3.** A schematic illustration of the complete pathway of the motor division of the facial nerve. (Reproduced with permission from Wilson-Pauwels L, Akesson EJ, Stewart PA, *Cranial Nerves: Anatomy and Clinical Comments.* B.C. Decker, 1988.)

clinician is trying to determine if a facial paralysis is due to a central or peripheral lesion: central lesions spare the forehead muscle since they receive input from both cerebral cortices, whereas peripheral lesions will involve all branches of the facial nerve.

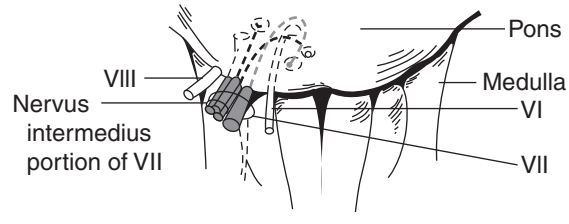
In addition to these voluntary neural projections to the facial nerve, there is also an extrapyramidal cortical input to the facial nucleus from the hypothalamus, the globus pallidus, and the frontal lobe, all of which control involuntary facial expression associated with emotion. Additional projections to the facial nuclei from the visual system are involved in the blink reflex. Projections from the trigeminal nerve and nuclei contribute to the corneal reflex, whereas those from the auditory nuclei help the eye close involuntarily in response to loud noises.

Facial Nucleus & Brainstem

The efferent projections from the facial motor nucleus emerge dorsomedially to form a compact bundle that loops over the caudal end of the abducens nucleus beneath the facial colliculus or internal genu (or turn). The neurons then pass between the facial nerve nucleus and the trigeminal spinal nucleus, emerging from the brainstem at the pontomedullary junction (Figure 69–4).

Nervus Intermedius

In addition to supplying motor innervation to the muscles of facial expression, other neuronal projections found in association with the facial nerve are partially responsible for taste, cutaneous sensation of the external ear, proprioception, lacrimation, and salivation (Table 69–1; Figure 69–5). This bundle of these nerves, termed the *nervus intermedius*, or Neve of Wrisberg, exits the brainstem adjacent to the motor



▲ **Figure 69–4.** The anatomy of the facial nerve (CN VII), cochlear nerve, and vestibular nerve (CN VII), as they exit the brainstem at the level of the pontomedullary junction. (Reproduced, with permission from Wilson-Pauwels L, Akesson EJ, Stewart PA, *Cranial Nerves: Anatomy and Clinical Comments.* B.C. Decker Inc.: Toronto; 1988.)

Table 69–1. Subdivisions and Functions of the Facial Nerve.

Facial Nerve Subdivision	Function
Branchial motor	Muscles of facial expression Posterior belly of digastric muscle Stylohyoid muscle Stapedius muscle
Visceral motor	Salivation—lacrimal, sub-mandibular, and sublingual Nasal mucosa or mucous membrane
General sensory	Sensory to auricular concha External auditory canal Tympanic membrane
Special sensory	Chorda tympani nerve—taste to anterior two-thirds of the tongue

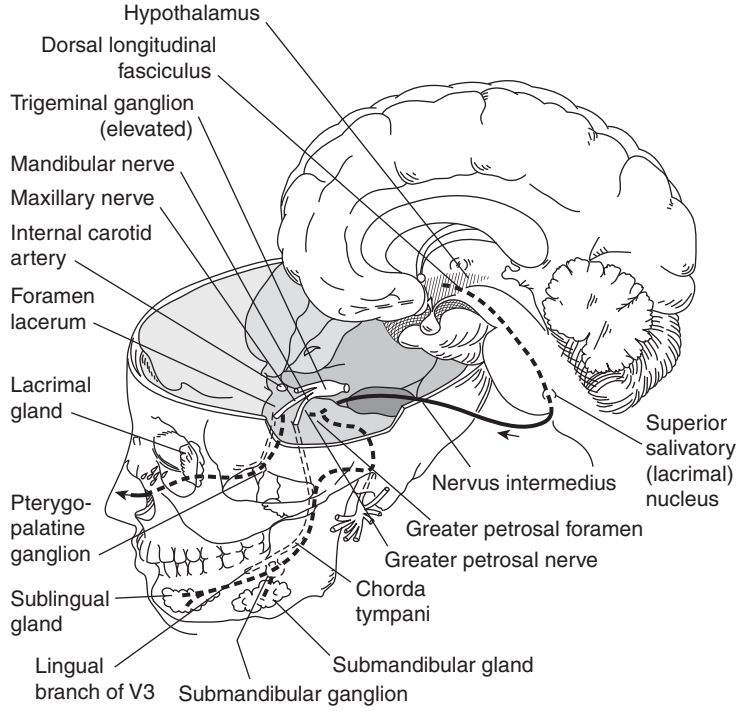
branch of the facial nerve. The general visceral efferent fibers of the *nervus intermedius* are preganglionic parasympathetic neurons that innervate the lacrimal, submandibular, sublingual, and minor salivary glands. The cell bodies of these nerves arise in the superior salivatory nucleus and join the facial nerve after it has passed the abducens nucleus. They travel together until reaching the geniculate ganglion in the temporal bone. At this point, the greater superficial petrosal nerve branches offs, containing the neurons destined for the pterygopalatine ganglion. The greater superficial petrosal nerve ultimately innervates the lacrimal, minor salivary, and mucosal glands of the palate and nose. The remaining fibers form part of the chorda tympani nerve, proceed to the submandibular ganglion, and eventually proceed to the submandibular and sublingual salivary glands.

The special visceral afferent fibers, which also form a portion of the chorda tympani nerve, receive input from the taste buds of the anterior two-thirds of the tongue, as well as the hard and soft palates (Figure 69–6). These sensory afferents for taste have their cell bodies in the geniculate ganglion and will eventually synapse in the medulla, in the nucleus solitarius.

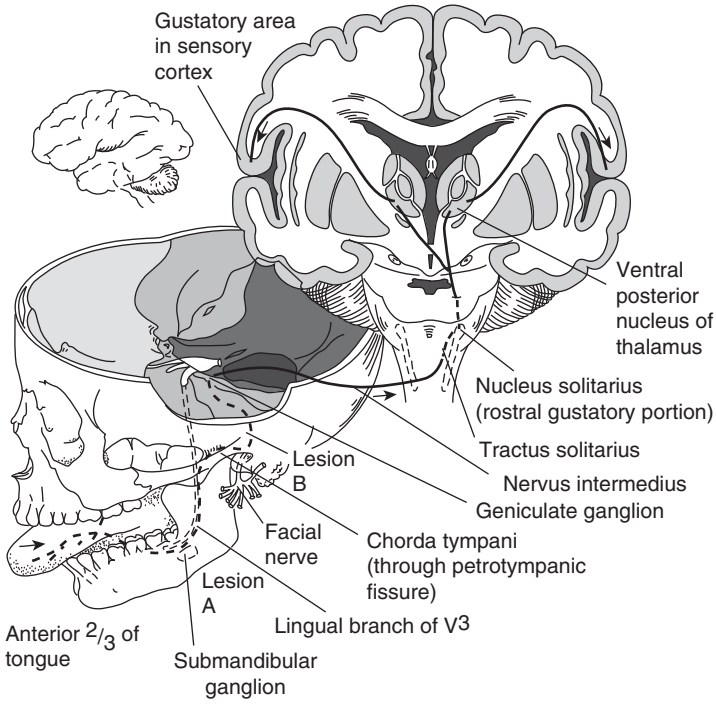
The general sensory afferent neurons of the nervus intermedius are responsible for cutaneous sensory information from the external ear canal and postauricular region. These cutaneous sensory fibers enter the spinal trigeminal tracts without synapsing in the geniculate ganglion.

Cerebellopontine Angle

The facial nerve leaves the brainstem at the pontomedullary junction (see Figure 69–4). At this location, it lies in close approximation to the eighth cranial nerve (the vestibulocochlear nerve). This intimate relationship takes on critical importance when disease, most commonly a vestibular schwannoma, arises in the region of the cerebellopontine angle. In this location, the facial nerve is placed in jeopardy



▲ **Figure 69–5.** The anatomy of the visceral motor portion of the facial nerve, making up the nervus intermedius, or Wrisberg nerve. The preganglionic, parasympathetic portions of this nerve have cell bodies located in the abducens nucleus. From there they travel toward the geniculate ganglion in the temporal bone, located at the first genu of the facial nerve on the floor of the middle cranial fossa. Fibers from this nerve are destined to innervate the lacrimal gland, the minor salivary glands, and the mucosal glands of the palate and nose. (Reproduced with permission from Wilson-Pauwels L, Akesson EJ, Stewart PA, *Cranial Nerves: Anatomy and Clinical Comments.* B.C. Decker Inc.: Toronto; 1988.)



▲ **Figure 69–6.** The anatomy of the special sensory component of the facial nerve, comprising the chorda tympani nerve. (Reproduced with permission from Wilson-Pauwels L, Akesson EJ, Stewart PA: *Cranial Nerves: Anatomy and Clinical Comments.* B.C. Decker Inc.: Toronto; 1988.)

both during the growth of the tumor and during attempted surgical resection in this area.

During its lateral course through the cerebellopontine angle and internal auditory canal (IAC), the relative positions of the facial and cochleovestibular nerves change by rotating 90°. In the cerebellopontine angle, the facial nerve is covered with pia, bathed in cerebrospinal fluid, and is devoid of epineurium. As a result, the nerve is very susceptible to trauma or manipulation in this region, such as during intracranial surgery.

INTRATEMPORAL NERVE PATHWAYS

After traversing the cerebellopontine angle, the facial nerve enters the temporal bone along the posterior face of the petrous bone. Within the temporal bone, the facial nerve successively passes through 4 regions prior to its exit out of the stylomastoid foramen: (1) the IAC, (2) the labyrinthine segment, (3) the intratympanic segment, and (4) the descending segment (Figures 69–7 through Figure 69–9). From the lateral end of the IAC to its exit out the stylomastoid foramen, the nerve travels approximately 3 cm within the facial canal, also known as the fallopian canal.

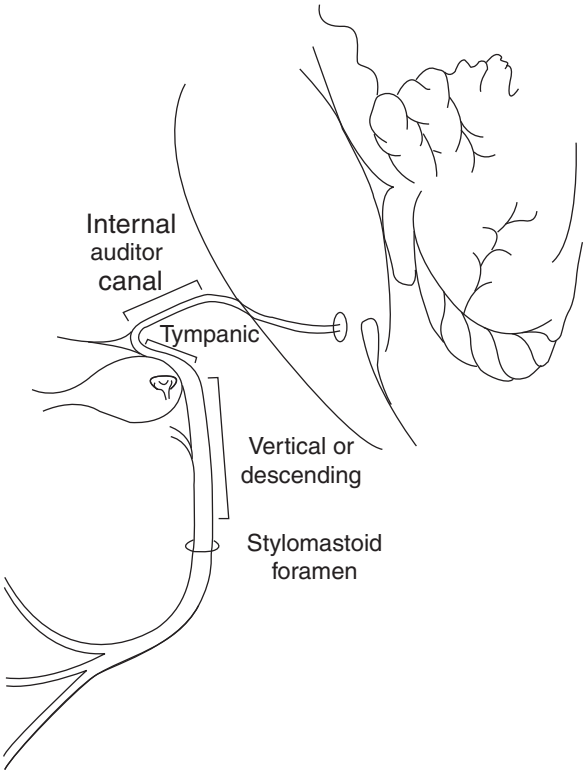
Internal Auditory Canal

After traversing the cerebellopontine angle, the facial nerve enters the temporal bone along the posterior face of the petrous bone, piercing the internal auditory meatus. At the lateral end of the IAC, a ridge of bone, the traverse crest, divides the IAC into superior and inferior portions. It is at this lateral portion of the IAC that the anatomy is most consistent: the superior portion is occupied by the facial nerve anteriorly and the superior vestibular nerve posteriorly (see Figure 69–8). These two nerves are additionally divided by a bony ridge, the vertical crest or "Bill's bar." The inferior portion of the IAC, below the transverse crest, contains the cochlear nerve (anterior) and the inferior vestibular nerve (posterior). Within the IAC, the dural covering of the facial nerve is transformed to epineurium.

Labyrinthine Segment

At the lateral portion of the IAC, the facial nerve pierces the meatal foramen to enter the labyrinthine segment. The labyrinthine segment is notable in that it is the narrowest portion of the fallopian canal, where it averages <0.7 mm in diameter and occupies the canal to the greatest proportional extent. As a result, it is believed that infections or inflammations of the facial nerve within this region can lead to temporary or permanent paralysis of the nerve, such as in Bell's palsy.

The distal end of the geniculate ganglion is considered the end of the labyrinthine segment of the nerve and lies just superior to the nerve. While it is generally bone-covered just below the floor of the middle cranial fossa, the geniculate ganglion is dehiscent into the middle fossa up to 15% of the time. Arising from the geniculate ganglion is the greater superficial petrosal nerve.



▲ **Figure 69–7.** The intratemporal divisions of the facial nerve. After passing through the internal auditory meatus on the posterior face of the petrous temporal bone, the nerve enters its canalicular segment, within the IAC. It then becomes the labyrinthine segment, as it traverses between the cochlea and the vestibular labyrinth. After making its first genu (bend) at the geniculate ganglion, it becomes the tympanic segment, coursing through the middle ear space, just superior to the oval window. It then makes its second major genu at the level of the horizontal semicircular canal and becomes the vertical or descending segment. After passing through the stylomastoid foramen, it becomes extracranial.

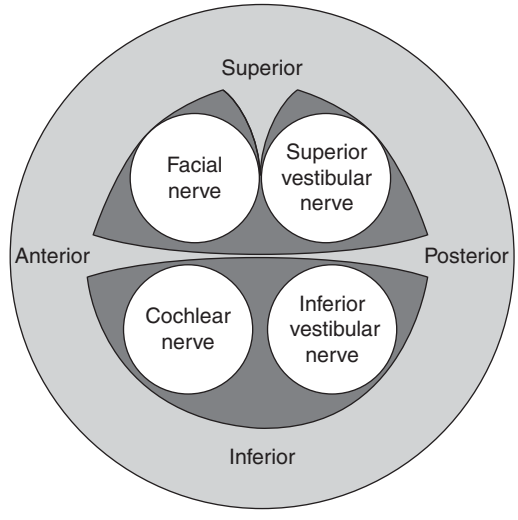
Tympanic Segment

At the geniculate ganglion, the facial nerve makes its first genu and becomes the tympanic segment of the facial nerve, so called because it travels within the middle ear space. This portion of the nerve is approximately 10 mm long. As the nerve enters the tympanic space, it is positioned just superiorly, medially, and anteriorly to the cochleariform process, which serves as an excellent anatomical landmark during surgical identification of the nerve. An additional useful landmark, the "cog," which is a small bony prominence projecting from the roof of the epitympanum, lies just superior to the facial nerve as it enters the tympanic cavity. The facial nerve then travels posteriorly along the medial portion of the epitympanum, passing superior to the oval window and stapes. The nerve then curves inferiorly at its second genu, just posterior to the oval window, pyramidal process, and stapedial tendon, and anterior to the horizontal semicircular canal. It is this portion of the nerve that is susceptible to injury during surgery since processes such as cholesteatoma will frequently erode the bone covering the facial nerve in this region, leaving it precariously exposed.

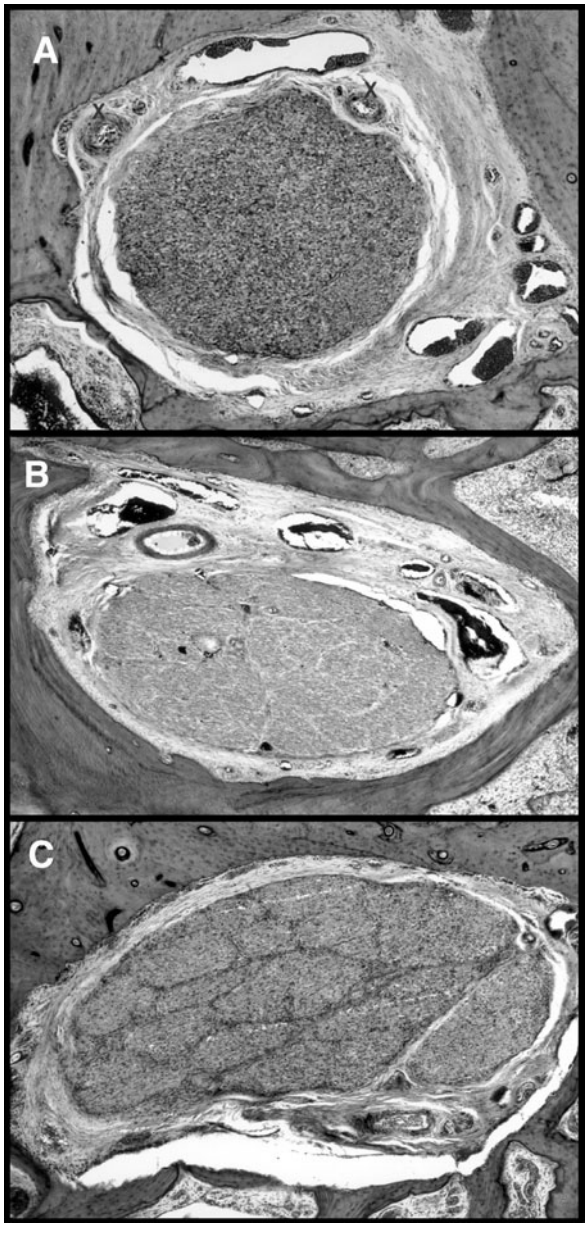
In addition to bony dehiscence from pathology, natural fallopian canal dehiscences have also been described in cadaver specimens, a majority of which occurred in the tympanic segment. In more than 80% of cases, the dehiscences involved the portions of the canal adjacent to the oval window.

Vertical, Descending, or Mastoid Segment

After the second genu, the nerve traverses the synonymously named vertical, descending, or mastoid segment en route to the stylomastoid foramen. As the facial nerve descends inferiorly in this portion, it gradually assumes a more lateral position. The facial nerve branch of the stapedius muscle arises in this segment, traveling a short distance to the stapedius muscle. More inferiorly, the chorda tympani nerve, which carries preganglionic parasympathetic fibers to the



▲ **Figure 69–8.** A stylized representation of the anatomy of the lateral aspect of the internal auditory canal. The facial nerve lies at the most anterior and superior location at this level.



▲ **Figure 69–9.** Histological cross sections of the facial nerve at 3 points along its course within the temporal bone. Proximally within the temporal bone at the level of the internal auditory canal, **(A)** the individual nerve fascicles are not defined and nerve elements appear homogenous. **(B)** As the nerve proceeds through the tympanic segment and **(C)** at the level of the stylomastoid foramen, individual nerve fascicles becomes increasingly defined.

submaxillary and sublingual glands and taste fibers to the ipsilateral anterior two-thirds of the tongue, arises from the facial nerve and travels superiorly, laterally, and anteriorly back toward the middle ear space. The angle between the chorda tympani nerve and the descending portion of the facial nerve is approximately 30° and delineates a triangular space known as the facial recess. The facial recess is an important surgical route of entry into the middle ear space, enabling access of the stapes superstructure, the promontory, and the round window niche.

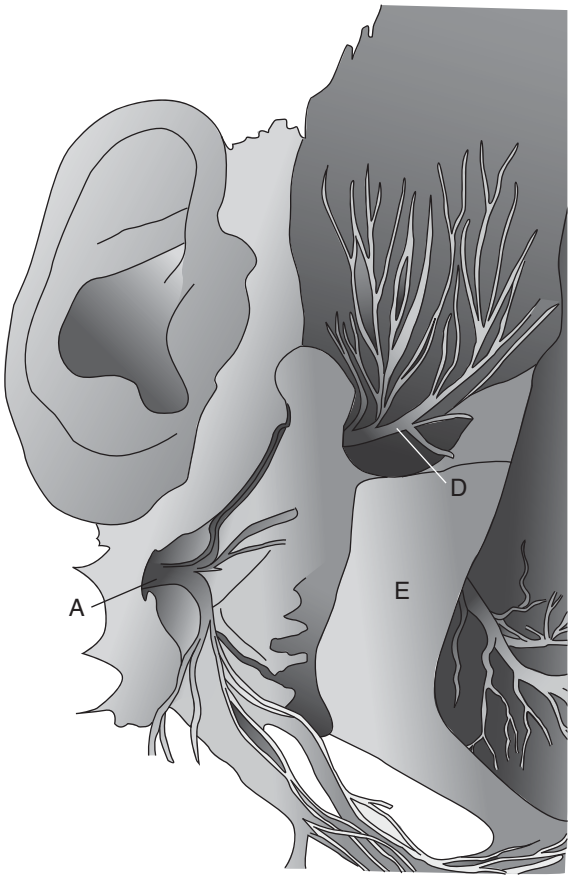
In its most inferior portion, the facial nerve takes on a close proximity to the digastric ridge and muscle, where the nerve is consistently medial and anterior to these structures. An additional close anatomic landmark in this region includes the sigmoid sinus, where it passes deep to the facial nerve in this region. Upon exiting the stylomastoid foramen, the nerve becomes encased in the thick fibrous tissue of the cranial base periosteum and digastric muscle.

Although the facial nerve most commonly descends in its vertical segment as a single nerve, bifurcations, trifurcations, and hypoplasia of the facial nerve have been found within the mastoid segment. Additionally, the chorda tympani nerve has been noted to arise from the facial nerve anywhere from the stylomastoid foramen to the geniculate ganglion.

PERIPHERAL FACIAL NERVE ANATOMY

The facial nerve exits the skull base through the stylomastoid foramen, between the mastoid tip laterally and the styloid process medially (Figure 69–10). At the stylomastoid foramen, the facial nerve passes into the parotid gland, typically as a single large trunk. The nerve then divides within the parotid gland into its temporofacial and cervicofacial branches. Rarely, this division can occur within the temporal bone and exit the stylomastoid foramen as separate branches. One branch is the posterior auricular nerve that courses lateral to the mastoid and is joined by a filament of the auricular branch of the vagus nerve.

Within the parotid gland, the nerve can assume numerous configurations, with frequent anastomoses between branches. However, generally five main branches of the nerve can be identified: (1) the temporal, (2) the zygomatic, (3) the buccal, (4) the mandibular, and (5) the cervical. The temporal branch innervates the frontalis muscle, which allows for the voluntary raising of eyebrows. The zygomatic branch innervates the orbicularis oculi muscle and is critical for proper eye closure. The buccal nerve innervates the buccinator and orbicularis oris, allowing for proper mouth closure and cheek muscle activity. The mandibular branch innerves the platysma. The posterior auricular nerve, arising just after the exit of the facial nerve from the stylomastoid foramen, sends branches to the occipitalis muscle posteriorly on the skull.



▲ **Figure 69–10.** A portion of an illustration from Sir Charles Bell, demonstrating the exit of the facial nerve from the stylomastoid foramen. (Reproduced with permission from Bell C, *The Nervous System of the Human Body*. Longman; 1830. Plate VII.)

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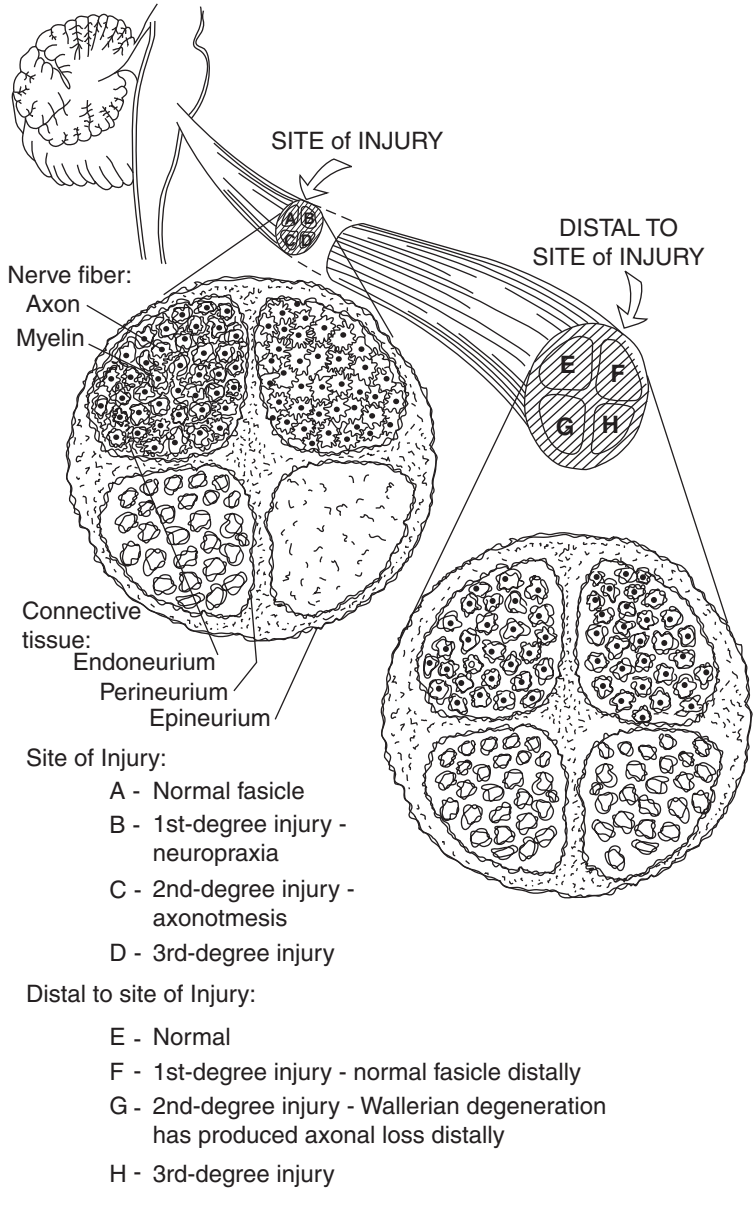
FACIAL NERVE PHYSIOLOGY

ANATOMIC CONSIDERATIONS

The facial nerve trunk consists of approximately 10,000 nerve fibers, approximately 7000 of which are myelinated motor fibers. The facial nerve sheath consists of several layers. The endoneurium, closely adherent to the layer of Schwann cells of the axons, surrounds each nerve fiber. The perineurium, which is the intermediate layer surrounding groups of fascicles, provides tensile strength to the nerve and is believed to represent the primary barrier to the spread of infection. The outermost layer of the nerve is the epineurium. This outer layer contains the vasa nervorum, which provides the blood supply to the nerve.

CLASSIFICATION OF FACIAL NERVE DEGENERATION

If the facial nerve is injured, various degrees of injury may result. Several models allow for a clinical determination of the degree of nerve fiber injury that produces an irreversible conduction block (ie, fiber degeneration). It was originally proposed that peripheral nerve injury involves varying degrees of neuropraxia (blockade), axonotmesis (division of individual fibers), and neurotmesis (division of fascicles and epineurium). A clinical–pathological classification of nerve injury, the **Sunderland Classification** scheme



▲ **Figure 69–11.** A model of graded neural injury that details clinical–pathological classifications. Microanatomic changes in cranial nerve injury are demonstrated in cross section. The potential for appropriate axonal regeneration across the site of injury is dictated principally by the status of connective tissue elements.

(Figure 69–11), is widely accepted and grades the extent of injury as follows:

1. **First-degree injuries** *are characterized by the blockage of axoplasm flow within the axon. There is sufficient pressure to restrict its replenishment when metabolic needs dictate. This blockade is sometimes referred to as neuropraxia. Although an action potential cannot be propagated across the lesion site, a stimulus applied distal to the lesion will conduct normally to produce an evoked response.*
2. **Second-degree injuries** *entail axonal and myelin disruption distal to the injury site as a result of the progression of a first-degree injury. Such injuries eliminate the propagation of an externally applied stimulus as wallerian degeneration of the axon ensues.*
3. **Third-degree injuries** *involve complete disruption of the axon including its surrounding myelin and endoneurium.*
4. **Fourth-degree injuries** *entail the complete disruption of the perineurium.*

5. **Fifth-degree injuries** *entail the disruption of the epineurium.*
6. **Sixth-degree injuries,** *a proposed addition to the Sunderland classification by later authors, take into account the observed patterns of blunt and penetrating injuries of the nerve. These injuries are characterized by normal function through some fascicles and varying degrees of injury (first-degree through fifth-degree injuries), differentially involving fascicles across the nerve trunk.*

Central to Sunderland's classification is the notion that axonal recovery depends on the integrity of the connective tissue elements of the nerve trunk. This model predicts a high likelihood for the complete recovery of peripheral innervation when endoneurial tubules remain intact to support reinnervation, as is the case with first- and second-degree injuries. In contrast, disruption of the endoneurium—a third-degree injury or worse in this model—increases the likelihood of irreversible axonal injury and aberrant patterns of regeneration.

An example of abnormal neural regrowth is "crocodile tears," or increased lacrimation associated with eating. It occurs when efferent fibers normally targeted to travel with the chorda tympani nerve to the submandibular and sublingual glands are misdirected through the greater superficial petrosal nerve to the lacrimal gland. This results in parasympathetic innervation of the lacrimal gland as well as the normal target, the salivary glands. As a result, when eating, instead of getting the normal salivary response to increase the salivation, the neuronal signal causes tearing of the lacrimal gland.

Kim J MD PhD, Moon IS MD, Shim DB MD, Lee WS MD PhD. The effect of surgical timing on functional outcomes of traumatic facial nerve paralysis. *J Trauma*. 2009. [PMID: 20032793]
Sunderland S. *Nerve and Nerve Injuries*. 2nd ed. E & S Livingstone Ltd; 1968.

FACIAL NERVE TESTING

The impaired transmission of neural impulses can result from physiological blockage (in the absence of nerve fiber degeneration) and axonal discontinuity with wallerian degeneration. Because the clinical presentation of a facial paralysis does not distinguish between simple conduction block and axonal disruption, investigators have explored an array of testing procedures designed to define the extent of nerve injury (Table 69–2).

In an initial evaluation of patients with acute facial paralysis, the clinician should aim to determine the prognosis for recovery as well as the cause of the paralysis. Early determination of the prognosis for recovery may permit intervention both to minimize nerve injury and to optimize regeneration.

TOPOGNOSTIC TESTING

Topognostic test batteries are intended to determine the level of facial nerve injury by inference from which branch(es) are functional. If tearing is diminished, the lesion is assumed to be proximal to the point at which the greater superficial petrosal nerve branches from the geniculate ganglion. Abnormal stapedial muscle function, as revealed by immittance testing, presumably reflects nerve impairment above the stapedial motor branch from the facial nerve trunk distal to the posterior genu. The functioning of the chorda tympani nerve can be determined by submandibular gland secretion and taste testing. Dysgeusia and diminished salivary gland flow presumably reflect nerve impairment above the branch point of the chorda tympani nerve from the vertical segment of the facial nerve in the mastoid.

Early observations suggested that more proximal levels of dysfunction correlated with a higher risk of degeneration and incomplete recovery. However, topognostic modalities have often provided inconsistent information on the level of neural injury, and are subject to the vagaries produced by "skip" lesions of the nerve that affect the motor, sensory, and autonomic portions of the nerve differently For example, the Schirmer tear test, an apparent index of proximal nerve function establishing a lesion at or above the level of the geniculate ganglion, has been subsequently shown to have an accuracy rate of only 60% using intraoperative electrical stimulation to specify the site of nerve conduction block in Bell's palsy. However, the Schirmer test has great practical value in assessing tear production and the need for adjunctive measures for eye care.

Because topognostic testing carries inherent vagaries, electrophysiological testing (below) has emerged as the diagnostic approach of choice in assessing nerve conductivity and the risk of irreversible degeneration of nerve fibers.

ELECTROPHYSIOLOGICAL TESTING

The interpretation and validity of electrophysiological testing of an acute facial palsy rests on two constructs with regard to nerve fiber function:

1. Segmentally demyelinated fibers maintain the capacity to propagate a stimulus, albeit at a higher threshold, than that of normal fibers. Anatomically intact fibers will therefore continue to propagate an applied stimulus, whereas those that have become disrupted and subsequently degenerated will not.
2. By estimating the proportion of degenerated motor fibers, a clinician may distinguish palsies that will fail to recover spontaneously and will produce long-term sequelae.

Electrophysiological testing ideally provides an index of the severity of injury to the total nerve trunk by reflecting the proportion of motor fibers that have progressed beyond a first-degree injury. Correlation of the ultimate level of recovery with early electrophysiological findings determines

Table 69–2. Tests of Facial Nerve Function.

Test	Measure	Advantages	Disadvantages
Minimal excitability test	The lowest stimulus intensity that consistently excites all branches on the uninvolved side	Portability Patient comfort Easy to perform	Subjective Relies on visual detection
Maximal excitability test	Compares response on involved vs, uninvolved side of face	Portability Patient comfort Easy to perform	Subjective Relies on visual detection
Electroneuronography and evoked electromyography (EMG)	Assesses the facial motor response to a supramaximal stimulus Records the compound muscle action potential Reflects% motor fibers of the facial nerve that have undergone degeneration <90% denervation prognosticates excellent recovery Repeated every other day to detect ongoing degeneration beyond the 90% critical level	Useful early in the course of facial paralysis Some measures useful in predicting the ultimate level of spontaneous recovery	Patient discomfort
Electromyography	Measures postsynaptic membrane potentials Motor unit potentials in five muscle groups in the first 3 days after onset of palsy associated with good outcome in >90% of patients	Precision characterization of motor units	Possible pitfalls with early testing Sparse residual motor units that suggest a favorable outcome may be evident despite severe injury to large portions of fibers that are at risk for degeneration
Antidromic conduction	F wave represents activity in facial muscles generated by antidromically activated motor neurons In Bell palsy, F wave seen only after recovery begun	Can provide direct and immediate assessment of facial nerve function	Limited dynamic range and prognostic value Primarily animal testing, research
Magnetic simulation	Electromagnetic coil to produce neural activation	Intensity of the stimulus is minimally attenuated by intervening tissue	Limited clinical utility Difficult to interpret results
Trigeminofacial reflex	EMG recording of the blink reflex Compares responses between the affected and normal sides Abolished R1 reflex associated with little chance of recovery in the first 2 months after onset of paralysis	Easy to perform	May be limited by small response amplitude

the prognostic value of the test in identifying the subset of facial palsy patients who will not obtain satisfactory, spontaneous recovery.

Clinically available electrophysiological tests indirectly assess the severity of injury to the intratemporal facial nerve. Given its course within the Fallopian canal, electrical stimulation proximal to the site of conduction blockade is possible only when the nerve is activated intracranially. For this reason, the ability of a nerve to propagate an impulse is assessed distal to the stylomastoid foramen. Even in the presence of severe neural injury, conduction distal to a lesion will continue until its axoplasm is consumed and wallerian degeneration ensues. This process requires 48–72 hours to progress from intratemporal to extratemporal segments, thereby rendering electrical stimulation tests falsely normal during this period. Routine electrophysiological tests therefore fail

to detect nerve conduction as it occurs, thereby delaying the differentiation of neuropraxia from degeneration.

Nerve Excitability Testing

Minimal excitability testing with the Hilger nerve stimulator has provided a readily accessible method of facial nerve assessment. The test is indexed according to the thresholds for visually detectable activity generated by surface stimulation of a facial nerve branch. The test reflects elevated thresholds for neuromuscular stimulation produced by axonal disruption and degeneration. The lowest stimulus intensity that consistently excites all branches on the uninvolved side establishes the normal threshold. A 2.0–3.5 mA difference between the uninvolved and involved sides is reported to suggest impending denervation.

This test offers technical advantages in the portability of the necessary equipment and the use of minimal stimulation, which is more comfortable for the patient than maximal stimulation tests. The test, however, introduces subjectivity in that it relies on the visual detection of a response of a limited number of facial muscles. In addition, current threshold levels for peripheral branches are likely to selectively activate large nerve fibers with lower thresholds and those fibers closer to the stimulating electrode, thereby excluding an unknown proportion of motor fibers from the assessment.

Fisch U. Prognostic value of electrical tests in acute facial paralysis. *Am J Otol*. 1984;5(6):494. [PMID: 6393772] Review,

Gantz BJ, Gmur A, Fisch U. Intraoperative evoked electromyography in Bell's palsy. *Am J Otolaryngol*. 1982;3(4):273. [PMID: 7149140] (The technique of intraoperative evoked electromyography is described in detail. The limited extent of the blocked motor fibers suggests that segmental, rather than total, intratemporal decompression is needed in Bell's palsy.)

Lewis BI, Adour KK, Kahn JM et al. Hilger facial nerve stimulator: A 25-year update. *Laryngoscope*. 1991;101(1 Pt 1):71–74. [PMID: 1984555]

Maximal Stimulation Test

A test of maximal electrical stimulation can be used to determine whether nerve degeneration has developed in the course of an acute facial paralysis. It involves a transcutaneous electrical impulse designed to saturate the nerve with current, activating all functioning fibers. The response on the involved side is characterized as being (1) equal to the contralateral side, (2) minimally diminished (50% of normal), (3) markedly diminished (<25% of normal), or (4) absent.

When the response is markedly diminished or absent within the first 2 week of the clinical paralysis, it has been found that there is a 75% chance of incomplete facial nerve recovery. When the response completely disappeared within the first 10 days, recovery was typically incomplete and significant sequelae ensued. Conversely, if responses were symmetric during the first 10 days of a clinical paralysis, complete return was found in more than 90% of patients tested. The use of supramaximal stimulation provides sensitivity and consistency in testing when used early in the course of an acute facial paralysis. However, the interpretation of the maximal stimulation test relies on a subjective evaluation of the visually graded evoked response.

May M. Nerve excitability test in facial palsy: limitations in its use based on a study of 130 case. *Laryngoscope*. 1972;82:2122. [PMID: 5081746] (This study describes the utility and drawbacks of the facial nerve excitability test based upon the author's personal experience.)

May M, Blumenthal F, Klein S. Acute Bell's palsy: Prognostic value of evoked electromyography, max stimulation and other electrical tests. *Am J Otol*. 1983;5:107. [PMID: 6881304] (Evoked electromyography and maximal stimulation tests were the most accurate electrical tests for predicting the course of acute facial paralysis when they were performed serially within the first 10 d after onset.)

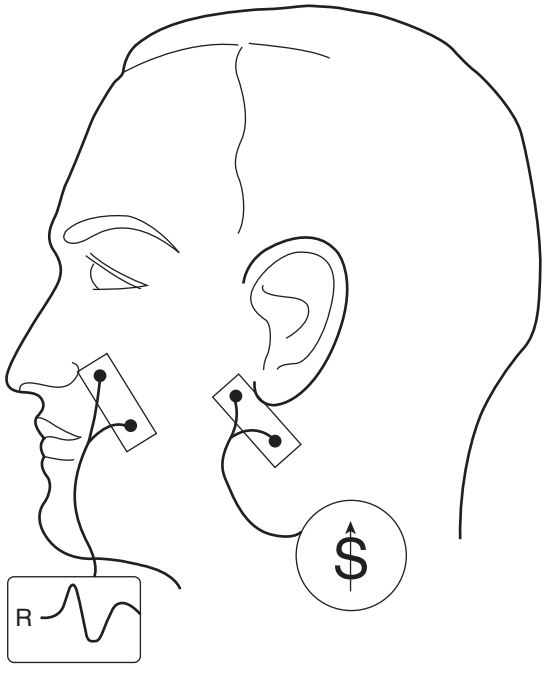
Ushio M, Kondo K, Takeuchi N et al. Prediction of the prognosis of Bell's palsy using multivariate analyses. *Otol Neurotol*. 2008;29(1):69. [PMID: 18199959]

Evoked Electromyography & Electroneuronography

Similar to the maximal stimulation test, evoked electromyography (EEMG) or electroneuronography (ENoG) assesses the facial motor response to a supramaximal stimulus. In contrast to maximal stimulation testing, the EEMG technique records the compound muscle action potential (CMAP) with surface electrodes placed in the nasolabial fold. The CMAP can be graphically displayed for quantitative analysis and printed for the medical record (Figure 69–12). Waveform responses are analyzed to compare peak-to-peak amplitudes between normal and involved sides.

Patients with incomplete paralyses due to Bell's palsy invariably recover function to normal or near-normal levels and do not require EEMG evaluation. The reappearance of facial movement within 3–4 week after onset also predicts an excellent prognosis for functional recovery. EMG sampling of motor activity to detect visually imperceptible facial function is advised.

When assessed within a critical time window, reductions in the amplitude of the EEMG response of the affected side are considered to reflect the percentage of motor fibers of the facial nerve that have undergone degeneration. Facial EEMG is most reliable during the initial phase of accelerated denervation when reliable results can be obtained (ie, in the first 2–3 week following the onset of a paralysis due to Bell's palsy or herpes zoster oticus). When neuropraxic fibers become "deblocked" either in the recovery phase or later on, as axons regenerate peripherally, stimulated nerve fibers discharge asynchronously. Because regenerated fibers do not discharge in synchrony, the response is disorganized and consequently diminished. This phenomenon imposes a time constraint on the reliability of EEMG testing that must be considered in interpreting the test results.



▲ **Figure 69–12.** Placement of recording and stimulating electrodes for facial EEMG recordings. The compound muscle action potential is reflected in the biphasic electromyographic response.

ENoG is most useful early in the course of facial paralysis. More than 50% of patients with complete paralysis who exhibit a ≥90% reduction in CMAP amplitude have less than a satisfactory, spontaneous return of facial function. When results demonstrate <90% denervation (>10% in CMAP amplitude relative to the normal side), excellent recovery has been uniformly observed.

It is recommend that EEMG testing should be repeated on an every-other-day basis to detect ongoing degeneration beyond the 90% critical level. The time span of reduced electrical excitability (ie, the velocity of denervation as demonstrated by repeated testing) and the degree of degradation of the CMAP response (ie, the nadir of the response) are most useful in predicting the ultimate level of spontaneous recovery. The earlier the EEMG response drops to ≤10% of normal, the worse the prognosis is.

Chung WH, Lee JC, Cho DY et al. Waveform reliability with different recording electrode placement in facial electroneuronography. *J Laryngol Otol*. 2004;118(6):421. [PMID: 15285858]

Coker NJ. Facial electroneuronography: analysis of techniques and correlation with degenerating motoneurons. *Laryngoscope*. 1992;102:747. [PMID: 9226049] (A comprehensive review of electroneuronography.)

Linder TE, Abdelkafy W, Cavero-Vanek S. The management of peripheral facial nerve palsy: "paresis" versus "paralysis" and sources of ambiguity in study designs. *Otol Neurotol*. 2010;31(2):319.[PMID: 20009779]

Ushio M, Kondo K, Takeuchi N et al. Prediction of the prognosis of Bell's palsy using multivariate analyses. *Otol Neurotol*. 2008;29(1):69. [PMID: 18199959]

Electromyography

The electromyographic (EMG) response reflects postsynaptic membrane potentials that may be either initiated at the neuromuscular junction with voluntary activation or generated spontaneously across the muscle membrane.

Voluntarily and spontaneously generated facial motor responses can help to characterize the condition of motor units with precision. However, the results obtained with testing in any single field should be buttressed with testing in adjacent fields. Motor unit potentials in four of five muscle groups in the first 3 days after the onset of an acute facial paralysis is associated with a satisfactory outcome in more than 90% of patients. Motor units in two of three muscle groups predicted a satisfactory outcome in 87% of patients. When motor units were either limited to one muscle group or abolished, satisfactory recovery was found in only 11% of cases.

Although these findings suggest a role for early EMG testing in prognosticating functional recovery, others have noted potential pitfalls of early EMG testing that may mislead the examiner. Sparse residual motor units that suggest a favorable outcome may be evident despite severe injury to large portions of fibers that are at risk for degeneration. The clinical evidence of this was noted as an unsatisfactory recovery despite voluntary motor potentials in 38% of Bell's palsy patients. These observations suggest that EMG assessment should be performed within at least two muscle groups to more accurately assess the degree of denervation.

Early in the course of an acute facial paralysis, preserved facial motor activity may escape clinical inspection and yet provide prognostic information when combined with other testing modalities. For example, subclinical motor activity that is still detectable by the EMG may complement the use of EEMG in the early phase of a clinical paralysis. EMG monitoring is of limited use in detecting early degeneration since electrical evidence of nerve degeneration is absent in the first 10 days of the paralysis. Ten to 14 days following the onset of a clinical paralysis, EMG recordings reflect the dynamic resting membrane potentials of postsynaptic elements. In this phase, muscle membrane, deprived of "trophic" substances that are normally transported through the axon, undergoes changes that destabilize the resting potential. These changes produce spontaneous depolarizations reflected in the EMG as fibrillation potentials. Such changes are interpreted as indicative of persistent denervation.

Substantial axonal loss and impaired reinnervation yield fibrillation potentials as long as postsynaptic membranes

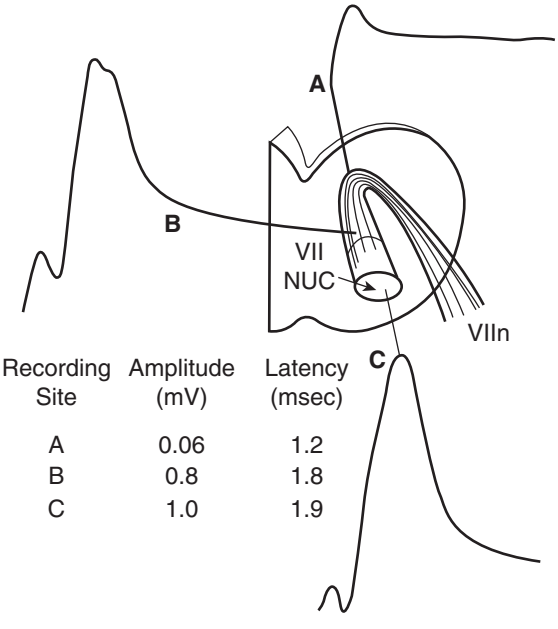
remain electrically active. With persistent denervation, EMG recordings are silent and the short burst of discharges normally found on needle insertion is absent. Conversely, successful reinnervation generates high-frequency polyphasic potentials that increase in amplitude and duration and replace fibrillation potentials. In rare cases of protracted paralysis due to Bell's palsy, longitudinal EMG evaluations detect persistent nerve degeneration or reinnervation.

Granger C. Prognosis in Bell's palsy. *Arch Phys Med Rehab*. 1976;57:33. [PMID: 1247374] (Using clinical and electromyographic methods, it should be possible to forecast recovery within 3 d after onset in order to preselect patients in need of any proposed curative treatment program designed to salvage the facial nerve.)

Grosheva M, Guntinas-Lichius O. Significance of electromyography to predict and evaluate facial function outcome after acute peripheral facial palsy. *Eur Arch Otorhinolaryngol*. 2007;264(12):1491. [Epub 2007 Jul 5. PMID: 17611766]

May M, Blumenthal F, Klein S. Acute Bell's palsy: prognostic value of evoked electromyography, max stimulation and other electrical tests. *Am J Otol*. 1983;5:107. [PMID: 6881304] (Evoked electromyography and maximal stimulation tests were the most accurate electrical tests for predicting the course of acute facial paralysis when they were performed serially within the first 10 days after onset.)

Sillman JS, Niparko JK, Lee SS et al. Prognostic value of evoked and standard electromyography in acute facial paralysis. *Otolaryngol Head Neck Surg*. 1992;107:377. [PMID: 1408222] (The findings from this study support previous reports of the prognostic value of EEMG in idiopathic facial paralysis, but suggest that this test may have less predictive value in the evaluation of facial paralysis as a result of trauma.)



▲ **Figure 69–13.** Topographical representation of mean amplitude and latency of evoked neural potentials from **(A)** the facial genu, **(B)** the dorsal region to the facial nucleus, and **(C)** the nucleus in experimental rodent preparation. Stimulus intensity = 0.4 mA; duration = 100 μs; N = 100 stimuli for each trial. (Reproduced with permission from Niparko JK, Kartush JM, Bledsoe SC, Graham MD, Antidromically evoked facial nerve response. *Am J Otolaryngol.* 1985;6:353.)

Facial Nerve Assessment with Central Activation

The previously described electrodiagnostic tests indirectly assess the severity of injury to the intratemporal segment of the facial nerve. Investigators have explored alternate testing procedures in which the facial nerve is activated central to the presumed site of involvement within the temporal bone.

A. Antidromic Conduction

Testing via antidromic (retrograde) conduction provides an alternative to electrodiagnostic testing of peripheral fibers that, at least theoretically, can provide a direct and immediate assessment of facial nerve function. Antidromic conduction of electrical activity in the facial nerve can be measured with near- and far-field techniques in animals (Figure 69–13), and clinically with middle ear recording electrodes. It has been demonstrated that the far-field response to antidromic stimulation represented composite activity along the facial pathway and did not appear to reflect stimulation of the facial nerve at a specific site along the intracranial segment.

The F-wave represents activity in facial muscles generated by antidromically activated motor neurons and contains no reflex components. For electrodiagnostic purposes, F-waves evoked by electrical stimulation may be recorded with intramuscular needle electrodes. This response has a long latency and is normally small in amplitude, thereby limiting its dynamic range and prognostic value. In patients with Bell's palsy, electrical stimulation of the nerve reliably produces F-wave responses only after the recovery has begun.

B. Magnetic Stimulation

Transcranial magnetic stimulation employs an electromagnetic coil to produce neural activation. This method of neural activation is unique in that the intensity of the stimulus is minimally attenuated by intervening tissue. This feature enables central activation via a transcranial application of induced current. Animal studies have demonstrated that transcranial magnetic stimulation can be used to activate the facial nerve centrally, although the precise site of stimulation is difficult to determine. Observations suggest that the evoked response is likely due to the excitation of the facial nerve intratemporally or intracranially rather than via cortical or brainstem excitation.

Clinical experience with electromagnetic stimulation in pathological states, including Bell's palsy, is in keeping with observations that localize the lesion intratemporally. In 11 patients with a recent onset of Bell's palsy, none demonstrated evoked CMAPs with magnetic stimulation. The lack of response is attributed to the elevation in threshold associated with segmental demyelination and the inability of the current generated by the electromagnetic field to reach the threshold.

Further refinement in the application and interpretation of transcranial magnetic stimulation for prognosticating facial nerve lesions awaits further understanding of the actual site of activation. The development of coils that will facilitate a more focused current offers the possibility of site-specific stimulation of the central facial motor tract and intracranial segment of the facial nerve—sites proximal to the typical sites of nerve injury for most acute facial paralyses.

C. Trigeminofacial Reflex

The blink reflex can be tested clinically to assess the efferent arc contributed by cranial nerve VII. EMG recording of the trigeminofacial reflex provides a quantitative assessment of facial nerve conduction via activation of the facial nucleus centrally. This technique records action potentials reflexively generated in the orbicularis oculi muscle in response to an electrical stimulus applied to the supraorbital area (V1 branch). Responses between the affected and normal sides are compared to provide quantitative assessment of the reflex, thereby providing a measure of the functional integrity of the facial nerve. Trigeminofacial reflex testing of acute facial paralysis may be limited by small response amplitudes.

An abolished R1 trigeminofacial reflex response is associated with little chance of recovery in the first 2 months following the onset of paralysis. Preserved, early R1 responses predicted return to normal facial nerve function within the first month. The performance of this test in selecting those patients with an absent R1 response who have a poor long-term prognosis is yet to be evaluated.

Cocito D, Isoardo G, Migliaretti G et al. Intracranial stimulation of the facial nerve: normative values with magnetic coil in 240 nerves. *Neurol Sci*. 2003;23(6):307. [PMID: 12624718]

Nakatani H, Iwai M, Takeda T et al. Waveform changes in antidromic facial nerve responses in patients with Bell's palsy. *Ann Otol Rhinol Laryngol*. 2002;111(2):128. [PMID: 11860064]

Kartush JM, Bouchard KB, Graham MD et al. Magnetic stimulation of the facial nerve. *Am J Otol*. 1989;10:14. [PMID: 2719085] (Normal volunteers and one patient with acute facial paralysis were studied with both magnetic and electric stimulation of the facial nerve.)

Kartush JM, Garcia P, Telian SA. The source of far-field antidromic facial nerve potentials. *Am J Otolaryngol*. 1987;8:199. [PMID: 3631416] (This study attempts to identify the generator sites of the far-field antidromic facial nerve response in dogs and suggests the following for the montage and stimulus protocol employed: (1) the far-field antidromic response is a volume-conducted nerve action potential generated primarily from the mastoid segment, (2) complete transection of the facial nerve at the CPA has little effect on the responses, and (3) there appears to be no significant supranuclear generator site.)

Niparko JK, Kartush JM, Bledsoe SC et al. Antidromically evoked facial nerve response. *Am J Otolaryngol*. 1985;6:353. [PMID: 4073377] (Antidromic conduction testing was tested. Results suggest that the recorded potentials measured represent antidromic activation of the facial nerve, further suggesting that antidromic testing may provide a useful means of assessing proximal facial nerve function in pathological states.)

Sawney BB, Kayan A. A study of the F wave from the facial muscles. *Electromyog*. 1970;3:287. [PMID: 5509973]

Schriefer TN, Mills KR, Murray NMF. Evaluation of proximal facial nerve conduction by transcranial magnetic stimulation. *J Neurol Neurosurg Psych*. 1988;51:60. [PMID: 3351531] (A magnetic stimulator was used for direct transcutaneous stimulation of the intracranial portion of the facial nerve in patients with a variety of facial nerve pathologies.)

von Dincklage F, Koppe P, Kotsch J et al. Investigation of threshold and magnitude criteria of the nociceptive blink reflex. *Clin Neurophysiol*. 2010. [Epub ahead of print. PMID: 20181518]

Zealar D, Kurago Z. Facial nerve recording from the eardrum. *Otolaryngol Head Neck Surg*. 1985;93:474. [PMID: 3931021] (A noninvasive technique is described for recording from the facial nerve within the fallopian canal using electrodes placed on the eardrum.)

70 Disorders of the Facial Nerve

Lawrence R. Lustig, MD
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Facial nerve dysfunction can dramatically affect a patient's quality of life. The human face is a focal point for expression and interpersonal communication, whereas facial motor movement contributes to eye protection, speech articulation, chewing and swallowing, and emotional expression. Thus, the patient with a facial palsy suffers not only the functional consequences of impaired facial motion but also the psychological impact of a skewed facial appearance.

ACUTE FACIAL PALSIES

ESSENTIALS OF DIAGNOSIS

Bell's Palsy

- Acute onset, with unilateral paresis or paralysis of the face in a pattern consistent with peripheral nerve dysfunction (all branches affected).
- Rapid onset and evolution (<48 hours).
- Facial palsy may be associated with acute neuropathies affecting other cranial nerves (particularly, cranial nerves V–X).

Herpes Zoster Oticus (Ramsay Hunt syndrome)

- Acute peripheral facial palsy associated with otalgia and varicella-like cutaneous lesions that involve the external ear, skin of the ear canal, or the soft palate.
- Involvement often extends to cranial nerves V, IX, and X, and cervical branches that have anastomotic communications with the facial nerve.
- Differentiated from Bell's palsy by characteristic cutaneous ulcers and a higher incidence of hearing loss or balance dysfunction.

General Considerations

There are a variety of disorders that may be associated with unilateral facial palsies (Table 70–1). Bilateral facial palsy is much less frequent and occurs in less than 2% of patients presenting with an acute facial palsy (Table 70–2). Bilateral involvement typically reflects a systemic disorder with multiple manifestations. Because of their overlapping clinical presentation and treatment paradigms, Bell's palsy and herpes zoster oticus (also known as Ramsay Hunt syndrome) will be considered together.

1. Bell's Palsy

No identifiable cause is present for approximately 60–70% of cases of acute facial palsy. The clinical diagnosis of Bell's palsy is appropriately applied in such cases. Bell's palsy reveals several characteristics. The onset is that of an acute, unilateral paresis or paralysis of the face in a pattern consistent with peripheral nerve dysfunction (Figure 70–1). The onset and evolution are rapid—typically less than 48 hours. There may also be subtle but frequent associated dysfunction of cranial nerves V, VIII, IX, and X in association with Bell's palsy. Pain or numbness affecting the ear, mid-face, and tongue as well as taste disturbances are common. These observations suggest that the facial weakness seen in Bell's palsy is the inflammatory facial-motor component of a wider cranial polyneuropathy that is induced by viral agents admitted through mucosal membranes.

Recurrent facial palsy consistent with Bell's palsy occurs in 7–12.0% of patients. Ipsilateral recurrences approximate contralateral involvement. Recurrences are more likely in patients with a family history of Bell's palsy and the incidence of diabetes mellitus in recurrent Bell's palsy patients is 2.5 times that noted in nonrecurrent cases. Immunodeficiency is also associated with recurrences.

Table 70–1. Differential Diagnoses of Facial Paralysis.

Birth
- Molding
- Forceps delivery
- Myotonic dystrophy
- Möebius syndrome (facial diplegia associated with other cranial nerve deficits)

Trauma
- Cortical injuries
- Basilar skull fractures
- Brainstem injuries
- Penetrating injury to middle ear
- Facial injuries
- Altitude paralysis (barotrauma)
- Scuba diving (barotrauma)

Neurologic
- Opercular syndrome (cortical lesion in facial motor area)
- Millard-Gubler syndrome (abducens palsy with contralateral hemiplegia due to lesion in base of pons involving corticospinal tract)

Infection
- Malignant otitis externa
- Acute or chronic otitis media
- Cholesteatoma (acquired and congenital)
- Mastoiditis
- Meningitis
- Parotitis
- Chickenpox
- Herpes zoster oticus (Ramsay Hunt syndrome)
- Encephalitis
- Poliomyelitis (type I)
- Mumps
- Mononucleosis
- Leprosy
- HIV and AIDS
- Influenza
- Coxsackie virus
- Malaria
- Syphilis
- Scleroma
- Tuberculosis
- Botulism
- Mucormycosis
- Lyme disease

Genetic and Metabolic
- Diabetes mellitus
- Hyperthyroidism
- Pregnancy
- Hypertension
- Alcoholic neuropathy
- Bulbopontine paralysis
- Oculopharyngeal muscular dystrophy

Vascular
- Anomalous sigmoid sinus
- Benign intracranial hypertension
- Intratemporal aneurysm of internal carotid artery
- Embolization for epistaxis (external carotid artery branches)

Neoplastic
- Acoustic neuroma
- Glomus jugulare tumor
- Leukemia
- Meningioma
- Hemangioblastoma
- Hemangioma
- Pontine glioma
- Sarcoma
- Hydradenoma (external canal)
- Facial nerve neuroma
- Teratoma
- Fibrous dysplasia
- von Recklinghausen disease
- Carcinomatous encephalitis (Bannworth syndrome)
- Cholesterol granuloma
- Carcinoma (invasive or metastatic, from breast, kidney, lung, stomach, larynx, prostate, thyroid)

Toxic
- Thalidomide (Miehlke syndrome: cranial nerves VI and VII with atretic external ears)
- Tetanus
- Diphtheria
- Carbon monoxide
- Lead intoxication

Iatrogenic
- Mandibular block anesthesia
- Antitetanus serum
- Vaccine treatment for rabies
- Otologic, neurotologic, skull base, and parotid surgery iontophoresis (local anesthesia)
- Embolization

Idiopathic
- Familial Bell's palsy
- Melkersson-Rosenthal syndrome (recurrent facial palsy, furrowed tongue, faciolabial edema)
- Hereditary hypertrophic neuropathy (Charcot-Marie-Tooth disease, Dejerine-Scottas disease)
- Autoimmune syndromes of temporal arteritis, periarteritis nodosa, and other vasculitides
- Thrombotic thrombocytopenic purpura
- Landry-Guillain-Barré syndrome (ascending paralysis)
- Multiple sclerosis
- Myasthenia gravis
- Sarcoidosis (Heerfordt syndrome, uveoparotid fever)
- Wegener granulomatosis
- Eosinophilic granuloma
- Amyloidosis
- Hyperostoses (Paget disease, osteopetrosis)
- Kawasaki disease (infantile acute febrile mucocutaneous lymph node syndrome)

Reproduced, with permission, from May M: Differential diagnosis by history, physical findings, and laboratory results. In: May M, ed. The Facial Nerve. New York: Thieme-Stratton; 1986.

Table 70–2. Etiologies Associated with Bilateral Facial Palsies (may be Simultaneous or Delayed).

Bell palsy
Diabetes mellitus
Sarcoidosis (Heerfordt syndrome)
Periarteritis nodosa
Guillain-Barré syndrome
Myasthenia gravis
Basilar skull fracture
Bulbar palsies
Porphyrias
Leukemia
Myotonic dystrophia
Meningitis
Möbius syndrome
Botulism
Infectious mononucleosis
Leprosy
Malaria
Poliomyelitis
Lyme disease
Syphilis
Postvaccination neuropathy
Isoniazid
Osteopetrosis

2. Herpes Zoster Oticus

Herpes zoster oticus (Ramsay Hunt syndrome) is a syndrome of acute peripheral facial palsy associated with otalgia and varicella-like cutaneous lesions. It accounts for approximately 10–15% of acute facial palsy cases. The lesions may involve the external ear, particularly the meatal and preauricular skin, the skin of the ear canal, or the soft palate. These findings establish the diagnosis (Figure 70–2). Hearing loss, dysacusis, and vertigo reflect extension of the infection to involve the eighth cranial nerve. Involvement often extends to other cranial nerves (V, IX, and X) and cervical branches (2, 3, and 4) that have anastomotic communications with the facial nerve. Herpes zoster oticus is therefore differentiated from Bell's palsy by the characteristic cutaneous changes and a higher incidence of cochleosaccular dysfunction.

Pathogenesis

Studies of the intratemporal facial nerve suggest that Bell's palsy and herpes zoster oticus most commonly result from the impaired facial nerve conduction within the temporal bone. The facial nerve is admitted to the temporal bone via the meatal foramen to form the labyrinthine segment of the intratemporal facial nerve. The meatal foramen in labyrinthine section of the Fallopian canal is thought to be site of constriction in Bell's Palsy based on several lines of evidence: (1) In the labyrinthine segment, the nerve occupies more than 80% of the cross-sectional area of the canal, in contrast to occupying less than 75% in the remainder (Figure 70–3); (2) The diameter of the meatal foramen (Figure 70–3A) is substantially narrower than more peripheral segments of the facial canal with a circumferential band of periosteum that virtually seals the entry site and constricts the nerve at the this site (Figure 70–4); and (3) The facial nerve is without substantial epineurium in the meatal foramen and is instead encased by this periosteum. Thus, the meatal foramen appears to constitute a pressure transition zone or "physiological bottleneck" in the presence of neural edema. The ratio of the cross-sectional areas of the nerve to the meatal foramen is significantly smaller in pediatric temporal bones compared with those of adults. This observation may explain the low incidence of Bell's palsy in pediatric populations.

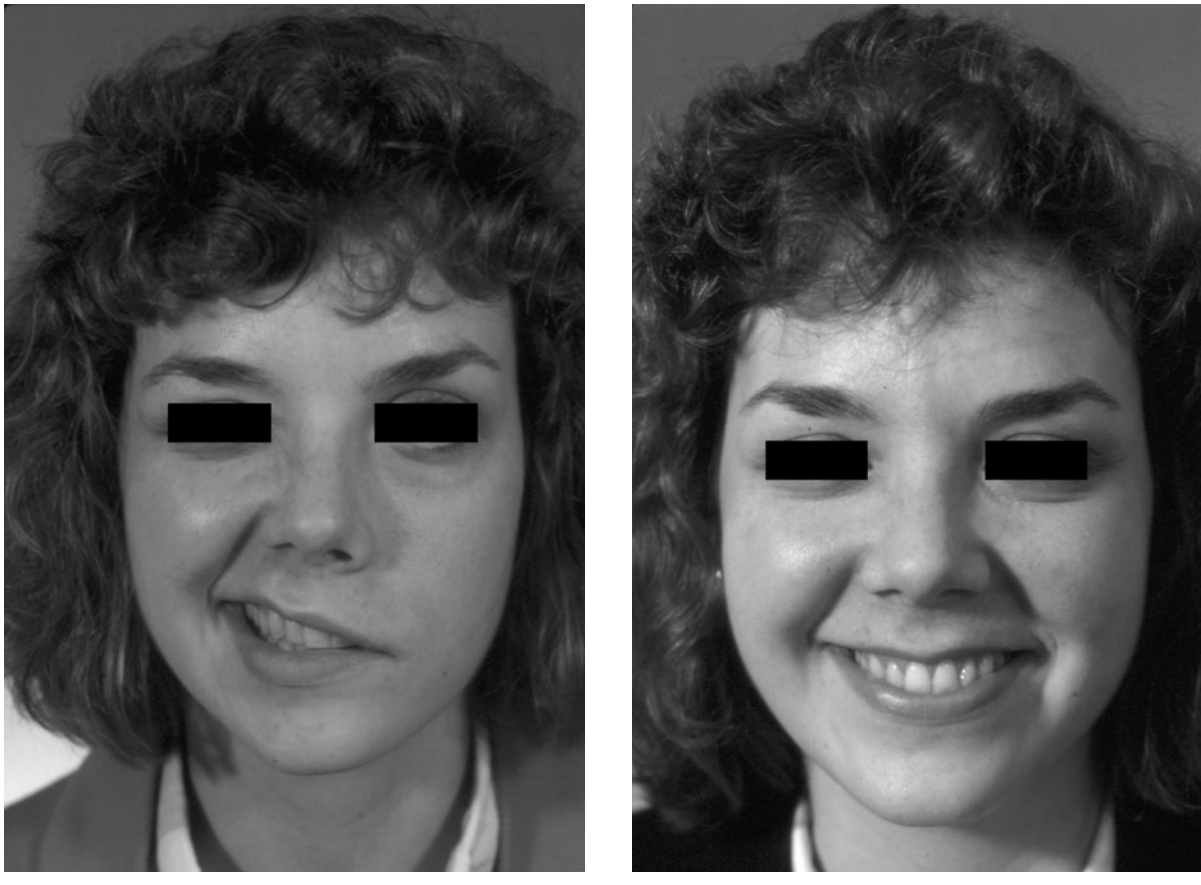
In patients with near-total degeneration undergoing facial nerve decompression for Bell paralysis, electrical stimulation demonstrated a transition in responsiveness in the (decompressed) region of the meatal foramen. Sequential stimulation in a distal-to-proximal direction from the second genu to the meatal foramen consistently revealed substantially diminished responses proximal to the meatal foramen. These observations strongly implicate the meatal foramen as the primary pathophysiological site in Bell's palsy.

Intraneural inflammatory changes, consistent with a viral infection, have been identified in the temporal bones of a Bell's palsy patient who died 13 days after onset. Substantial leukocytic infiltration and demyelinization of the somatic portion of the facial nerve were evident, most prominently in the proximal, intratemporal segment of the nerve. Although small vessel congestion was present, there was no evidence of arterial thrombosis. Other studies have demonstrated that intraneural vascular congestion and hemorrhage in the labyrinthine segment of the nerve were most prominent.

Most postmortem studies from patients with Bell's palsy demonstrate that diffuse involvement of the facial nerve in its intratemporal course was typical. Evidence of an inflammatory neuritis suggesting a viral etiology is frequently evident, though not uniformly observed.

The likelihood of the meatal foramen as the critical site for nerve injury in herpes zoster oticus is supported by neuropathological findings demonstrating a sharp demarcation between the degenerated nerve distal to and normal nerve proximal to the meatal foramen.

The several postulated mechanisms of nerve injury underlying Bell's palsy are not necessarily exclusive of one another. Several pathological events may be sequential and synergistic in manifesting a clinical facial palsy, and the disease may represent a spectrum of entities with varied pathogeneses. Although inflammation and ischemia likely dominate early processes in Bell's palsy, neural blockade and degeneration as well as subsequent fibroblastic response likely manifest later in the sequence. Given the confinement of the nerve trunk within the meatal foramen, it is likely that compression at this site is a critical if not determinative event in the genesis of Bell's palsy and is triggered by one or a combination of the above etiologies. Histopathological findings suggest that the



A B

▲ **Figure 70–1. (A)** Prototypic case of Bell's palsy. This 28-year-old woman experienced the onset of an acute, left-sided paralysis of the face over a 24-hour period, in a pattern consistent with peripheral nerve dysfunction. Treatment consisted of oral steroid dosing at pharmacological doses for 10 days, followed by a 2-week taper. **(B)** Full recovery of facial motor function 2 months after onset.

facial palsy component of herpes zoster oticus is manifest by a similar process of entrapment, with typically a higher risk of irreversible degeneration of nerve fibers.

Eicher SA, Coker NJ, Alford BR et al. A comparative study of the fallopian canal at the meatal foramen and labyrinthine segment in young children and adults. *Arch Otolaryngol Head Neck Surg*. 1990;116:1030. [PMID: 2383386] (This report, documenting the differences in facial nerve palsy between children and adults, suggests that the facial nerve is not as tightly contained at the meatal foramen in children and provides a possible explanation for the relative infrequency of Bell's palsy in this age group.)

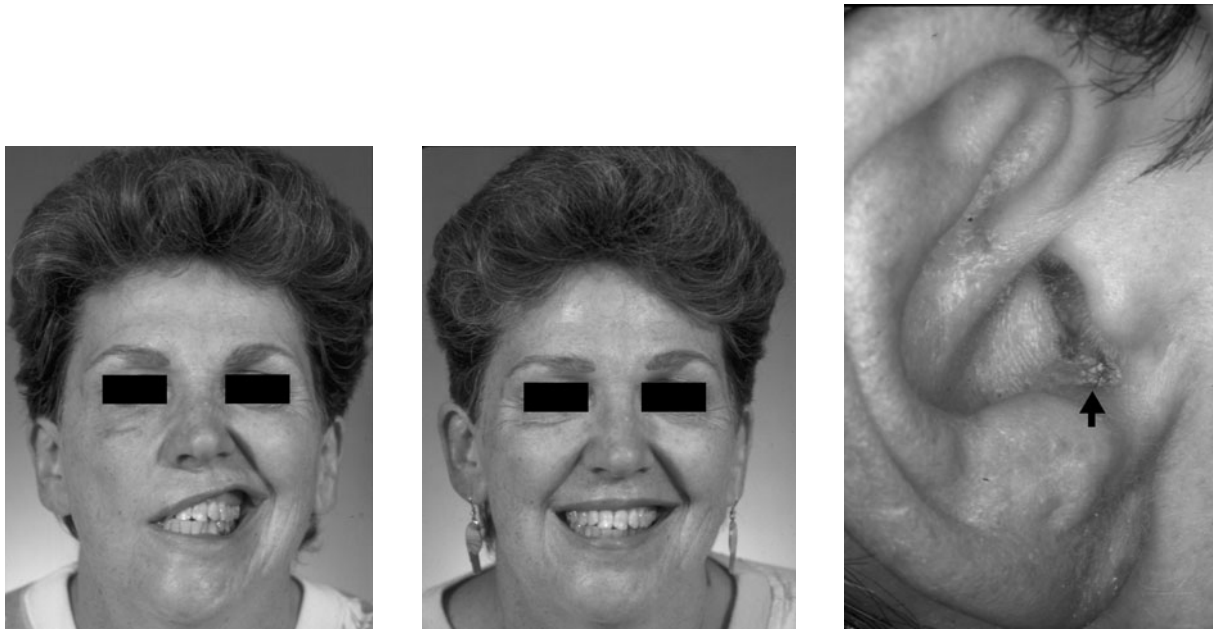
Gantz B, Gmur A, Fisch U. Intraoperative evoked electromyography in Bell's palsy. *Am J Otolaryngol*. 1982;3:273. [PMID: 7149140] (In this report, the technique of intraoperative evoked electromyography is described in detail.)

Gilchrist JM. Seventh cranial neuropathy. *Semin Neurol*. 2009;29(1):5. [Epub 2009 Feb 12. Review. PMID: 19214928]

Hsieh RL, Wu CW, Wang LY et al. Correlates of degree of nerve involvement in early Bell's palsy. *BMC Neurol*. 2009;9:22. [PMID: 19500424]

Jackson CG, Hyams VJ, Johnson GD et al. Pathologic findings in the labyrinthine segment of the facial nerve in a case of facial paralysis. *Ann Otol Rhinol Laryngol*. 1990;99:327. [PMID: 2337309] (The histopathological findings for a patient with acute facial paralysis caused by herpes zoster oticus who obtained no return of active facial function after 1 year are presented in this manuscript, and are consistent with observations that the lesion producing Bell's palsy and herpes zoster oticus usually is situated at the meatal foramen.)

Lee DH, Chae SY, Park YS et al. Prognostic value of electroneurography in Bell's palsy and Ramsay-Hunt's syndrome. *Clin Otolaryngol*. 2006;31(2):144. [PMID: 16620335]



A B C

▲ **Figure 70–2.** **(A)** Prototypic case of herpes zoster oticus. This 53-year-old woman experienced the onset of a right-sided facial paralysis with marked right-sided otalgia and throat pain. She presented 3 days after the onset of her symptoms and demonstrated minimal facial motor activity on evoked electromyography. Treatment consisted of oral steroid dosing at pharmacological doses for 10 days, followed by a 2-week taper, and acyclovir given intravenously for 1 week. **(B)** Full recovery of facial motor function 4 months after onset. **(C)** Skin lesion of the right external meatus in the same patient with oticus in the crusting phase at the time of presentation.

Liston SL, Kleid MS. Histopathology of Bell's palsy. *Laryngoscope*. 1989;99:23. [PMID: 2642582] (The histopathology of the facial nerve 1 week after the onset of Bell's palsy is reported.)

Proctor B, Corgill DA, Proud G. The pathology of Bell's palsy. *Trans Am Acad Ophthalmol Otolaryngol*. 1976;82:70. [PMID: 969098] (This classic study examines the pathophysiology of Bell's palsy.)

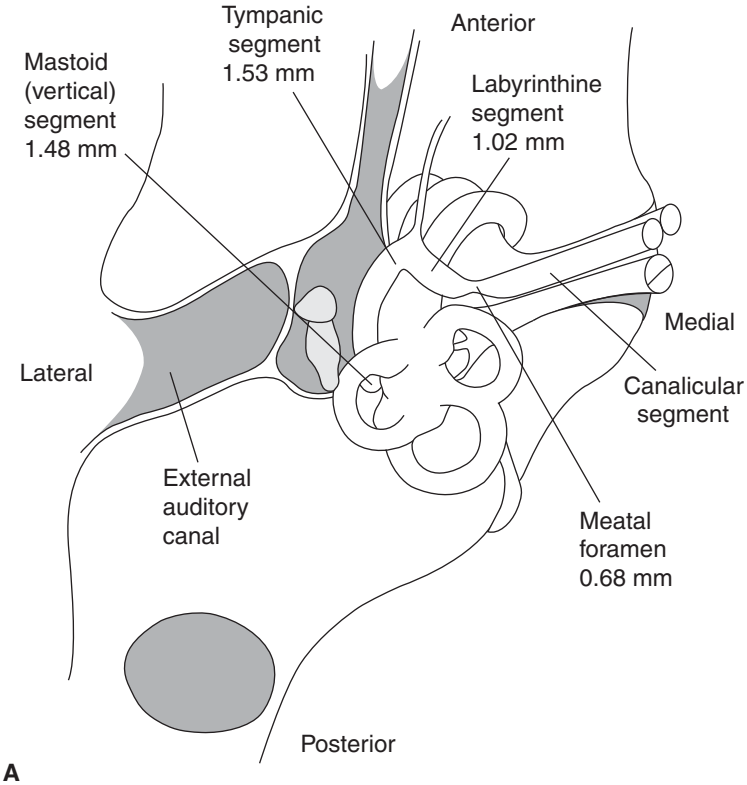
Proctor B, Nager GT. The facial canal: normal anatomy variations and anomalies. *Ann Otol Rhinol Laryngol*. 1982;97:33. [PMID: 6814328] (This classic study provides a detailed descriptive anatomy with emphasis on the relations of the facial canal to adjacent structures, including the variations in the course of the facial canal.)

Etiology

A. Viral Neuritis

There is a significant resemblance between Bell's palsy and other neuropathies known to be of viral origin. Poliomyelitis, mumps, Epstein-Barr virus, and rubella infections can manifest a neuritic component characterized by progressive neural dysfunction, often with subtotal regeneration as is often observed with Bell's palsy and herpes zoster oticus. There are multiple lines of evidence for a viral etiology in Bell's palsy based on clinical observations and experimental models reported over the last 20 years. Rabbit facial nerve trunks inoculated with herpes simplex virus demonstrate facial motor dysfunction that progressed to paralysis within the first week after inoculation. Herpes simplex virus Type I has been identified in isolates of the herpes simplex virus from the nasopharynx of patients during the acute phase of Bell's palsy. A higher prevalence of herpes simplex viral antibodies has been identified in patients with Bell's palsy as compared with gender- and age-matched controls. Herpes simplex virus has a well-known predilection for sensory neurons as well as a predilection to exist in a latent phase in sensory cell bodies of the ganglion. The facial nerve contains sensory neurons with cell bodies located in the geniculate ganglion, and it is believed that infection of the facial nerve, such as a geniculate ganglionitis, underlies Bell's palsy.

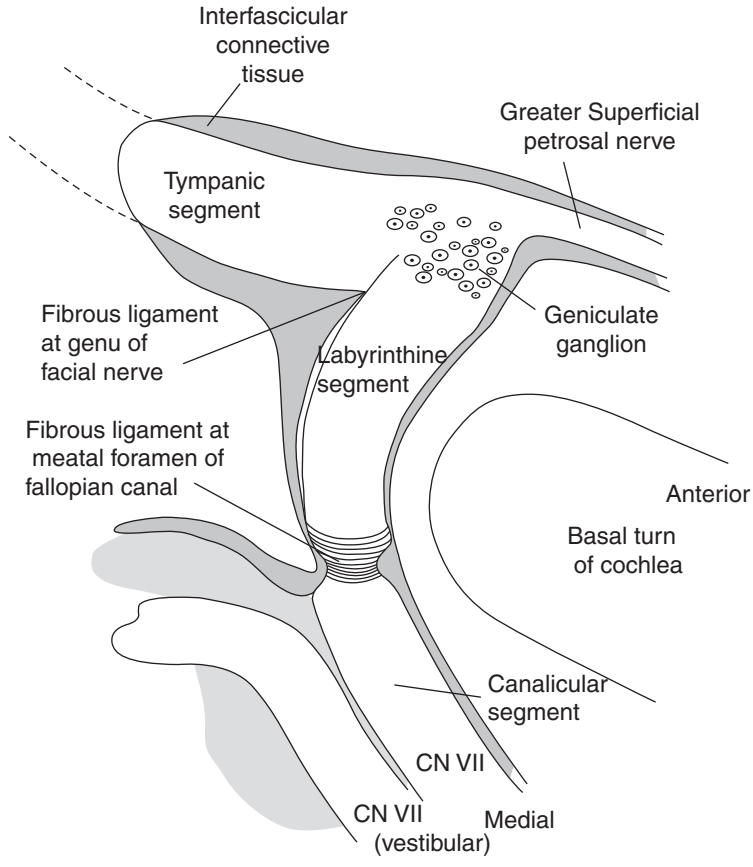
The presence of the herpes simplex virus has been detected in epineurial biopsies from a patient undergoing facial nerve decompression for Bell paralysis. While this finding further links Bell's palsy with a herpes simplex viral infection, ultrastructural studies of autopsy material from asymptomatic patients has demonstrated herpes simplex viral particles in sensory ganglia of regional cranial nerves,



▲ **Figure 70–3. (A)** Caliber of the (intratemporal) facial canal from the meatal foramen to the mastoid segment. **(B)** Computed tomography scan of temporal bones revealing the fallopian canal caliber for the labyrinthine segment proximal to the geniculate ganglion (white arrows).

most notably the trigeminal ganglion. Thus, evidence of viral presence in the facial nerve, although highly suggestive, does not prove conclusively that the herpes simplex virus bears a causal role in Bell's palsy.

The role of the varicella-zoster virus as etiologic in herpes zoster oticus is supported strongly by the characteristic varicelliform rash. This rash assumes a dermatologic distribution in a pattern that mimics the distribution of afferent fibers of



▲ **Figure 70–4.** Surgical anatomy of the meatal foramen, labyrinthine segment, and geniculate fossa.

the facial nerve. Serological confirmation of varicella-zoster infection is often, but not always, possible. Histological studies indicate facial dysfunction with herpes zoster oticus to be the result of an entrapment neuropathy, with more pronounced nerve fiber degeneration than that typically found in histopathological studies of Bell's palsy.

The herpes simplex and varicella-zoster agents are both DNA viruses of the herpes virus group and differ subtly in their ultrastructural features. Although differences in biological behavior suggest that neuritides resulting from these viruses should manifest clinically distinguishable differences in their clinical presentation, infections from herpes simplex and varicella-zoster viruses may mimic one another. Furthermore, herpes simplex, mumps, and cytomegalovirus infections may produce a clinical picture resembling herpes zoster oticus; varicella-zoster neuritis may occur in the absence of a rash (ie, zoster sine eruptione).

B. Ischemic Insult

One time-honored concept of the genesis of Bell's palsy holds that impaired neural conduction follows small vessel ischemia. The facial nerve derives its blood supply from an extrinsic, circumneural vessel network derived from three principle sources: (1) the labyrinthine artery (proximally), (2) the middle meningeal artery (centrally), and (3) the stylomastoid artery (distally). The circumneural system connects to an intrinsic vascular supply of small vessel tributaries within the perineurial compartment. The pathological process is thought to involve the intrinsic system of vessels. Pressure elevations within the intraneural compartments produce venous stasis, stagnation of capillary flow, and a cycle of additional edema and an elevation in intraneural pressure. Circulatory sludging and, ultimately, tissue damage through acidosis and anoxia ensue. The mechanism by which the cascade of primary ischemia is initiated remains unclear.

C. Immunologic Injury

Several investigations have implicated immunologic injury as a potential cofactor in Bell's palsy. Neuropathological findings of segmental demyelinization accompanied by lymphocytic infiltration of the perineurium support this etiology. Autoimmune mechanisms of nerve injury have also been

suggested; evidence for humoral and cellular autoimmunity has been reported. Immunoassay methods have been used to detect acute-phase antibodies within the chorda tympani nerve from three of seven patients with Bell's palsy. Immune complexes found in the chorda tympani nerve fibers were characteristic of viral–antibody (Type III) immunologic reaction, suggesting an immune injury triggered by the presence of viral antigens.

Brown J. Bell's palsy: A five-year review of 174 consecutive cases. An attempted double-blind study. *Laryngoscope*. 1982;92:1369. [PMID: 6757616] (This paper examines 174 consecutive cases of Bell's palsy that were clinically divided into a group with incomplete facial palsy and a group with complete facial palsy, outlining the prognosis in each group.)

Brown MM, Thompson A, Goh BT et al. Bell's palsy and HIV infection. *J Neurol Neurosurg Psych*. 1988;51:425. [PMID: 3361335] (This report describes unilateral infranuclear facial palsy that developed in three patients who were positive for antibodies to HIV.)

Djupseland G, Berdal P, Johannsen TA et al. Virus infection as a cause of acute peripheral facial palsy. *Acta Otolaryngol*. 1976;102:403. [PMID: 938319] (This study examines the relationship between acute facial palsy and evidence of varicella-zoster infection. The study also demonstrated that an inflammatory reaction preceded or coincided with the facial palsy in all patients.)

Ho DD, Rota TR, Schooley RT et al. Isolation of HTLV-III from cerebrospinal fluid and neural tissues of patients with neurologic syndromes related to the acquired immunodeficiency syndrome. *N Engl J Med*. 1985;313:1493. [PMID: 2999591] (This study suggests that HTLV-III is neurotropic, is capable of causing acute meningitis, is responsible for acquired immunodeficiency syndrome (AIDS)-related chronic meningitis and dementia, and may be the cause of the spinal-cord degeneration and peripheral neuropathy in AIDS and AIDS-related complex.)

Jonsson L, Stiernstedt G, Thomander L. Tick-borne Borrelia infection in patients with Bell's palsy. *Arch Otolaryngol Head Neck Surg*. 1987;113:303. [PMID: 3814376] (This study evaluates 94 patients diagnosed as having Bell's palsy for evidence of Lyme disease infection.)

Kennedy PG. Herpes simplex virus type 1 and Bell's palsy-a current assessment of the controversy. *J Neurovirol*. 2010;16(1):1. [PMID: 20113184]

Khine H, Mayers M, Avner JR et al. Association between herpes simplex virus-1 infection and idiopathic unilateral facial paralysis in children and adolescents. *Pediatr Infect Dis J*. 2008;27(5):468. [PMID: 18360300]

Komolafe MA, Fatusi OA, Alatise OI et al. The role of human immunodeficiency virus infection in infranuclear facial paralysis. *J Natl Med Assoc*. 2009;101(4):361. [PMID: 19397228]

Mair IW, Flugsrud LB. Peripheral facial palsy and herpes zoster infection. *J Laryngol Otol*. 1976;90:373. [PMID: 178812] (This paper evaluates 133 consecutive cases of peripheral facial palsy and provides evidence for simultaneous infection with the varicella-zoster virus in 9 patients [6–8%].)

Njoo FL, Wertheim-van Dillen P, Devriese PP. Serology in facial paralysis caused by clinically presumed herpes zoster infection. *Arch Otorhinolaryngol*. 1988;245:230. [PMID: 2845904] (This retrospective study examined the relationship between facial palsy and varicella zoster virus infection.)

Pitts DB, Adour KK, Hilsinger RL. Recurrent Bell's palsy: analysis of 140 patients. *Laryngoscope*. 1988;535. [PMID: 3362016] (This report documents the clinical presentation, treatment, and outcome in a group of 140 patients with recurrent Bell's palsy. The authors also outline a new classification system for ease of computer analysis and for a simplified discussion of recurrent facial paralysis.)

Robillard PRB, Hilsinger RL, Adour KK. Ramsay Hunt facial paralysis: clinical analysis of 185 patients. *Otolaryngol Head Neck Surg*. 1986;95:292. [PMID: 3108776] (This prospective study evaluates 185 patients with Ramsay Hunt syndrome. The facial palsy of Ramsay Hunt syndrome was found to be more severe, to cause late neural denervation, and to have a less favorable recovery profile than Bell [herpes simplex] facial palsy.)

Musani MA, Farooqui AN, Usman A, et al. Association of herpes simplex virus infection and Bell's palsy. *J Pak Med Assoc*. 2009;59(12):823. [PMID: 20201172]

Vahlne A, Edstrom S, Arstila P et al. Bell's palsy and herpes simplex virus. *Arch Otolaryngol*. 1981;107:79. [PMID: 6258547] (The possible association of some viral infections with the onset of Bell's palsy was examined in a study of 142 patients.)

Incidence & Risk Factors

A wide spectrum of health care providers manage cases of acute facial palsy; an assessment of the true incidence of Bell's palsy is therefore complicated by this wide distribution of specialists. Nonetheless, this disorder is recognized as one of the most common neuropathies and appears to be universal in its occurrence. The incidence is approximately 15–40 per 100,000 individuals in the general population.

Age and gender influence the likelihood of contracting Bell's palsy. Bell's palsy is infrequent in patients under the age of 10 years, but thereafter increases in incidence with age. Females in their teens and twenties carry a predilection for the disorder. Among middle-aged adults, there is a nearly equal distribution by gender with a slight male predominance in older age groups. Epidemiological surveys indicate a seasonal variation in incidence in some geographic regions.

The risk posed by diabetes mellitus in developing Bell's palsy remains undetermined, although most studies suggest a heightened susceptibility. Several authors have demonstrated a correlation between pregnancy and acute facial palsy, particularly during the third trimester and with the presence of preeclampsia.

Immunodeficiency may also entail a heightened risk for acute facial palsy. Cranial neuropathies, including facial palsy, are observed with human immunodeficiency virus (HIV) infection, often in association with a symmetrical polyneuropathy. Facial dysfunction in this setting may also reflect either susceptibility to other infectious agents or the development of lymphoma. Facial palsy in association with HIV may occur in a clinical course characteristic of Bell's palsy or herpes zoster oticus. Neuropathies may appear at any stage of HIV infection: early after initial infection, as part of the chronic illness characterized by the AIDS, or with AIDS-related meningitis. Case series suggest that facial palsy in the setting of HIV infection not associated with neoplasm

demonstrates patterns of spontaneous recovery that are not unlike those of the general population.

Facial palsy associated with the conditions noted above is not necessarily diagnostic of Bell's palsy. Patients should be evaluated as completely as those who do not carry these risk factors, with the notable caveat of considering the risk and benefit of radiological studies in pregnancy.

Clinical Findings

A. Patient Evaluation

The diagnosis of Bell's palsy is one of exclusion. Facial motor disturbance should be characterized as Bell's palsy only after the exclusion of traumatic, neoplastic, infectious, metabolic, and congenital etiologies. Strict attention to the evaluation, particularly the history and otoscopic and neurological findings, often differentiates an acute facial palsy of another origin from a true case of Bell's palsy.

On the clinical examination, the severity of the palsy should be recorded by one of the standard facial nerve grading schemes. In particular, one should assess for the ability to close the eyelid, as this will have the greatest functional significance. The presence of vesicles within the auricle or external auditory canal may reveal the diagnosis of herpes zoster oticus. Pain or numbness affecting the ear, mid-face, and tongue, as well as taste disturbances, are common.

B. Laboratory Findings

Blood and cerebrospinal fluid studies will only rarely differentiate a facial palsy and are largely unwarranted for most cases of Bell's palsy. For atypical cases though, one should consider Lyme titers and a search for a paraneoplastic syndrome.

C. Imaging Studies

Routine radiological evaluation is generally not recommended for most cases of acute facial palsy, particularly when the clinical course matches that of Bell's palsy or herpes zoster oticus. However, should the patient's recovery be incomplete over 3-months time, the palsy becomes recurrent, or associated cranial nerve deficits develop, then scans are warranted. Magnetic resonance imaging scanning with dye enhancement should include the brain, the skull base, and the temporal bone to rule out a lesion along the entire course of the facial nerve. High-resolution computed tomography (CT) scanning may be useful to define the bony detail in the course of the facial nerve within the fallopian (facial) canal.

Treatment

A. Pretreatment Assessment

Both pharmacological and surgical treatments are designed to reduce the likelihood of residual facial dysfunction in susceptible patients with acute facial palsies. Prior reports have documented the reasons underlying the difficulty in assessing the efficacy of steroids and other therapeutic modalities for Bell's palsy. Evaluation of the response is complicated by the potential for spontaneous remission for most acute palsies. Impediments such as the fragmentation of care of facial palsy patients, as well as the difficulty in obtaining early assessment and maintaining strict experimental conditions, have thwarted systematic, definitive studies.

In order to assess the response to treatment, patients with facial palsy should be initially stratified using clinical and electrophysiological criteria (see Chapter 69, Anatomy, Physiology, and Testing of the Facial Nerve). The assessment of the ultimate outcome requires sensitive and objective measures and a classification system that is universally accepted. As with any study of treatment effect, inconclusive or negative results may reflect insensitive measures of outcome.

A variety of facial nerve classification schemes have been proposed. The difficulty, of course, lies in translating facial impairment into a classification that is continuous and enables precise comparisons of functional recovery. Intermediate levels of recovery are particularly difficult to classify with consistency among observers. Although simplicity in the classification enhances acceptance, subtle differences in the quality of the outcome are less likely to be differentiated. Presently, the House-Brackmann grading system has been adopted by the American Academy of Otolaryngology-Head and Neck Surgery and has found the greatest acceptance among otolaryngologists in the United States (Table 70–3).

1. Steroid therapy—Most early studies of the value of steroids in treating Bell's palsy were based on comparisons of treated patients with retrospective controls. While double-blinded, randomized, controlled clinical trials have demonstrated a significantly higher rate of complete functional recovery in glucocorticoid-treated patients in comparison to the control group in most studies, the lack of randomization and concurrent controls and the dose of glucocorticoid utilized have not completely resolved the question.

Some double-blinded trials have demonstrated beneficial effects of glucocorticoid therapy as long as therapy was initiated early in the course of the palsy.

Meta-analytic reviews of steroids in the treatment of Bell's palsy suggest that they may have the following effects: (1) reducing the risk of denervation if initiated early on, (2) preventing or lessening synkinesis, (3) preventing progression of incomplete to complete paralysis, (4) hastening recovery, and (5) preventing autonomic synkinesis (crocodile tearing). Together, these studies point to the effectiveness of steroids, particularly if given early in the course of disease. From a practical standpoint, in light of the low risk of side effects and minimal costs involved, prednisone is commonly started at the initial visit—even in patients with partial palsy—on the chance that a complete palsy might evolve within a few days. The initiation of steroid therapy during the first 24 hours of symptoms might confer a higher likelihood of

Table 70–3. The House-Brackmann Facial Nerve Grading Scale.

Grade	Function
I	Normal
II	Normal tone and symmetry at rest Slight weakness on close inspection Good to moderate movement of forehead Complete eye closure with minimum effort Slight asymmetry of mouth with movement
III	Normal tone and symmetry at rest Obvious but not disfiguring facial asymmetry Synkinesis may be noticeable but not severe, ± hemifacial spasm or contracture Slight to moderate forehead motion Complete eye closure with effort Slight weakness of mouth with maximum effort
IV	Normal tone and symmetry at rest Asymmetry is disfiguring or results in obvious facial weakness No perceptible forehead movement Incomplete eye closure Asymmetrical motion of mouth with maximum effort
V	Asymmetrical facial appearance at rest Slight, barely noticeable movement No forehead movement Incomplete eye closure Slight movement of mouth with effort
VI	No facial function perceptible

Reproduced, with permission, from House JW, Brackmann DE. Facial nerve grading system. Otolaryngol Head Neck Surg. 1985,93:146.

recovery. In patients with Ramsay Hunt syndrome, higher rates of full recovery have been noted by some studies for patients receiving intravenous therapy.

A. Glucocorticoid steroids—Glucocorticoid steroids exert an inhibitory effect on virtually every phase of the inflammatory response and thus have assumed an important role in treating a vast range of inflammatory and immune-mediated disorders. The precise mechanism by which steroids exert beneficial effects is incompletely defined in many of the conditions for which they are prescribed. In many cases, guidelines and indications for steroid treatment are empiric. Such guidelines apply to the use of steroids in the treatment of Bell's palsy, herpes zoster oticus, and other facial palsies. Nonetheless, the pharmacological effects of steroids make them attractive agents for ameliorating symptoms associated with the acute phases of Bell's palsy and herpes zoster oticus, improving the likelihood of full recovery. In addition to their anti-inflammatory properties, the glucocorticoid steroids also exert a facilitatory action on the neuromuscular junction. These combined effects may contribute to the recovery of neuromusculature function in disorders such as inflammatory polyradiculoneuropathies (the Landry-Guillain-Barré syndrome), the pathology of which is marked by inflammatory, segmental demyelinization.

The desired goal of glucocorticoid therapy for acute facial paralysis is to induce effective anti-inflammatory control. In order to provide such control, the inflammatory process should be countered with consistent, pharmacological levels of an anti-inflammatory agent, beginning as soon as possible. Once the inflammatory process is checked and the stimulus for inflammation removed, therapy can be discontinued. However, abrupt withdrawal may be followed by a rebound of disease activity. To prevent reacceleration of the inflammatory process, a tapered withdrawal of the daily glucocorticoid dose over 10–14 days is recommended.

Based on the theoretical active phase of the herpes simplex and varicella-zoster viruses (3 and 14 days, respectively), the following strategy for steroid treatment of Bell's palsy and herpes zoster oticus has been proposed: oral prednisone (1 mg/kg/d) divided into 3 doses per day for 7–10 days. The daily dose should then be tapered to zero over the following 10 days. Theoretically, this dosing regimen maximizes anti-inflammatory activity while minimizing side effects and is consistent with anti-inflammatory schedules that are effective in controlling acute hypersensitivity as well as autoimmune and other inflammatory disorders.

When administered intravenously, methylprednisolone is prescribed at 1 g/d administered intravenously as either a single dose or in 3 divided doses for 3–7 days, followed by an oral prednisone taper.

B. Side effects of steroid therapy—Side effects that are likely to be manifest during short-term steroid treatment include hyperglycemic action. Given the high incidence of glucose intolerance in some series of acute facial palsy patients, steroids should be initially prescribed with caution. Other acute side effects include CNS changes such as psychotic breaks, fluid and electrolyte disturbances, acne, increased intraocular pressure, and gastrointestinal irritation. Corticosteroids are category C drugs in pregnant patients.

An adverse effect of glucocorticoid administration that deserves special consideration is a heightened susceptibility to infection. Glucocorticoids should be used with caution in patients with existing GI infections and in cases of latent tuberculosis. The effects of glucocorticoids on cellular and humoral components of inflammation may lessen host immunity to bacterial, viral, and fungal infections. Latent infections may become reactivated and spread. Moreover, suppression of the inflammatory response may conceal symptoms and signs of infection.

While effects on host resistance have been demonstrated in experimental trials, typical daily doses of glucocorticoids (1 mg/kg/d of prednisone or its equivalent) given for 2 weeks or less are only rarely associated with an increased

susceptibility to infection. The risk of steroid-induced dissemination of viruses presents a particular concern in treating acute facial palsies of viral origin. The risk of virus dissemination is significant with steroid therapy beyond 1 month and in immunosuppressed patients. Otherwise, clinical experience suggests that the risk of this complication is minimal and that steroids can ameliorate postherpetic neuralgia.

2. Antiviral therapy—Antiviral therapy represents a newer adjunct in treating acute facial palsy of viral origin. A number of meta-analyses have now examined the role for antiviral therapy in patients with Bell's palsy. These studies have predominantly looked at the use of oral steroids with or without the addition of antiviral therapy, in an attempt to discern if there is incremental benefit to the antiviral therapy. While most of these studies demonstrated clear benefit with oral steroids, none has shown convincing evidence of benefit with the addition of antiviral treatment.

In contrast, antiviral therapy is a standard part of treatment for herpes zoster oticus. In cell culture, acyclovir inhibits the herpes simplex Types I and II, varicella-zoster, and Epstein-Barr viruses and cytomegalovirus.

Indications for the use of acyclovir include genital herpes, herpes simplex encephalitis, and varicella-zoster infections in immunocompromised patients. Early reports suggest that acyclovir may mitigate neurological deficits produced by herpes zoster oticus.

A. Intravenous antiviral agents—Intravenous acyclovir (10 mg/kg every 8 hours for 7 days) produced substantially greater functional return in patients treated within the first 72 hours after the onset of paralysis. Moreover, preliminary reports have demonstrated early recovery of facial nerve function and reversal of sensorineural hearing loss associated with herpes zoster oticus in response to the drug early on, though these are nonrandomized trials..

B. Oral antiviral agents—Oral antiviral agents are significantly less costly and more convenient than intravenous agents. An exception to the general preference for oral antiviral agents exists in immunocompromised patients with severe or widespread herpes zoster oticus. Newer antiviral drugs, including valacyclovir, famciclovir, and penciclovir, are better absorbed after oral administration than acyclovir and have increasingly been used in treating Ramsay Hunt syndrome. However, these drugs are more expensive than acyclovir. Valacyclovir may be superior to acyclovir in limiting zoster pain.

Acyclovir has also been used for the treatment of Bell's palsy. When compared with patients who received oral prednisone alone, some studies have identified a higher recovery rate as well as reduced rates of synkinesis in Bell's palsy patients given oral acyclovir plus prednisone, but these findings have not been born out in larger meta-analyses, as conflicting studies have found little benefit from adding oral acyclovir to prednisone in Bell's palsy.

Synthesizing the myriad clinical trials on the topic, one can say that oral acyclovir appears reasonably indicated in all cases of herpes zoster oticus. Although proof of efficacy is limited in Bell's palsy, low risks and costs associated with acyclovir suggests that it may be reasonable to include its use in patients with complete facial paralysis. Acyclovir is prescribed at 400 or 800 mg five times daily and administered orally for 7–10 days in Bell's palsy. Alternately, acyclovir may be prescribed at 300–1000 mg (5–10 mg/kg) three times daily administered intravenously. Higher acyclovir doses (ie, 4000 mg/day orally) are recommended for patients suffering from herpes zoster oticus. Intravenous dosing is often indicated for immunocompromised individuals with severe infection. The main side effects of antiviral agents are nausea, malaise, injection site reactions, and mild renal insufficiency. Acyclovir is a category B drug in pregnant patients.

3. Physical Therapy

A. Electrical stimulation—Transcutaneous electrical (galvanic) stimulation of the facial muscles has been used in an effort to maintain membrane conductivity and reduce muscle atrophy. It has also been used to potentially limit residua such as persistent paresis in patients with longstanding facial palsy. There exist few compelling, comparative trials to support this practice, although interest in this measure persists. Electrical stimulation may also improve function in chronic facial palsy. Patients left with partial deficits often benefit from physical therapy. Electromyographic and mirror feedback has been used to facilitate muscle reeducation to assist in the recovery of symmetric facial tone and expression.

B. Eye care—The cornea is vulnerable to drying and foreign body irritation in acute facial palsy due to orbicularis oculi dysfunction. Corneal desiccation and abrasion can result from incidental contact, particularly during sleep, and can progress to cataract formation. Measures that confer corneal protection are recommended. Examination of the cornea by slit lamp biomicroscopy and either fluorescein or rose bengal staining provides the most sensitive measure for the early detection of corneal compromise. For mild facial paresis, therapy is generally not needed, unless dysfunction of cranial nerve V is present because the combination of a facial weakness and dysesthesia dramatically increases the risk of corneal exposure and ulceration. For moderate-to-severe deficits, a corneal moistening regimen should consist of a moisture chamber, artificial tears during the daytime, and ocular ointments at night. Sunglasses or other protective eyewear should be worn to protect the eyes in the outdoors. The lower eyelid can be gently elevated with adhesive tape running obliquely from the lower lid to the orbital rim, temporarily improving lid closure.

In longer standing cases of facial palsy, lubrication and occlusion are insufficient to protect the cornea. Implanting a gold weight in the upper lid, which will induce ptosis, and reducing the exposed area of cornea may augment lid

suturing. This procedure is often augmented by elevating the lower lid via a lateral canthopexy, in which the tarsal ligament is suspended to the periorbital periosteum. Joining the upper and lower lid margins laterally (tarsorrhaphy) may be performed to narrow the palpebral fissure. The standard procedure calls for suturing a margin of upper and lower lid together from the lateral canthus inward. The width of the tarsorrhaphy is adjusted to optimize the degree of lid closure. If neural recovery ensues, the tarsorrhaphy can be reversed.

B. Surgical Measures

Mounting anatomic and electrophysiological evidence of a specific anatomic lesion site in Bell's palsy has guided the choice of procedures for surgical intervention. These approaches now focus on decompressing the meatal foramen and adjacent labyrinthine segment of the nerve for cases thought to have a poor prognosis for complete recovery with medical treatment alone.

1. Nerve decompression—Surgical approaches to treating acute facial palsy are based on the premise that axonal ischemia can be reduced by the decompression of nerve segments presumed to be inflamed and entrapped. Facial nerve decompression, aimed at alleviating Bell's palsy and herpes zoster oticus, has been variably embraced for more than 70 years. The roll of surgery has evolved in concert with developments in electrophysiological testing and techniques of enhanced surgical exposure of the facial nerve.

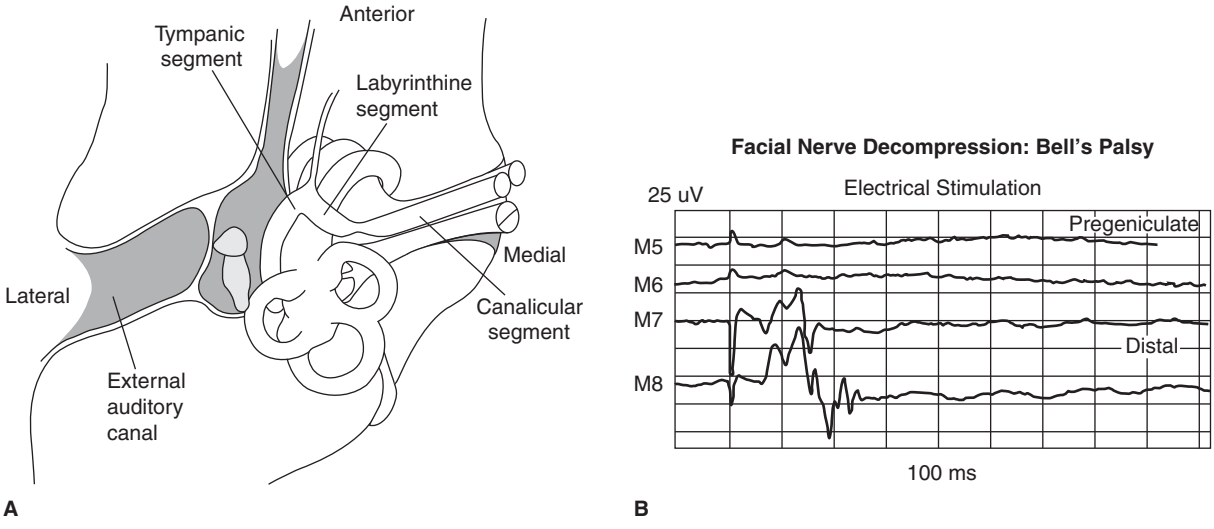
A. Preoperative considerations—Evoked electromyography (EEMG) may be used to help stratify patients who might benefit from facial nerve decompression. Surgical treatment is offered when evoked response amplitudes are 10% (or less) of the normal side. This criterion is based on the observation that approximately half of patients who progressed to a nadir of 95–100% degeneration within 2 week of the onset of the paralysis demonstrated a permanent, unsatisfactory recovery of facial function. Furthermore, most patients who reach a 90% level of degeneration progressed beyond 94% degeneration in the EEMG profile. Therefore, the proposal that immediate surgical decompression be performed as soon as the 90% level of degeneration has been reached entailed unnecessary surgery in, at most, 10% of patients. All patients who underwent decompression when degeneration reached 90% demonstrated a satisfactory return of facial movement. The 90% rate of satisfactory outcome with surgery compared favorably with the 50% chance of satisfactory return noted in patients who were not operated on and who were matched by EEMG profile. Surgery performed on eight patients in the third week after the onset of the palsy, when degeneration exceeded 90%, did not significantly improve the return of facial function. However, two patients in this group demonstrated an exceptional return of facial movement after decompression. These observations suggest that studies of more patients with delayed degeneration are needed before the role of surgical decompression can be assessed definitively in this subset of patients.

B. Transmastoid approach—Both transmastoid and middle fossa approaches have been described, though transmastoid approaches are thought to provide limited exposure of the meatal foramen due to the interposed labyrinth. The transmastoid approach to the geniculate ganglion and the labyrinthine segment obviates a craniotomy, but requires removal of the incus in poorly pneumatized bones to facilitate exposure of the facial nerve proximal to the cochleariform process. Some studies have shown that facial nerve decompression using the transmastoid approach improved recovery in patients whose maximal nerve stimulation responses were reduced by 75% or more. However, long-term follow-up of these patients failed to evidence significant benefit from this procedure as compared with the spontaneous recovery rate found in other studies.

C. Middle cranial fossa approach—The middle cranial fossa approach to the meatal, labyrinthine, and geniculate segments of the nerve facilitates direct decompression with small though significant risk to the labyrinth (Figure 70–5A). Permanent ipsilateral auditory and vestibular loss, meningitis, and subarachnoid hemorrhage are potential complications of facial nerve decompression via a middle cranial fossa approach. This approach also permits direct stimulation of the facial nerve proximal to the meatal foramen, enabling verification of the site of impairment if a complete loss of response to electrical stimulation has not yet occurred. Intraoperative stimulus trials typically reveal severely decreased to absent responses proximal to the foramen. However, stimulation distal to the foramen typically evokes potentials of substantially greater amplification (Figure 70–5B).

2. Nerve grafting—Facial motor reinnervation may be accomplished by either grafting a section of normal peripheral nerve over a damaged area, bringing fibers from the intact facial nerve across the midline to innervate the paralyzed side, or by direct anastomosis of the ipsilateral hypoglossal nerve with the peripheral facial nerve. Nerve grafting may be augmented by muscle transfer procedures, since atrophy of facial muscles may render the muscle fibers less amenable to reinnervation. A wide variety of reconstructive procedures including rhytidectomy, blepharoplasty, brow lift, and fascial slings can improve resting tone and symmetry.

Aberrant regeneration may give rise to inappropriate patterns of reinnervation wherein specific muscle groups receive excessive neural inputs. Spasm and synkinesis with facial nerve recovery often produce undesired eye closure (Figure 70–6). This form of aberrant facial nerve regeneration can often be managed with subcutaneous or intramuscular botulinum toxin injections. Botulinum toxin, which induces temporary paresis in targeted muscles for up to 6 months, can reduce disability with tonic contractions, hemi-



▲ **Figure 70–5.** **(A)** Schematic of the approach to the intracanalicular and labyrinthine segments of the facial nerve via a middle cranial fossa. **(B)** Electrically evoked responses obtained after decompression of the meatal foramen in a patient with Bell paralysis and >90% reduction on preoperative EEMG. P-pregeniculate (proximal) site of stimulation. D-distal site of stimulation at the tympanic segment of the facial nerve. Responses of reduced amplitude to pregeniculate stimulation suggest the lesion is in the labyrinthine segment of the facial nerve. (A: Adapted, with permission, from Fisch U, Esslen E. Total intratemporal exposure of the facial nerve: Pathologic findings in Bell's palsy. *Arch Otolaryngol.* 1972;95:335; B: Adapted, with permission, from Gantz B, Gmur A, Fisch U. Intraoperative electromyography in Bell's palsy. *Am J Otolaryngol.* 1982;3:273.)

facial spasm, and synkinesis. Side effects of botulinum toxin are rare and typically reveal severely decreased to absent responses proximal to the foramen. However, stimulation distal to the foramen typically evokes potentials of substantially greater amplification.

Prognosis

Most series that have assessed surgical decompression of the facial nerve in Bell's palsy have been small and retrospective and have targeted subjects most likely to suffer residual deficits (ie, patients with complete palsies and severe reductions in neural conductivity as demonstrated by electrophysiological testing). No surgical series has been randomized and several studies have shown no benefit, though these studies all utilized a transmastoid approach to decompression. Results that have employed the middle fossa approach have included multicenter, prospective data, though subjects were nonrandomized. In these studies, patients recovered completely or with slight residual deficits in 91% of the surgical group, but in only 42% of a similar, medically treated group, suggesting a benefit of decompression using this surgical approach. Because of the difficult nature of designing such a controlled trial, the precise role of facial nerve decompression in the management of Bell's palsy and herpes zoster oticus remains unclear at present.

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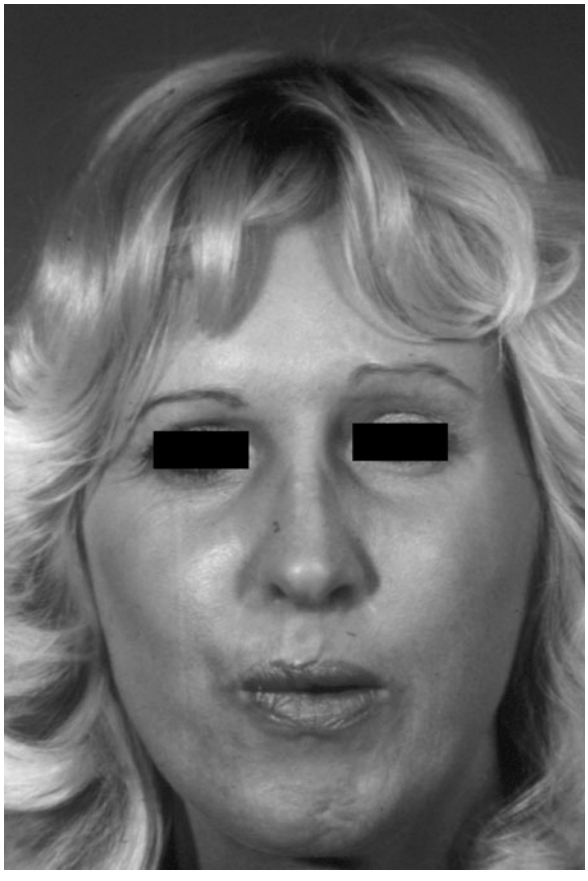
Fisch U, Esslen E. Total intratemporal exposure of the facial nerve: P athologic findings in Bell's palsy. *Arch Otolaryngol*. 1972;95:335. [PMID: 5018255] (This report highlights the intraoperative and pathological findings of the facial nerve during intratemporal decompression of the nerve.)



▲ **Figure 70–6.** 38-year-old woman 1 year after recovery from Bell paralysis with synkinetic closure of left eye with lip movement.

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Uscategui T, Doree C, Chamberlain IJ et al.. Corticosteroids as adjuvant to antiviral treatment in Ramsay Hunt syndrome (herpes zoster oticus with facial palsy) in adults. *Cochrane Database Syst Rev*. 2008;(3):CD006852. Review. [PMID: 18646170]

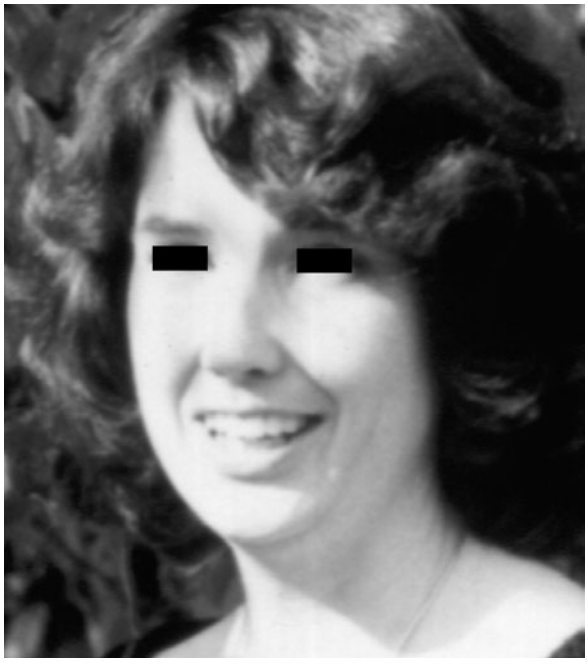
OTHER FACIAL NERVE DISORDERS

Next to Bell's palsy, the most common causes of acute, peripheral facial paralysis are trauma, herpes zoster oticus, bacterial infection, perinatal factors, and neoplastic involvement of the nerve. An acute facial palsy due to trauma or infection often presents with characteristic findings that readily point to a diagnosis. In contrast, differentiating neoplastic involvement of the facial nerve from Bell's palsy frequently poses a dilemma. Several other disorders (described below) should be considered in the clinical evaluation of an acute facial palsy. It must always be remembered that Bell's palsy is a diagnosis of exclusion, and one should therefore consider the following disorders in the context of the presenting symptoms and signs of the patient.

1. Facial Nerve Neoplasms

A variety of neoplasms may induce a facial palsy, which is occasionally acute in onset (see Table 70–1 and Figure 70–7). It is estimated that there is an incidence of sudden facial palsy in 27% of patients found to have neoplastic involvement of the nerve—a surprisingly high incidence given the slow growth and encapsulation of most tumors responsible for the palsy.

While Bell's palsy may present with a variety of associated symptoms, atypical presentations warrant consideration of other etiologies, particularly neoplasms. A facial palsy produced by a neoplasm may differ only subtly from Bell's palsy. There are characteristic historical and clinical features that suggest that a neoplasm is responsible for a facial palsy and necessitate further evaluation (Table 70–4).



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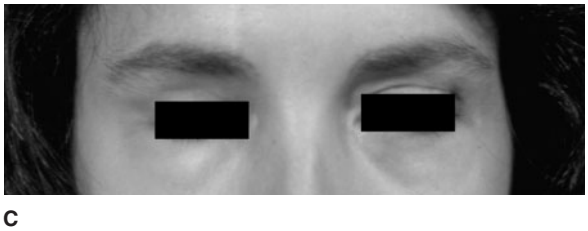

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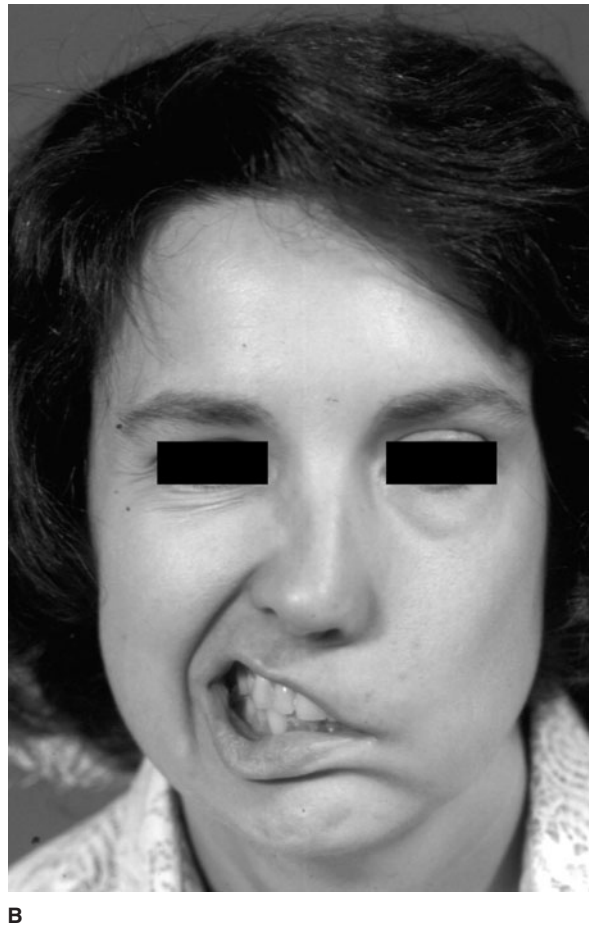
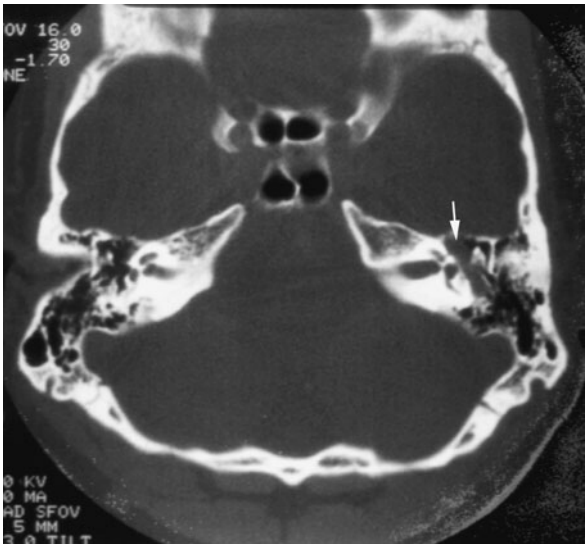


B

▲ **Figure 70–7.** **(A)** A 42-year-old woman prior to onset of facial dysfunction. **(B)** Left facial paralysis of 1-year duration mistakenly attributed to Bell's palsy. Severe facial skewing due to complete loss of facial motor tone is apparent. **(C)** The severity of the patient's facial nerve dysfunction allows for only passive closure of the left eye. *(Continued)*



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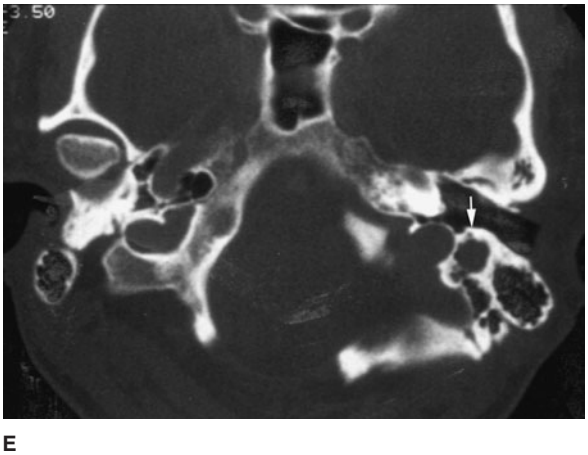

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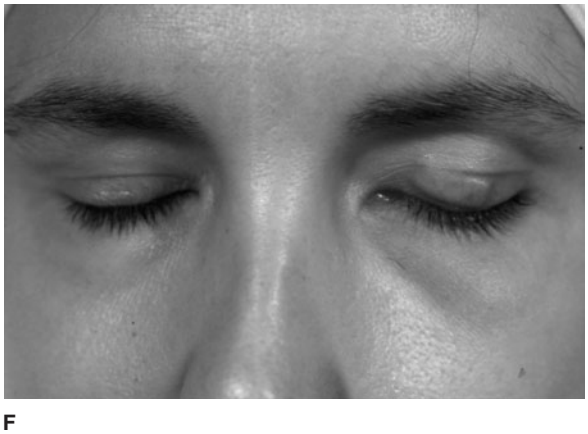

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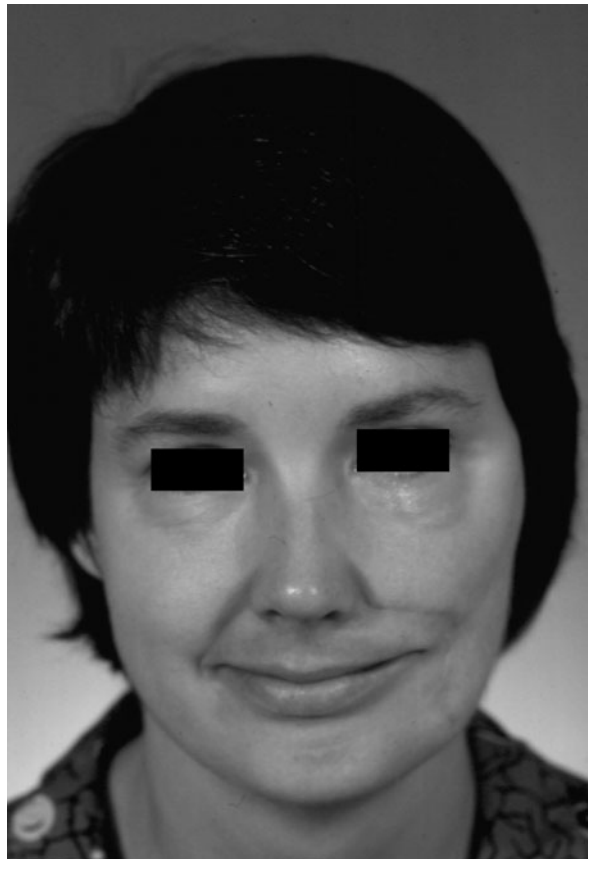

G

▲ **Figure 70–7.** *(Continued)* **(D)** Computed tomography scan of temporal bones demonstrating facial nerve neuroma involving the tympanic segment (arrow). **(E)** Computed tomography scan of temporal bones revealing expansion of fallopian canal within the mastoid segment that is filled with soft-tissue density. **(F)** After resection of facial schwannoma from meatal foramen to stylomastoid foramen, a sural nerve graft was placed. Reinnervation did not occur, requiring lower lid acanthopelyx and (gold) weighting of upper eyelid to achieve eye closure. **(G)** Early postoperative view after left temporalis transposition to achieve lower facial soft-tissue support.

Table 70–4 Clinical Features Suggesting a Facial Palsy in Neoplasia

Progression of a facial palsy over 3 week or longer
No return of facial function within 3–6 months
Failure to resolve an incomplete paresis within 2 months
Facial hyperkinesia, particularly hemifacial spasm, antecedent to the palsy
Associated dysfunction of regional cranial nerves
Prolonged otalgia or facial pain
Mass in the middle ear, external ear canal, digastric region, or parotid gland
Recurrent ipsilateral palsy

Although Bell's palsy may recur, a recurrent palsy indicates the need for an exhaustive tumor search with radiological evaluation of exploratory surgery, which is performed rarely. A neoplasm, most frequently a facial neuroma, has been identified in 9% of patients who underwent surgery for recurrent facial palsy. When the diagnosis of a neoplasm is delayed or missed, the neoplasm carries the potential consequences of extension into the labyrinth and cranial fossae. Extension into the cerebellopontine angle diminishes the opportunity for effective reanimation with direct neural anastomosis, underscoring both the need for vigilance in cases of atypical facial palsy and the importance of early diagnosis.

Facial nerve hemangiomas may also present with facial palsy. A classic presentation of a patient with a facial nerve hemangioma is one of recurrent and progressively more severe episodes of unilateral facial palsy. Treatment involves surgical excision, often at the expense of residual facial nerve function.

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2. Melkersson-Rosenthal Syndrome

General Considerations

Melkersson-Rosenthal syndrome represents a constellation of facial anomalies that include unilateral facial palsy, episodic or progressive facial edema, and lingua plicata (scrotal tongue). The syndrome is usually sporadic in occurrence, although familial occurrence has been described.

Pathogenesis

Although the pathophysiological basis for Melkersson-Rosenthal syndrome is uncertain, granulomatous changes have been evident in biopsies of edematous tissues in cases with chronic edema. A purely inflammatory basis for the syndrome is therefore doubtful. The syndrome thus may reflect a more generalized autonomic dysfunction that manifests as vasomotor instability. Further support for this assertion comes from the association of Melkersson-Rosenthal syndrome with migraine headaches and megacolon.

Clinical Findings

Patients may show oligosymptomatic (two of three symptoms) forms of the syndrome. Lingua plicata is most likely to occur early in life, whereas facial edema generally occurs after the initial episode of facial weakness (Figures 70–8 and 70–9). Facial dysfunction may be heralded by the onset of a facial swelling, but more typically precedes the swelling by months or years.

Episodes of facial paresis or paralysis typically begin in childhood or adolescence. Edema of the lips and palatal mucosa produces a ruddy appearance. Swelling often extends to the cheeks, eyelids, nose, and chin and may be dramatic. Progressive disfigurement can result from recurrent facial swelling. Facial weakness assumes a peripheral distribution and can be differentiated from Bell's palsy only when other manifestations of the syndrome are apparent or noted on the history. While a relapsing course is usual, good to excellent recovery is typical. However, cases of progressive dysfunction have been described.

Treatment

The treatment of facial palsy associated with Melkersson-Rosenthal syndrome is empiric. Anti-inflammatory (steroid) therapy has been employed. Reports of surgical decompression of the meatal and labyrinthine segments suggest a benefit in preventing further recurrence of the palsy.

Dutt SN, Mirza S, Irving RM, Donaldson I. Total decompression of facial nerve for Melkersson-Rosenthal syndrome. *J Laryngol Otol*. 2000;114(11):870. [PMID: 11144840] (This study describes a successful case of a surgical decompression of the facial nerve in a 27-year-old woman with Melkersson-Rosenthal syndrome and reviews the literature pertaining to facial nerve decompression for this syndrome.)
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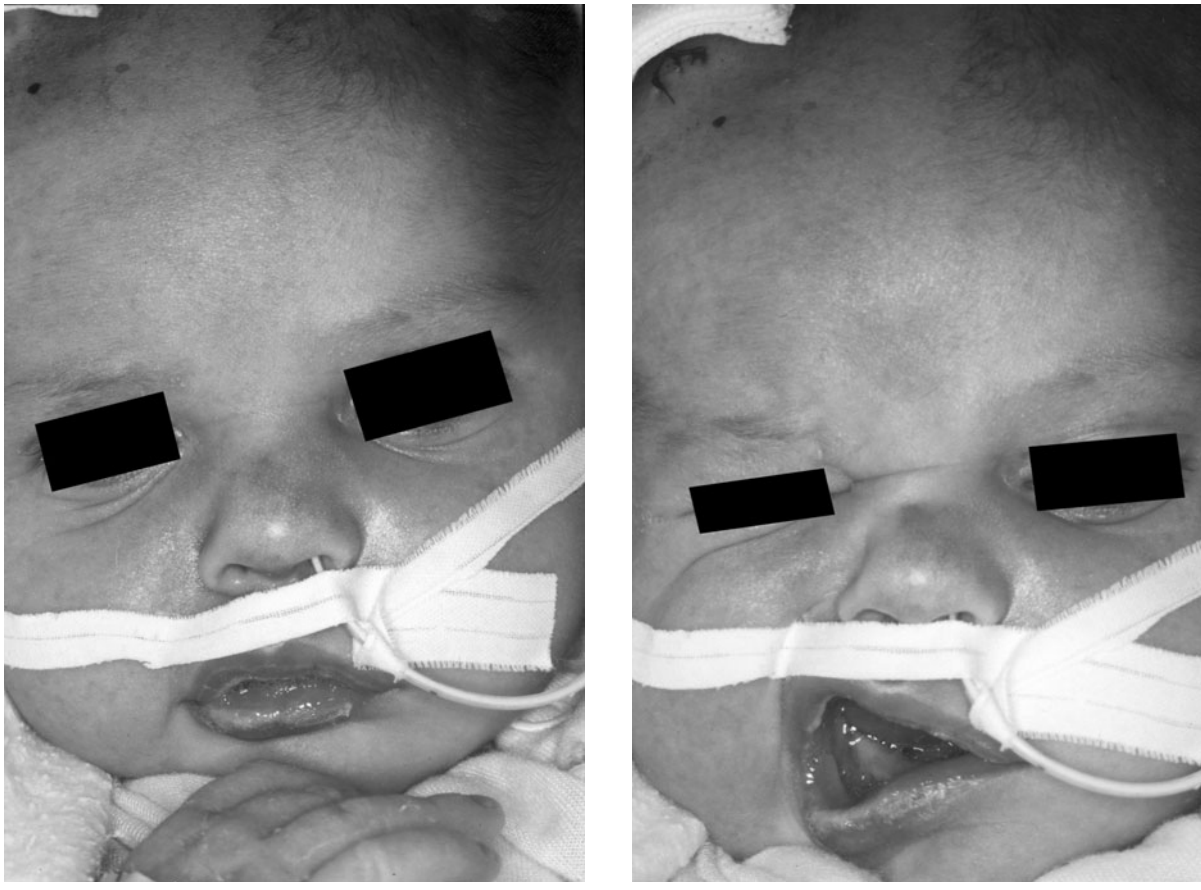


A B

▲ **Figure 70–8.** Facial paralysis in newborns and young infants can be difficult to detect at rest owing to high facial tone in these age groups. Right facial paralysis in a neonate with medulloblastoma of the caudal brain stem. A right esotropia indicates a right abducens paralysis combined with right facial nerve paralysis is shown. **(A)** Face at rest. **(B)** An asymmetric crying facies.

1992;89(5):815. [PMID: 1561252] (This manuscript reports on 14 patients with Melkersson-Rosenthal syndrome and provides an algorithm that guides the surgeon with regard to both the medical and surgical treatment of the patient with this syndrome.)

Grundfast KM, Guarisco JL, Thomsen JR. Diverse etiologies of facial paralysis in children. *Int J Pediatr Otorhinolaryngol.* 1990;19(3):223. [PMID: 2170282] (This report reviews 25 cases of children with facial paralysis that results from a number of etiologies.)

3. Lyme Disease

General Considerations

Lyme disease is a multisystem infection induced by the tick-borne strain of the *Borrelia burgdorferi* spirochete. The occurrence of acute facial palsy in association with Lyme disease is well recognized. Unilateral or bilateral facial palsy may occur in up to 11% of patients with Lyme disease. The ratio of unilateral to bilateral involvement is 3:1.

Clinical Findings

A. Symptoms and Signs

While the majority of patients with facial palsy associated with Lyme disease note an antecedent rash adjacent to the site of a tick bite, others may not; the palsy may be the presenting sign of the illness. The interval between the onset of the rash and facial palsy is less than 2 months. Facial palsy may occur in association with other neurological deficits produced by meningoencephalitis and radiculoneuritis.

Following a tick bite and a 1- to 4-week incubation period, skin lesions develop in approximately 50% of infected individuals in association with flu-like symptoms. Less than half of patients suspected to have Lyme disease can recall a

previous tick bite. Within weeks to months after the initial infection, constitutional, neurological, and cardiac manifestations, including ipsilateral or bilateral facial palsy, may appear. Arthritic symptoms typically follow.

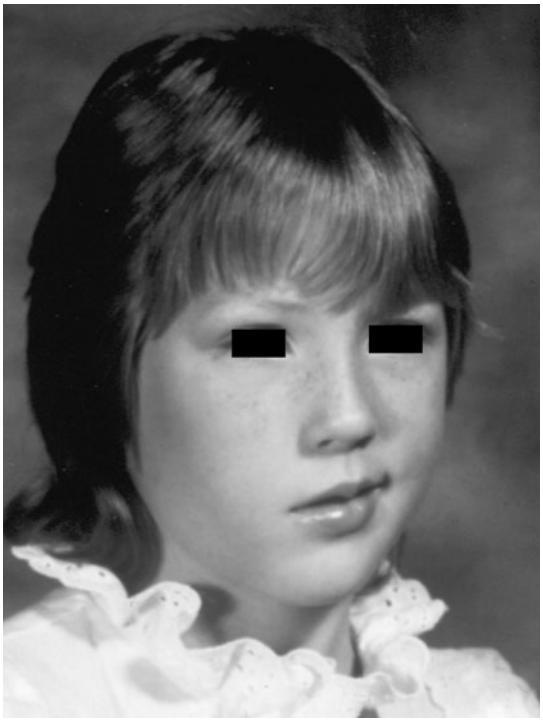
B. Laboratory Findings

If Lyme disease is suspected, diagnostic testing should include serological testing with ELISA (**E**nzyme-**L**inked **I**mmuno**S**orbent **A**ssay) to search for IgG and IgM antibodies. By some reports, serological evidence of Lyme disease has been found in up to 20% of patients diagnosed with Bell's palsy.

Treatment

Early antibiotic treatment is thought to enhance symptomatic improvement and prevent long-term sequelae. A 3-week course of either tetracycline (for adults) or penicillin (for children) is recommended, with erythromycin administered as an alternative choice. Adequate antibiosis provides high rates of recovery of facial function with a generally good prognosis for facial nerve recovery. Residual dysfunction was more likely in patients with bilateral involvement.

Bagger-Sjöbäck D, Remahl S, Ericsson M. Long-term outcome of facial palsy in neuroborreliosis. *Otol Neurotol*. 2005;26(4):790. [PMID: 16015186]



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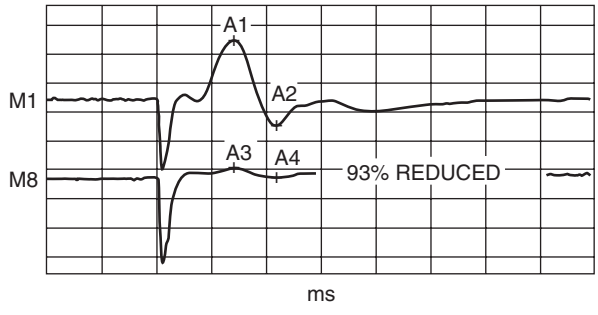

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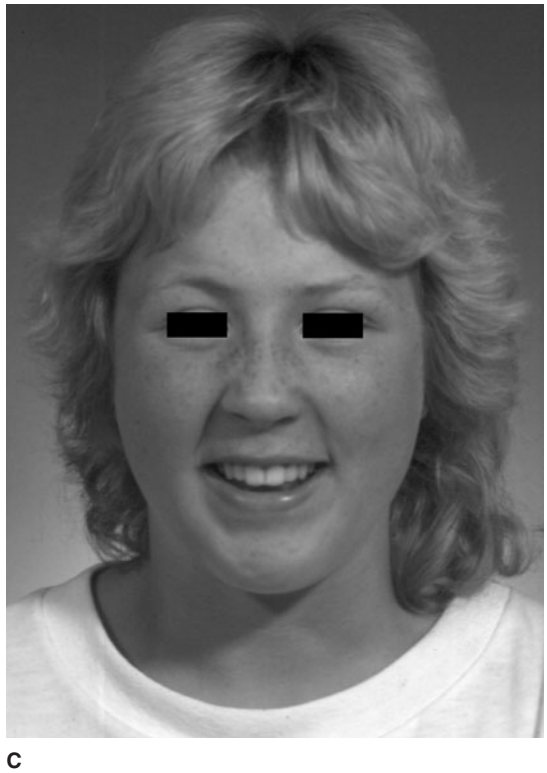
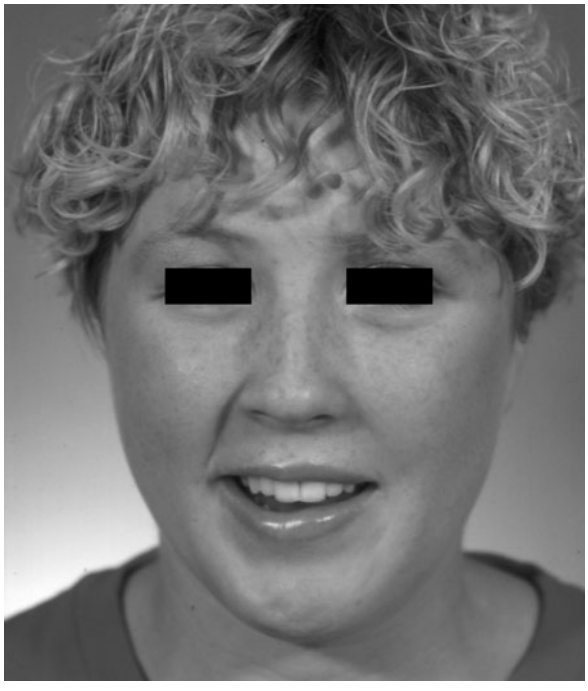


C

▲ **Figure 70–9.** **(A)** An 8-year-old girl during the initial episode of right facial paralysis associated with lower facial and lip swelling. This patient experienced three subsequent episodes of right facial paralysis with swelling on a yearly basis. **(B)** At age 12, evoked electromyography demonstrated poor responsiveness on the right side in association with an episode of paralysis. Facial nerve decompression via a middle cranial fossa approach was performed. No subsequent episodes of facial palsy have been noted over the ensuing 5 years. **(C)** Patient at age 13 years. *(Continued)*



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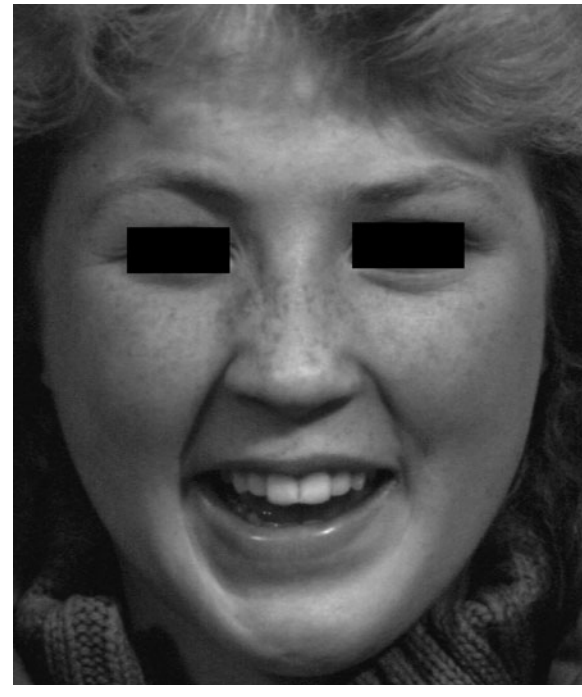

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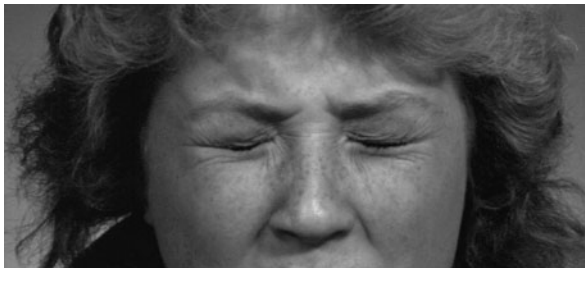


E

▲ **Figure 70–9.** *(Continued)* **(D)** Patient at age 15 years. **(E** and **F)** Patient at age 17 revealing full facial movement, with some synkinetic eye closure with lip movement.

Hagemann G, Aroyo IM. Bilateral facial palsy in neuroborreliosis. *Arch Neurol*. 2009;66(4):534. No abstract available. [PMID: 19364942]

Nigrovic LE, Thompson AD, Fine AM et al. Clinical predictors of Lyme disease among children with a peripheral facial palsy at an emergency department in a Lyme disease-endemic area. *Pediatrics*. 2008;122(5):e1080. [Epub 2008 Oct 17.PMID: 18931349]

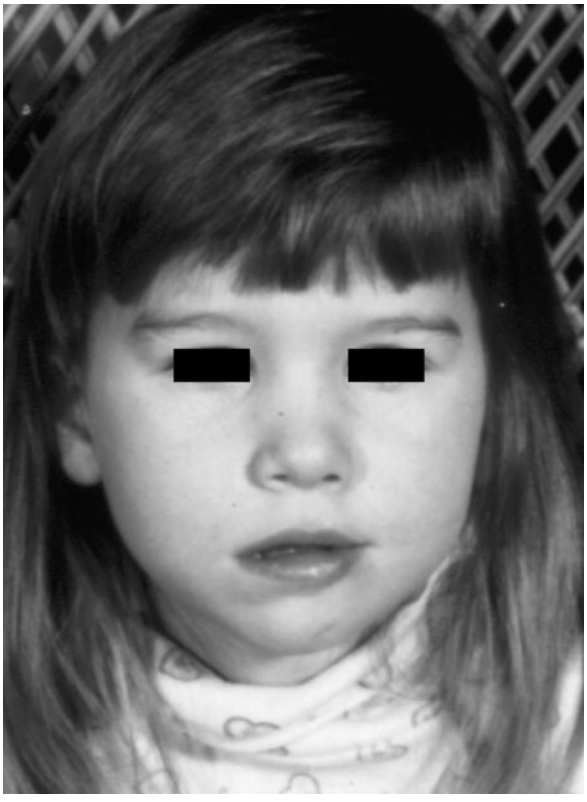
Skogman BH, Croner S, Nordwall M, et al. Lyme neuroborreliosis in children: A prospective study of clinical features, prognosis, and outcome. *Pediatr Infect Dis J*. 2008;27(12):1089. [PMID: 19008771]

Tveitnes D, Øymar K, Natås O. Acute facial nerve palsy in children: how often is it lyme borreliosis? *Scand J Infect Dis*. 2007;39(5):425. [PMID: 17464865]

4. Acute Otitis Media & Mastoiditis

▶ Clinical Findings

If the history or physical examination suggests evidence of prior or existing otitis media, or if there is a history of prior otologic surgery, an otogenic etiology should be suspected (Figure 70–10). Concomitant symptoms of hearing loss, otorrhea, and vestibular symptoms are highly suggestive of an otogenic etiology. Facial palsy due to acute suppurative otitis media is typically seen in children who appear toxic and manifest otoscopic findings of middle ear empyema. The palsy is often progressive over a 2- to 3-day interval. In such cases, there is often a history of recent episodes of otitis



▲ **Figure 70–10.** Unsuspected right facial palsy in a child who was found 2 week later to have a complete facial paralysis in association with right-sided otitis media, underscoring the subtle nature of facial paralysis in young children.

media that have been partially treated. In cases of prolonged palsy, radiographic evaluation of the temporal bone may rarely disclose coalescence of infection in the mastoid. Facial palsy associated with acute suppurative otitis media is generally the result of toxic neuritis and can be adequately treated with wide myringotomy and systemic antibiotics.

Treatment

Cortical mastoidectomy is required when antibiotics and myringotomy fail to render the patient afebrile after 24 hours, or when facial paralysis persists beyond 1 week. The surgical objective is to drain the empyema; extended nerve decompression is unnecessary except in cases of prolonged dysfunction.

Dubey SP, Larawin V. Complications of chronic suppurative otitis media and their management. *Laryngoscope*. 2007;117(2):264. [PMID: 17277619]

Leskinen K, Jero J. Acute complications of otitis media in adults. *Clin Otolaryngol*. 2005;30(6):511. [PMID: 16402975]

Makeham TP, Croxson GR, Coulson S. Infective causes of facial nerve paralysis. *Otol Neurotol*. 2007;28(1):100. [PMID: 17031324]

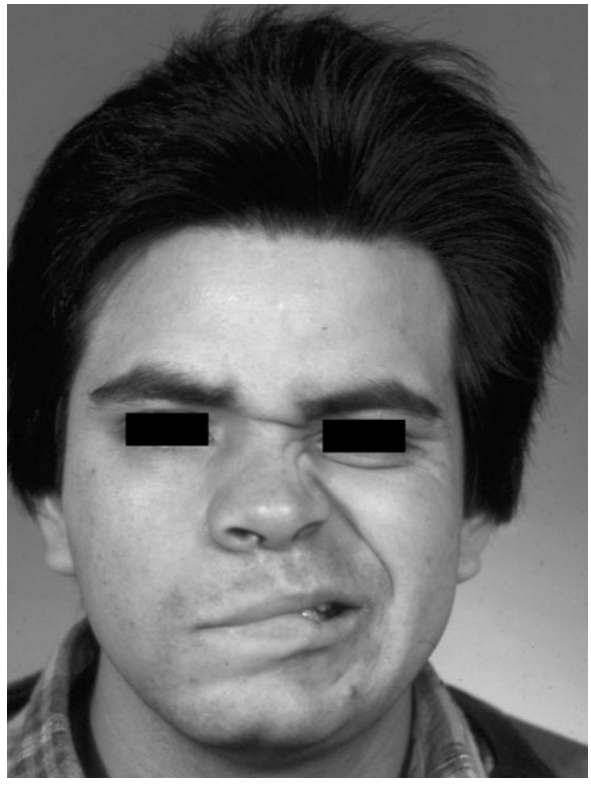
Wang CH, Chang YC, Shih HM et al. Facial palsy in children: emergency department management and outcome. *Pediatr Emerg Care*. 2010;26(2):121. [PMID: 20093994]

Yonamine FK, Tuma J, Silva RF et al. Facial paralysis associated with acute otitis media. *Braz J Otorhinolaryngol*. 2009;75(2):228. [PMID: 19575108]

5. Chronic Otitis Media

Chronic suppurative otitis media, manifesting mucosal inflammation or cholesteatoma, may produce an associated facial palsy (Figure 70–11; also see Figure 70–10). Facial nerve dysfunction associated with chronic suppurative otitis media reflects a toxic neuritis, external compression, or intraneural compression from edema or abscess.

Facial palsy associated with this disorder should be addressed surgically as soon as possible. Surgical removal of irreversible disease in the middle ear and mastoid, as well as



▲ **Figure 70–11.** Chronic suppurative otitis media manifesting as an associated facial palsy.

decompression of the involved segment of the nerve without slitting the sheath, is advised. Longstanding paralysis (but less than 2 years in duration) requires sectioning of attenuated tympanic or mastoid segments of the nerve followed by grafting.

Dubey SP, Larawin V. Complications of chronic suppurative otitis media and their management. *Laryngoscope*. 2007;117(2):264. [PMID: 17277619]
Makeham TP, Croxson GR, Coulson S. Infective causes of facial nerve paralysis. *Otol Neurotol*. 2007;28(1):100. [PMID: 17031324]
Quaranta N, Cassano M, Quaranta A. Facial paralysis associated with cholesteatoma: a review of 13 cases. *Otol Neurotol*. 2007;28(3):405. [PMID: 17414046]

6. Necrotizing (Malignant) Otitis Externa

Clinical Findings

Infection by *Pseudomonas aeruginosa* is the primary offending agent in necrotizing infection of the external auditory canal and temporal bone. These infections are observed in patients with diabetes mellitus or in others who are immunocompromised. Patients typically present with symptoms of otorrhea and progressive, disabling otalgia. The pathognomonic signs are otoscopic evidence of ear canal inflammation or a breech of the external canal skin at the bony-cartilaginous junction. The breech is filled with granulation tissue. Facial palsy is ominous and reflects skull base extension of the osteomyelitic process along vascular channels. The diagnosis is based on the clinical presentation in association with radioisotope gallium and technetium scanning that demonstrates osteomyelitis of the temporal bone.

Treatment

Treatment of necrotizing otitis externa requires aggressive management with intravenously administered antipseudomonal antibiotics, which should be maintained for 8–12 week to facilitate sequestration of the infection. Aggressive debridement of granulation tissue within the ear canal is key to promoting the replacement of necrotic bone with viable tissue. Because necrotizing otitis externa is associated with extensive ischemia of the skull base, the operative debridement of the tympanic bone, the mastoid, and the skull base is indicated only when medical treatment fails to improve. Radioisotope scanning can be helpful while following the progress of the infection and helps to determine the length of the course of intravenous therapy that is required.

Carfrae MJ, Kesser BW. Malignant otitis externa. *Otolaryngol Clin North Am*. 2008;41(3):537, viii–ix. Review. [PMID: 18435997]
Clark MP, Pretorius PM, Byren I et al. Central or atypical skull base osteomyelitis: diagnosis and treatment. *Skull Base*. 2009;19(4):247. [PMID: 20046592]
Joshua BZ, Sulkes J, Raveh E et al. Predicting outcome of malignant external otitis. *Otol Neurotol*. 2008;29(3):339. [PMID: 18317396]
Mani N, Sudhoff H, Rajagopal S et al. Cranial nerve involvement in malignant external otitis: implications for clinical outcome. *Laryngoscope*. 2007;117(5):907. [PMID: 17473694]
Soudry E, Joshua BZ, Sulkes J et al. Characteristics and prognosis of malignant external otitis with facial paralysis. *Arch Otolaryngol Head Neck Surg*. 2007;133(10):1002. [PMID: 17938323]

7. Childhood Facial Palsy

General Considerations

The evaluation of a facial palsy in a child should be guided by the fact that although Bell's palsy is the most common etiology for childhood facial palsies, it accounts for a substantially smaller proportion of palsies relative to adults. For instance, a clinically or radiographically identified etiology can be found in 20% of adult palsies initially diagnosed as Bell's palsy; this incidence may reach as high as 72% in childhood palsies. Patients under the age of 18 years with facial palsy are most likely to have an etiology of Bell's palsy (42%), trauma (21%), infection (13%), congenital causes (8%), and neoplasms (2%).

Clinical Findings

The onset of facial palsy in childhood is frequently obscured by the excellent tone of aponeurotic tissues and skin and, therefore, the excellent static suspension of central and lower portions of the face. Consequently, childhood facial nerve disorders are often referred to as "asymmetric crying facies" (see Figure 70–8).

Treatment

The treatment for childhood facial palsies generally follows that for adults.

Cha HE, Baek MK, Yoon JH et al. Clinical features and management of facial nerve paralysis in children: Analysis of 24 cases. *J Laryngol Otol*. 2009:1. [Epub ahead of print. PMID: 20025809]
Shargorodsky J, Lin HW, Gopen Q. Facial nerve palsy in the pediatric population. *Clin Pediatr (Phila)*. 2010. [Epub ahead of print. PMID: 20139107]
Shih WH, Tseng FY, Yeh TH et al. Outcomes of facial palsy in children. *Acta Otolaryngol*. 2008:1. [Epub ahead of print. PMID: 18923943]
Wang CH, Chang YC, Shih HM et al. Facial palsy in children: emergency department management and outcome. *Pediatr Emerg Care*. 2010;26(2):121. [PMID: 20093994]
Woollard AC, Harrison DH, Grobbelaar AO. An approach to bilateral facial paralysis. *J Plast Reconstr Aesthet Surg*. 2010. [Epub ahead of print. PMID: 20206590]

8. Perinatal Facial Palsy

Traumatic Perinatal Facial Palsy

Intrauterine trauma to the facial nerve may occur as a consequence of compression from the maternal sacrum. Prolonged labor and forceps delivery may produce facial nerve trauma. The extratemporal facial nerve is at risk because the absence of an overlying mastoid tip places the vertical segment of the nerve at risk for injury. A traumatic cause of the facial nerve dysfunction is suggested by hemotympanum, periauricular ecchymosis, and the progressive decline of facial nerve responsiveness to an applied stimulus.

The assessment of perinatal facial nerve dysfunction relies heavily on electrodiagnosis. Electromyographic evidence of preserved or declining neuromuscular activity is most diagnostic. In the absence of such activity, muscle biopsy may be required to determine whether a congenital palsy exists.

A review of the etiologic basis for facial palsy in 95 newborns indicated that a traumatic etiology was suspected in 74 cases (78%), as suggested by signs of periauricular injury or electrical testing (evoked and spontaneous electromyography). There was excellent recovery in 41 of 45 children with perinatal trauma. Occasional cases of poor recovery, however, suggest the need for a radiographic and electrodiagnostic evaluation in order to detect an unfavorable prognosis for spontaneous recovery. In such cases, surgical exploration and decompression of the nerve may be critical for effective reanimation.

May M, Fria RJ, Blumenthal F et al. Facial paralysis in children: differential diagnosis. *Otolaryngol Head Neck Surg*. 1981;89:841. [PMID: 6799919] (The differential diagnosis in 170 patients with facial paralysis between birth and 18 years of age is reviewed in this manuscript, and symptoms and signs associated with each diagnosis are presented.)

Saito H, Takeda T, Kishimoto S. Neonatal facial nerve defect. *Acta Otolaryngol Suppl.* 1994;510:77. [PMID: 8128879]

Congenital Perinatal Facial Palsy

Newborn facial palsy unrelated to trauma accounts for a smaller proportion of cases than does traumatic facial palsy. Both syndromic and nonsyndromic forms of congenital facial palsy occur. The palsy may be complete or incomplete, unilateral or bilateral, and isolated to particular branches. Associated craniofacial malformations, often those involving first and second branchial arch derivatives, are common. Microtia and facial clefts are most frequently noted. Palsies isolated to a single branch, particularly the marginal mandibularis, indicate the need for a cardiac evaluation in light of a high rate of concurrent cardiac conductive and anatomic anomalies.

Otologic, electrodiagnostic, and radiological evaluations are performed, as necessary, to determine the etiology. A congenital neuromuscular etiology is suggested by a concomitant defect (or defects) involving other cranial nerves and the absence of evidence of electrical responsiveness to evoked and spontaneous electromyographic evaluation.

The Möbius syndrome encompasses a wide spectrum of anomalies due to dysgenesis at the level of the brain stem with resultant neuromuscular deficits peripherally. The bilateral absence of facial and abducens nerve function, as well as other cranial neuropathies, may occur. The auditory brainstem response is often abnormal and is a helpful adjunct in diagnosis.

The prognosis for effective facial animation with congenital facial palsies is poor. However, resting tone may provide adequate eye coverage and oral competence even into adulthood. Facial motor rehabilitative procedures and reconstructive procedures to affect better symmetry may be indicated later in life.

Bianchi B, Copelli C, Ferrari S, Ferri A, Sesenna E. Facial animation in children with Moebius and Moebius-like syndromes. *J Pediatr Surg*. 2009;44(11):2236. [PMID: 19944241]

Bogart KR, Matsumoto D. Living with moebius syndrome: adjustment, social competence, and satisfaction with life. *Cleft Palate Craniofac J*. 2010;47(2):134. [PMID: 20210634]

Cattaneo L, Chierici E, Bianchi B, Sesenna E, Pavesi G. The localization of facial motor impairment in sporadic Möbius syndrome. *Neurology*. 2006;66(12):1907. [PMID: 16801658]

Harris JP, Davidson TM, May M et al. Evaluation and treatment of congenital facial paralysis. *Arch Otolaryngol.* 1983;109:145. [PMID: 6824481] (In this paper, the authors recommend that the auditory brain-stem response test be included in the initial evaluation of patients with congenital facial paralysis.)

Sudarshan A, Goldie WD. The spectrum of congenital facial diplegia (Möbius syndrome). *Pediatr Neurol*. 1985;1(3):180. [PMID: 3880403] (This manuscript reviews Möebius syndrome, congenital facial diplegia with associated anomalies, and includes six cases that manifest a very broad spectrum of associated neurological anomalies.)

Reanimation of the Paralyzed Face

71

Ritvik P. Mehta, MD

General Considerations

Facial paralysis can result from a wide variety of etiologies including infectious, neurologic, congenital, neoplastic, traumatic, systemic, and iatrogenic causes. Regardless of cause, the management of facial paralysis is complex and often requires multidisciplinary intervention. The evaluation and treatment of facial paralysis is especially intricate because of the wide variation in the potential for regeneration and lack of reliable prognostic indicators for spontaneous recovery. Current management of facial paralysis consists of a combination of pharmacologic therapy, physical therapy for facial neuromuscular retraining, and surgical intervention via dynamic and static techniques for facial reanimation. This chapter will focus on the wide variety of surgical therapies available to the reconstructive surgeon for successful facial reanimation.

TREATMENT

ESSENTIALS OF DIAGNOSIS

- Cause and duration of facial paralysis determine appropriate treatment
- The choice of reanimation procedure is primarily limited by the duration of facial paralysis.

Surgical Management of Acute Facial Paralysis (<3 weeks)

Any surgical intervention for facial paralysis must carefully take into account the patient's age, medical history, residual hearing, segment of nerve injured, and the patient's expectations and risk tolerance. Management of acute facial paralysis may involve facial nerve decompression surgery in cases of virally induced facial paralysis (Bell's palsy, Ramsay–Hunt syndrome) or traumatic facial paralysis. Primary facial nerve repair/grafting is undertaken in cases of resection or transection of the facial nerve.

A. Facial Nerve Decompression

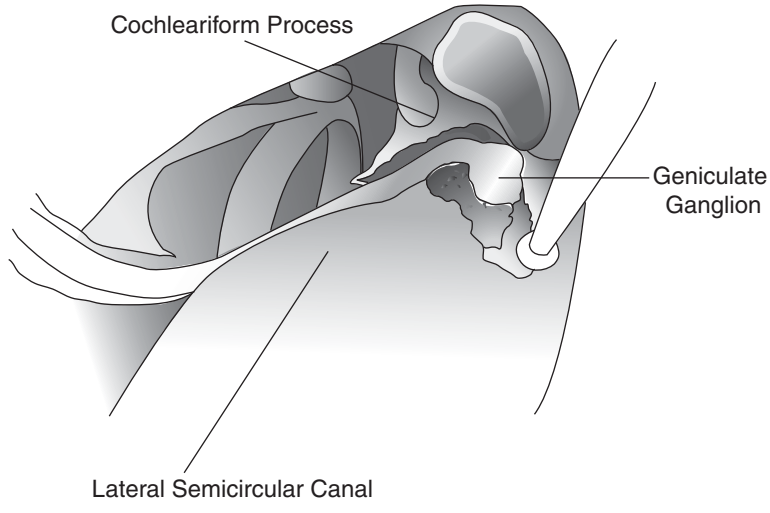
1. Transmastoid approach—The transmastoid approach for facial nerve decompression (Figure 71–1) can be utilized when the trauma is clearly localized to the tympanic or mastoid segments of the facial nerve. The nerve should be decompressed for 180° of its circumference. Important landmarks for this approach include the lateral semicircular canal, fossa incudis, and digastric ridge. The incus can be removed and then replaced as an interposition graft to achieve decompression of the tympanic segment of the facial nerve all the way to the geniculate ganglion.

2. Middle fossa approach—The middle fossa approach allows decompression of the facial nerve when the injury extends to the labyrinthine segment. It is sometimes used in combination with the transmastoid approach in cases of temporal bone trauma. Critical landmarks for this approach include the superior semicircular canal, the greater superficial petrosal nerve, and "Bill's bar" or the vertical crest separating the facial nerve from the superior vestibular nerve.

3. Translabyrinthine approach—The translabyrinthine approach can be utilized for decompression of the entire intratemporal course of the facial nerve in cases where cochleovestibular function is absent or has been destroyed by the trauma.

B. Facial Nerve Repair

1. Primary nerve repair—Primary neurroraphy provides the best return of facial nerve function. However, the primary repair should be tension free. This sometimes necessitates rerouting or mobilization of the adjacent facial nerve



▲ **Figure 71–1.** Transmastoid decompression of the facial nerve, left ear, with decompression of the geniculate ganglion (with permission Sofferman RA. Ch. 36 Facial Nerve Injury and Decompression. *Surgery of the Ear and Temporal Bone,* Lippincott Williams and Wilkins, 2005).

segments in order to provide a tension-free anastomosis. It is important to note that the distal nerve segments can be identified intraoperatively by electrical stimulation for up to 72 hours after nerve transection or injury, making early repair critical. Most authors today recommend epineurial repair of the facial nerve as suture placement with fascicular or perineurial repair is difficult and may injure the axons.

2. Cable grafting—Cable nerve grafts are utilized when a tension-free primary nerve repair is not possible. Popular choices for donor nerve grafts include: great auricular nerve, sural nerve, and the medial and lateral antebrachial cutaneous nerves. The ansa cervicalis has been used as a donor nerve as well as there may be some evidence that motor nerve grafts are better than sensory nerve grafts. With either primary nerve repair or cable grafting, it is generally accepted that the best possible outcome is House–Brackmann Grade III facial function.

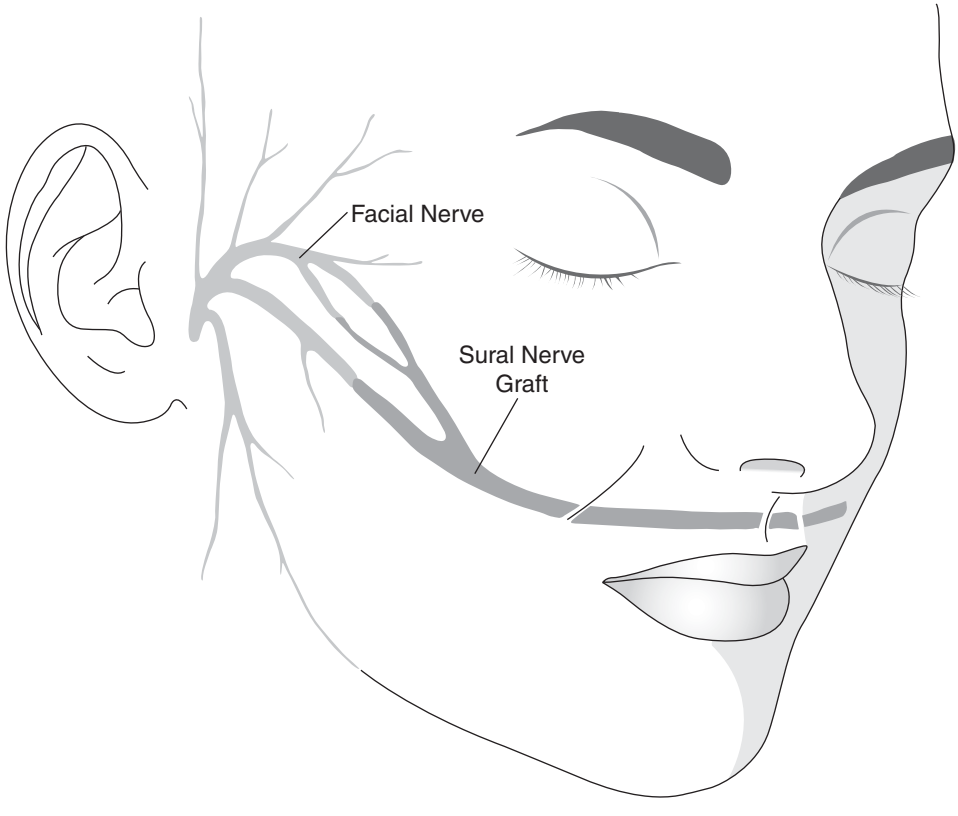
Chu TH, Du Y, Wu W. Motor nerve graft is better than sensory nerve graft for survival and regeneration of motoneurons after spinal root avulsion in adult rats. *Exp. Neurol*. 2008;212(2):52–55
Hadlock TA et al. Multimodality approach to management of the paralyzed face. *Laryngoscope*. 2006;116:1385–1389
Humphrey CD, Kriet JD. Nerve repair and cable grafting for facial paralysis. *Facial Plastic Surg*. 2008;24(2):170–176
Melvin TA, Limb CJ. Overview of facial paralysis: Current concepts. *Facial Plast Surg*. 2008;24(2): 155–163
Sofferman RA. Ch. 36 Facial nerve injury and decompression. *Surgery of the Ear and Temporal Bone*. Lippincott Williams and Wilkins, 2005.

C. Surgical Treatment of Intermediate Duration Facial Paralysis (3 weeks to 2 years)

The treatment of intermediate duration facial paralysis typically occurs in the setting of an anatomically intact facial nerve that has not recovered well. For example, facial paralysis after acoustic neuroma surgery in which the nerve is often intact but can have poor recovery due to stretch injury. Nerve transfers and nerve crossover procedures are typically the treatment of choice in this period as the native facial musculature is still viable.

1. Nerve transfers and cross-facial nerve grafting—Cross-facial nerve grafting can be utilized if the contralateral facial nerve is intact and functional. Terzis et al believe that the best outcomes from cross facial nerve grafting are if the period of denervation is less than 6 months. The surgical technique is a two-stage procedure. In the first stage, a modified preauricular face-lift incision is utilized on the normal, functional side of the face. After elevation of a skin flap anteriorly to the level of the lateral canthus, the superficial muscular aponeurotic system layer is penetrated anterior to the parotid gland and the branches of the facial nerve are identified using a nerve stimulator. Nerve branches are carefully selected for sacrifice depending on the desired innervations function and mapping of the innervations targets of each branch. A long sural nerve graft is tunneled to the contralateral face and the donor facial nerve branches are then sacrificed. Under magnification, the proximal end of the sural nerve graft is then coapted to the donor facial nerve branches (Figure 71–2). After a waiting period of 9 to 12 months, the second stage can be undertaken. In the second stage, secondary neurorraphies are performed between selected facial nerve branches and the cross face nerve grafts. Historically, however, cross-face nerve grafting has been fraught with unreliable outcomes. If the period of denervation is longer than 2 years, cross facial nerve grafting can be utilized in conjunction with free muscle transfer for smile reanimation as a more reliable procedure (discussed below).

Nerve transfer procedures have been described using a variety of donor nerves: hypoglossal, spinal accessory, masse-



▲ **Figure 71–2.** Coaptation of the sural nerve graft to the donor facial nerve branches anterior to the parotid gland followed by tunneling of the sural nerve graft to the contralateral paralyzed side of the face (with permission: Hadlock TA, Cheney ML, McKenna MJ. Chapter 38 Facial Reanimation Surgery. *Surgery of the Ear and Temporal Bone.* Lippincott Williams and Wilkins, 2005).

teric branch of the trigeminal nerve and motor branches of the cervical plexus. The most commonly used procedure is the hypoglossal—facial transfer. The classic XII–VII transfer involves transection of the entire hypoglossal nerve distal to the ansa cervicalis and coaptation to the main trunk of the facial nerve. Several modifications have been described (Figure 71–3).

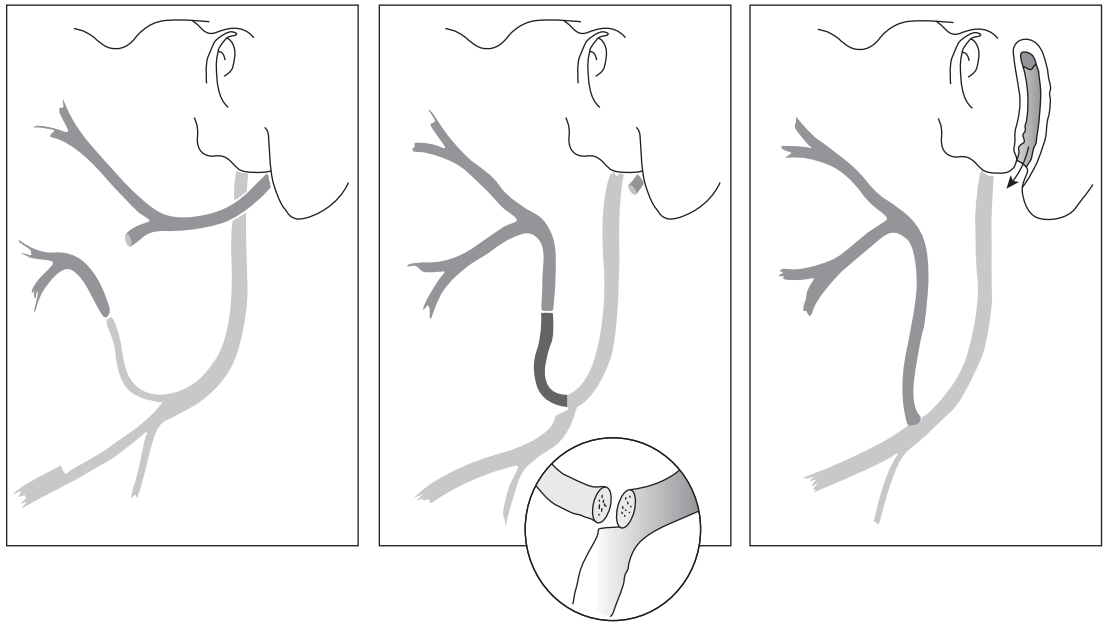
- "*Split*" *XII–VII transfer*: Approximately 30–40% of the hypoglossal nerve is divided longitudinally for several centimeters and approximated to the lower division of the facial nerve.
- *XII–VII jump graft*: End-to-side neurorrhaphy between hypoglossal nerve and a donor cable nerve graft (eg, great auricular nerve) which serves as a jump graft to the main trunk of the facial nerve.
- *Mobilization of mastoid segment of facial nerve*: The facial nerve can be mobilized in its mastoid segment from the second genu distally and rotated inferiorly to allow for direct coaptation to the hypoglossal nerve. This typically requires removal of the mastoid tip.

Hadlock TA, Cheney ML, McKenna MJ. Chapter 38 Facial reanimation surgery. *Surgery of the Ear and Temporal Bone*. Lippincott Williams and Wilkins, 2005.
Tai CY, Mackinnon S. Surgical options for facial reanimation. *Missouri Medicine*. 2006;103(3): 270–274
Terzis JK, Konofaos P. Nerve transfers in facial palsy. *Facial Plast Surg*. 2008;24(2): 177–193

SURGICAL TREATMENT OF CHRONIC FACIAL PARALYSIS (>2 YEARS)

ESSENTIALS OF DIAGNOSIS

- For chronic facial paralysis, muscle transfer (regional or free) is required for smile reanimation.
- Cross face nerve grafting in conjunction with free muscle transfer achieves involuntary, mimetic smile reanimation.



▲ **Figure 71–3.** Modifications of the hypoglossal-facial transfer. Left panel—Split XII–VII transfer; Center panel: XII–VII jump graft; Right panel—Mobilization of mastoid segment of VII (with permission: Hadlock TA, Cheney ML, McKenna MJ. Chapter 38 Facial Reanimation Surgery. *Surgery of the Ear and Temporal Bone,* Lippincott Williams and Wilkins, 2005).

In most cases of chronic facial paralysis of greater than 2 years duration, the native facial musculature has atrophied and requires the use of alternative muscles for facial reanimation. Muscle transfer techniques, including regional and free muscle transfer, are the mainstay of dynamic facial reanimation for chronic facial paralysis.

Static techniques for facial reanimation (such as oculoplastic procedures, eyelid weights, static facial suspension, etc) can be utilized for facial paralysis of any duration and will be discussed in the following.

Regional Muscle Transfer

The temporalis muscle transfer is the most commonly utilized regional muscle transfer for dynamic facial reanimation. Preoperatively, it is important to ensure that the patient has normal trigeminal nerve function and that the muscle is not atrophic. In the classic temporalis muscle transposition, a 1.5–2.0 cm wide strip of temporalis muscle is elevated from the cranium and rotated inferiorly over the zygoma to reach the oral commissure. The vector of this rotation is favorable because it is typically in the smile vector. A variety of techniques have been described for filling in the depression in the temple created by the muscle transfer including alloplastic implants, fat grafting, and use of the temporoparietal fascial flap for obliteration of the defect. A number of modifications of the temporalis transfer have been described.

- *Fascial extensions to the upper and lower lip*: Sherris et al have described the use of split fascia graft extensions to the upper and lower lip in order to allow the temporalis muscle transfer to pull the philtrum and lower lip back to the midline.
- *Temporalis tendon transfer*: In this technique, the temporalis tendon at the coronoid process is disarticulated and pulled down to the oral commissure. This technique avoids the midfacial bulkiness over the zygoma as well as eliminating the depression in the temporal fossa from classic temporalis muscle transposition. This technique can be performed via an open preauricular transzygomatic approach or a minimally invasive transbuccal approach through a nasolabial fold incision.

Other regional muscle transfers that have been described include the masseter muscle transfer for smile reanimation and the digastric muscle transfer for marginal mandibular nerve injuries. The masseteric muscle transfer is considered inferior to the temporalis muscle transfer because of its more lateral vector of pull.

Free Muscle Transfer

The field of facial reanimation has made a dramatic advance with the advent of microvascular free tissue transfer. Free muscle transfer can be utilized if the native facial musculature

has been resected, in cases where there is concurrent trigeminal nerve dysfunction precluding use of regional muscle transfer, and as the only reliable way of achieving involuntary, mimetic smile reanimation when used in conjunction with cross-face nerve grafting. A wide variety of muscles have been described for use in the treatment of facial paralysis including the gracilis, pectoralis minor, serratus anterior, latissimus dorsi, and others. The workhorse of free muscle transfer for facial reanimation remains the gracilis muscle. The gracilis muscle is a long, thin muscle located in the medial thigh (Figure 71–4A). It is easily harvested and provides an excellent neurovascular pedicle. Its location in the medial thigh permits the use of a two-team approach with one team for flap harvest and one team for preparation of the recipient site. For unilateral facial paralysis, the gracilis muscle transfer is typically done in two stages. In the first stage, a cross-face nerve graft is performed using a sural nerve graft as described above. After 6–12 months, the second stage is performed wherein the gracilis muscle is harvested and transferred to the paralyzed side of the face. Vascular anastomoses are performed to the facial artery and vein or to the superficial temporal vessels. The obturator nerve to the gracilis muscle is coapted to the distal end of the sural nerve graft placed at the first stage (Figure 71–4B). Typically, movement of the muscle is detected by six months but may take up to 1 year or longer.

In cases of bilateral facial paralysis (eg, Mobius syndrome), the gracilis-free muscle transfer can be performed as a single stage. In these cases, where there no cross-facial nerve grafting available, the masseteric branch of the trigeminal nerve is used as the donor nerve to drive the gracilis muscle. For bilateral cases, gracilis muscle transfer can be performed sequentially or simultaneously for both sides.

Boahene KDO. Dynamic muscle transfer in facial reanimation. *Facial Plastic Surg*. 2008;24(2):204–210
Chuang DC. Free tissue transfer for the treatment of facial paralysis. *Facial Plastic Surg*. 2008;24(2):194–203

Static Techniques for Facial Reanimation (can be utilized at any duration of facial paralysis)

There are significant benefits to static techniques of facial reanimation that can provide an alternative to or enhance the results of dynamic facial reanimation. Static techniques can be utilized in chronic facial paralysis or also for temporary facial paralysis when nerve recovery is expected. Static techniques for facial reanimation will be described for the upper and lower zones of the face.

A. Brow Ptosis Correction

Brow ptosis correction is an important part of management of the facial paralysis patient. A variety of treatment approaches have been described: direct brow lift (coronal, midforehead, or brow incision), endoscopic brow lift, or minimally invasive temporal brow lift using a biodegradable stabilization device (ENDOTINE; Coapt Systems Inc, Palo Alto, CA).

B. Management of the Eye

Oculoplastic management of the paralyzed eye is of paramount importance as exposure keratitis can lead to permanent visual loss. The upper eyelid can be managed with the following procedures as needed.

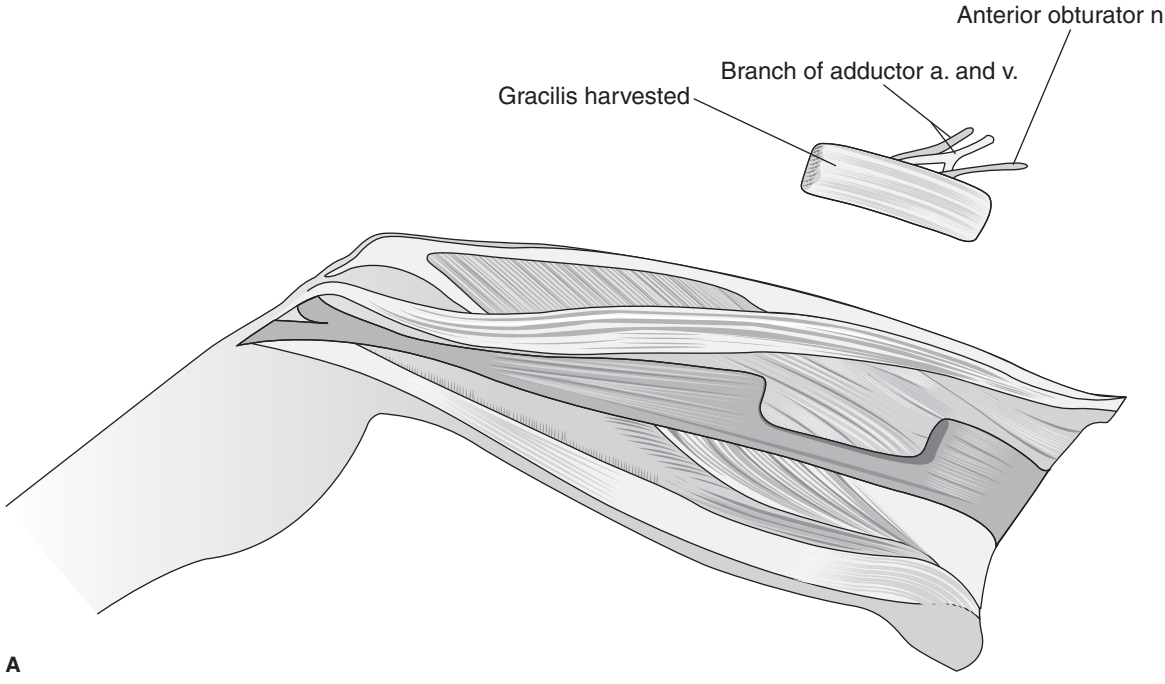
- *Eyelid weight placement*: Lid loading via placement of a gold or platinum weight is a very effective technique for correction of lagopthalmos. Thin profile platinum weights are becoming increasingly popular as they offer a better cosmetic outcome and decreased incidence of allergy as compared with gold implants.
- *Palpebral spring procedure*: The palpebral spring procedure is a technically difficult procedure that can be employed in lieu of an eyelid weight for lagopthalmos correction. The spring spans between the superior orbital rim periosteum and a pocket at the superior aspect of the tarsus.
- *Upper eyelid blepharoplasty*: In patients with significant dermatochalasis, conservative upper lid blepharoplasty can be performed to remove the excess skin.
- *Lateral tarsorrhaphy*: A permanent "reversible" lateral tarsorrhaphy can be performed using mattress sutures placed to coapt the lateral aspects of the upper and lower lid tarsal plates. Tarsorrhaphies are typically used in cases of exposure keratitis or in cases where there is loss of the corneal sensation in addition to lagopthalmos.

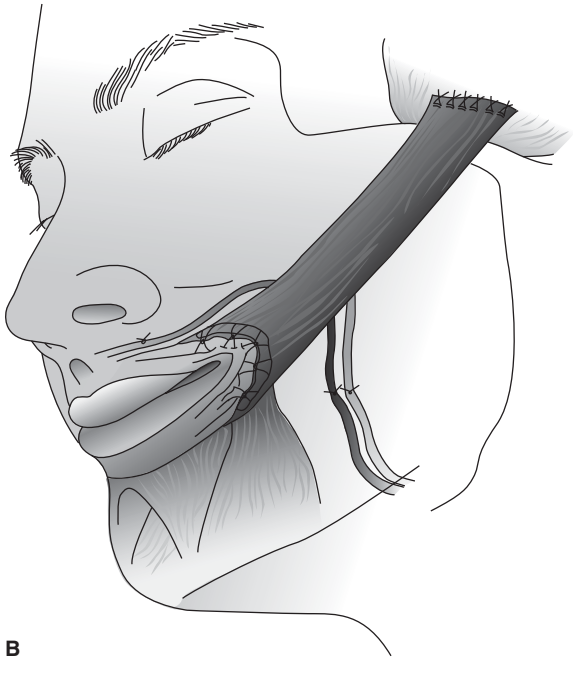
The lower eyelid is managed with the following procedures as needed.

- *Lateral tarsal strip procedure*: The lateral tarsal strip procedure is a powerful technique that can be used to address paralytic lower lid ectropion. In this technique, a lateral canthotomy is performed followed by inferior crus cantholysis. The lower tarsus is trimmed and sutured directly to the lateral orbital rim periosteum.
- *Medial canthopexy*: Medial paralytic ectropion of the lower eyelid is treated using a precaruncular medial canthopexy technique in which the medial tarsus is sutured to the periosteum of the lamina papyracea.

C. Nasolabial Fold Modification

Patients with effacement of the nasolabial fold or patients with overprominent nasolabial folds can be treated with a simple suture technique to create or efface the nasolabial fold crease.





▲ **Figure 71–4A.** Harvest of gracilis muscle from the medial thigh. **(B).** Inset of gracilis muscle in the paralyzed side of the face with vascular anastomosis to the facial artery and vein and neurorrhaphy of the obturator nerve to the cross-face nerve graft (with permission: Hadlock TA, Cheney ML, McKenna MJ. Chapter 38 Facial Reanimation Surgery. *Surgery of the Ear and Temporal Bone.* Lippincott Williams and Wilkins, 2005).

D. Static Facial Suspension

Static facial slings for facial support are typically placed from the zygomatic arch/temporalis fascia to the oral commissure and nasolabial fold. A number of materials have been described for use as the sling material including fascia lata, Gore-Tex, and AlloDerm. In addition, multivector suture techniques have also been described for facial suspension.

E. External Nasal Valve Repair

An often overlooked aspect of the patient with facial paralysis is external nasal valve collapse. This can be treated with a fascia lata sling from the alar base to the zygoma/temporalis fascia to stent open the external nasal valve.

Bergeron CM, Moe KS. The evaluation and treatment of upper eyelid paralysis. *Facial Plastic Surg*. 2008;24(2):220–230
Bergeron CM, Moe KS. The evaluation and treatment of lower eyelid paralysis. *Facial Plastic Surg*. 2008;24(2):231–241
Fay A, Rubin PA. Chapter 39 Oculoplastic considerations and management of facial paralysis. *Surgery of the Ear and Temporal Bone*. Lippincott Williams and Wilkins, 2005.

Table 71–1. Surgical Treatment Options for Acute, Intermediate, and Chronic Facial Paralysis.

Acute Facial Paralysis (<3 Weeks)	Intermediate-Duration Facial Paralysis (3 Weeks to 2 Years)	Chronic Facial Paralysis (>2 Years)
Facial nerve decompression Transmastoid Middle-fossa Translabyrinthine	Cross-face nerve grafting	Regional muscle transfers Temporalis Masseter Digastric
Facial nerve repair Primary Cable graft	Nerve Transfers Hypoglossal Masseteric Spinal accessory	Free muscle transfer Gracilis Serratus anterior Latissimus dorsi Pectoralis minor

Table 71–2. Static Facial Reanimation Techniques[a].

Static Techniques of Facial Rehabilitation
Brow ptosis correction
Management of the upper eyelid Eyelid weight placement Lateral tarsorrhaphy Palpebral spring procedure Upper eyelid blepharoplasty
Management of the lower eyelid Lateral tarsal strip procedure Medial canthopexy
Nasolabial fold modification
Static facial suspension
External nasal valve repair

[a]These Can be Performed for Acute, Intermediate, or Chronic Facial Paralysis as Needed.

Liu YM, Sherris DA. Static procedures for the management of the midface and lower face. *Facial Plastic Surg*. 2008; 24(2): 211–215
Meltzer NE, Byrne PJ. Management of the brow in facial paralysis. *Facial Plastic Surg*. 2008;24(2):216–219

Discussion

The reconstructive surgeon has a wide array of surgical treatment options for management of the patient with facial paralysis (Table 71–1). An organized, thoughtful approach is necessary when evaluating patients with facial paralysis to ensure that no obvious treatment choices are overlooked. For acute facial paralysis, the main surgical therapies are facial nerve decompression and facial nerve repair. For facial paralysis of intermediate duration, nerve transfer procedures are appropriate. For chronic facial paralysis, treatment typically requires regional or free muscle transfer. It is important to remember that static techniques of facial reanimation can be used for acute, intermediate, or chronic facial paralysis as these techniques are often important adjuncts to the overall management strategy (Table 71–2).

72 Scar Revision

Nathan Monhian, MD, FACS & Anil R. Shah, MD, FACS

General Considerations

With advances in the knowledge of wound healing, as well as the development of better materials and techniques, many options have become available in the treatment of patients with unsightly scars. Nevertheless, no technique has been devised to allow for total and permanent elimination of scars. Patients should be counseled to understand that the goal of scar revision is to replace one scar for another to improve the appearance and the acceptability of the scar.

The wound healing process is divided into three stages. In the **inflammatory phase**, the release of inflammatory mediators results in migration of fibroblasts into the wound. During the **proliferative phase**, an extracellular matrix is formed that comprises proteoglycans, fibronectin, hyaluronic acid, and collagen secreted by fibroblasts. Angiogenesis and re-epithelialization of the wound also occur during the proliferative phase. Collagen and the extracellular matrix mature in the **remodeling phase**, and the wound contracts. Wound strength reaches 20% of its preinjury strength at 3 weeks. The ultimate tensile strength of the wound is 70–80% of that of the uninjured skin.

Pathogenesis

A. Genetic Factors

Genetic factors contributing to poor scar formation are likely to be present in patients with Fitzpatrick skin Types III and above. Darker skins tend to form postinflammatory hyperpigmentation and are more likely to form keloids or hypertrophic scars. Younger skin has more tensile strength, which can lead to widening of the scar, whereas older skin tends to scar better because of a lesser amount of tension on the wound.

B. Iatrogenic Causes

Iatrogenic causes of poor scar formation include excessive soft tissue trauma while handling the skin, failure to reapproximate and evert the wound edges properly, and closure under excessive tension. Failure to evert the wound edges at the time of closure leads to formation of a depressed scar. Lack of deep support of the wound can lead to excessive tension on wound edges, resulting in a widened scar. Sutures from facial wounds should be removed after 5–7 days. Removing sutures too early or too late may lead to a wide scar or unsightly tracking, respectively. Early treatment with steroids or isotretinoin (Accutane) can adversely affect wound healing. It is recommended that laser resurfacing procedures or elective surgery, especially on the face, be delayed for at least 12–18 months after completing a course of isotretinoin.

C. Hypertrophic Scar, Keloids, and Widened Scars

Hypertrophic scars are self-limited scars, which hypertrophy within the limits of the wound but above the skin level. Hypertrophic scars are more common than keloids and occur without race predilection and in any age group. Initially, these scars are red, raised, pruritic, and occasionally painful, but they tend to flatten over time. They appear worse at 2 weeks to 2 months after wound closure. In general, hypertrophic scars are more responsive to steroid injections than are keloids.

Keloid scars can be distinguished from hypertrophic scars by spreading beyond the original wound. Keloids have a distinct race predilection to darker skins and occur most often in patients who are 10–30 years old. In contrast to hypertrophic scars, keloid scars remain raised, red, pruritic, and occasionally painful rather than regressing at a few months.

Widened scars are typically flat and depressed and do not have an erythematous or pruritic phase. They occur without race or age tendency and occur most frequently on the body. Wound color typically improves to match the uninjured skin with time.

Histologically, the collagen in both keloids and hypertrophic scars is organized in discrete nodules, frequently obliterating the rete pegs in the papillary dermis of the lesions. While collagen in normal dermis is arranged in discrete

fascicles separated by considerable interstitial space, collagen nodules in keloids and in hypertrophic scars appear avascular and unidirectional and are aligned in a highly stressed configuration. Collagen synthesis is greater in keloids than hypertrophic scars. Collagen synthesis is three times greater in keloids than hypertrophic scars and 20 times greater than in normal scars. Keloids immunochemically demonstrate a greater tissue concentration of immunoglobulin G (IgG) relative to hypertrophic scars and normal skin. Disagreement exists about whether hypertrophic scars can be differentiated from keloids using light microscopy. Blackburn and Cosman described eosinophilic refractile hyaline collagen fibers, an increase in mucinous ground substance, and a lack of fibroblasts in keloids. Scanning electron microscopy findings clearly demonstrate the randomly organized sheets of collagen with no obvious relationship to the skin surface in keloid scar formation.

Clinical Findings

Skin is anisotropic and nonlinear and has time-dependent properties. The term **anisotropic** indicates that the mechanical properties of skin vary with direction. The **relaxed skin tension lines** (RSTLs) are the lines of minimal tension of the skin; incisions parallel with these lines are under the least possible tension while healing. Perpendicular to the RSTLs are the lines of maximal extensibility. A fusiform excision parallel with the RSTLs and closed in the direction of the lines of maximal extensibility heals under minimal closing tension and results in the best scar.

Complications

Complications of scar revision vary according to the method used. These include local infection, graft or flap necrosis, and further scarring after the revision. Viral reactivation of the herpes zoster virus is a potential complication after dermabrasion or laser resurfacing. Laser resurfacing can also cause postinflammatory hyperpigmentation, which may last several months, or hypopigmentation, which may be difficult to treat. Resurfacing methods that go beyond the deep reticular dermis can cause further scarring instead of improving a scar.

Treatment

A. Nonsurgical Measures

1. Intralesional agents—For many years, corticosteroid injection has been established in the reduction of hypertrophic scars and keloids. Common preparations include triamcinolone acetonide (Kenalog) and triamcinolone diacetate (Aristocort). Steroids decrease fibroblast proliferation, reduce blood vessel formation, and interfere with fibrosis by inhibiting extracellular matrix protein gene expression (downregulates pro-α_1 collagen gene). By decreasing the production of collagen, a smaller scar is created. Doses ranging from 5 mg/mL to 40 mg/mL are injected at 3- to 6-week intervals. Typically, multiple injections are required to obtain the desired benefit. Complications of steroid injection include atrophy of the subcutaneous layer, granuloma formation, pigmentary changes, and development of telangiectasias.

New intralesional treatments have included the use of antimitotic agents such as bleomycin and 5-fluorouracil (5-FU). Small doses of these drugs may be injected into hypertrophic scar tissue with good results. Intralesional injections of 5-FU in combination with triamcinolone acetonide plus concomitant use of a pulsed-dye laser have had good results. Injections can be performed as frequently as three times per week. Injections of bleomycin into a keloid using a multipuncture technique have also shown some promise in scar flattening and preventing recurrence. Antimitotic medications should not be administered to pregnant women.

2. Soft tissue fillers—Atrophic and depressed scars may also be treated with injectable fillers in an attempt to provide bulk in areas of tissue deficiency. The most commonly used agents include nonanimal stabilized hyaluronic acid (Restylane, Juvederm, Captique, Elevess), animal based hyaluronic acid (Hylaform), hydroxyapatite (Radiesse), bovine collagen (Zyderm, Zyplast), pooled human collagen (micronized AlloDerm or Cymetra, CosmoDerm, CosmoPlast), autologous dermis, and fat. These biologically derived materials provide temporary correction (2–12 months). Synthetic materials such as expanded polytetrafluoroethylene (e-PTFE, GoreTex, SoftForm, UltraSoft, Advanta) may also be used to provide a filling effect in depressed areas. Injectable Fibrel and silicone are no longer in widespread use.

3. Silicone sheeting, hydration, and compression—Silicone has been used with relative success in the management of hypertrophic scars, although its mechanism of action is not clearly understood. Although it was initially hypothesized to work through pressure over the scar tissue, the efficacy of silicone has been demonstrated even in nonpressure dressings. It appears that hydration, or rather the ability of silicone to prevent wound desiccation, is a contributing mechanism. Hydration inhibits the in vitro production of collagen and glycosaminoglycans by fibroblasts. Silicone sheeting can be worn daily for as long as 12–24 hours daily, although its application is somewhat cumbersome. An alternative to silicone sheeting, silicone gel can be applied onto the scar. Both silicone gel and silicone sheeting have shown positive results in the reduction of scar size and erythema.

Continuous pressure at 80 mm Hg provided by tight-fitting dressings has been shown to prevent and modify scar formation. The potential mechanisms of action are local tissue hypoxia and reduction of the intralesional population of mast cells, which may affect fibroblast growth.

4. Pulsed-dye laser—The pulsed-dye 585-nm-wavelength laser can be effective in reducing scar erythema by reducing

neovascularization. Several treatments are usually required using a low to moderate fluence (5.0–7.0 J/cm^2) with no overlap. Hypertrophic scars may also shrink with this treatment as a result of a reduction in the number and activity of fibroblasts.

5. Dermabrasion—Raised, depressed, or hyperpigmented scars may benefit from superficial abrasion of the skin, which blends the scar with its surrounding tissue by changing the texture, color, and depth of the scar. The technique of resurfacing depends on the nature of the deformity. The goal of this technique is to even out any uneven surfaces. The depth of the dermabrasion depends on the depth of the scar. However, dermabrasion should not go beyond the reticular dermis; otherwise, greater scarring or hypopigmentation will result.

6. Laser resurfacing—Laser resurfacing has replaced mechanical dermabrasion in many practices. One advantage of laser resurfacing over mechanical dermabrasion is that the depth of penetration is easier to control. Another advantage is that there is no aerosolization of skin and blood, thereby lowering the risk of viral transmission. The thermal damage that results from laser resurfacing is advantageous in that it produces collagen contracture of 20–60%. However, the postoperative period of laser resurfacing is marked by prolonged erythema. The most common lasers in use for resurfacing are the high-energy pulsed CO_2 laser, which produces photothermal injury, and the erbium:YAG laser, which results in photomechanical injury to the skin. Combining different laser modalities, such as the pulsed-dye and CO_2 lasers, may provide an added advantage in scar improvement.

Fractional laser resurfacing (Fraxel SR) has been in use in treatment of scars, as well as dyschromia and poor skin texture. This approach is based on fractional photothermolysis. Unlike in CO_2 laser resurfacing, the fractionated method creates patterns of microscopic laser spots of 70 to 100 μm in diameter, called microthermal zones. Each laser spot is surrounded by healthy tissue, and most melanocytes and stem cells in papillary dermis are spared. This method avoids many of the side effects associated with traditional laser resurfacing and results in rapid re-epithelialization of the dermis and collagen remodeling. A recent survey of patients undergoing fractionated resurfacing shows great satisfaction among patients who had the procedures for deep acne scars.

7. Camouflage—Many patients who seek scar revisions may not be able to camouflage the scar or have minimal knowledge of available camouflage techniques. Makeup, hair, and accessories can sometimes offer excellent coverage of the scar. Newer makeup materials and techniques allow for better and more complete coverage of unsightly defects. Opaque cosmetics with a slightly low tone, which disguises the erythema of scars, generally provide better results.

B. Preoperative Considerations

1. Patient expectations—As with any cosmetic procedure, the patient's motivations and expectations for seeking corrective surgery should be carefully considered. In general, well-informed patients with realistic expectations have better overall outcomes. A patient should understand that scar revision is a process to improve the appearance of the scar by adjusting, repositioning, or narrowing the scar and that complete elimination of the scar is impossible at this point. However, the physician should be sensitive to the fact that the scar may represent a traumatic experience to the patient. If the revision does not meet the patient's expectations, the patient may suffer additional trauma. Occasionally, psychological counseling should be recommended in conjunction with scar revision.

2. Timing of scar revision—Scars in the inflammatory phase are prone to hypertrophy. The initial scar can be expected to change due to collagen remodeling and collagen fiber reorientation. Although collagen remodeling continues for 1–3 years, most significant changes occur in the first 4–6 months, and an average of 6 months' delay before revision is reasonable. Nevertheless, in clinical situations, where skin edges are grossly misaligned or the scar lies in an unfavorable direction, scar revision may prove beneficial as early as 2 months.

3. Scar analysis—Before embarking on a revision, the primary scar, and its desired location when revised, should be carefully analyzed. Scars can be classified according to their location, etiology, size, shape, contour, and color. Cosmetically favorable scars are similar in color to the surrounding tissue. They are also fine, flat, and well positioned in the face. Scars that are located in the periphery of the face, at a transition line between two cosmetic subunits, or directly in the midline are less conspicuous. The lack of one or more of these qualities results in an unsightly scar. Noticeable scars are wide, raised, or depressed, or are often hyperpigmented or hypopigmented compared with the adjacent skin. They may cut across different subunits or lie in an unfavorable direction. A scar contracture in sensitive areas—for example, at the vermilion or the eyelid—can distort adjacent structures and create cosmetic or functional deformities.

C. Surgical Measures

Appropriate scar management begins at the time of injury. Good surgical technique is essential for normal wound healing. Crushing the skin edges, tying sutures too tightly, and cauterizing too excessively may result in local tissue inflammation, necrosis, and poor scarring. Adequate wound humidity and coverage are also important for minimizing scar formation. Studies suggest that epithelial cells migrate more readily with adequate surface moisture. If the wound is kept moist, particularly with an occlusive dressing, migration proceeds more directly and efficiently. Local tissue

ischemia caused by infection, hematoma, foreign bodies, anemia, or poor surgical technique may slow wound healing. In addition, local wound infection prolongs wound healing. Bacteria delay normal healing phases by directly damaging cells of wound repair by prolonging the inflammatory phase as well as competing for oxygen and nutrients within the tissue. Surgical excision of hypertrophic scars or keloids may lead to recurrence rates of 45–100%.

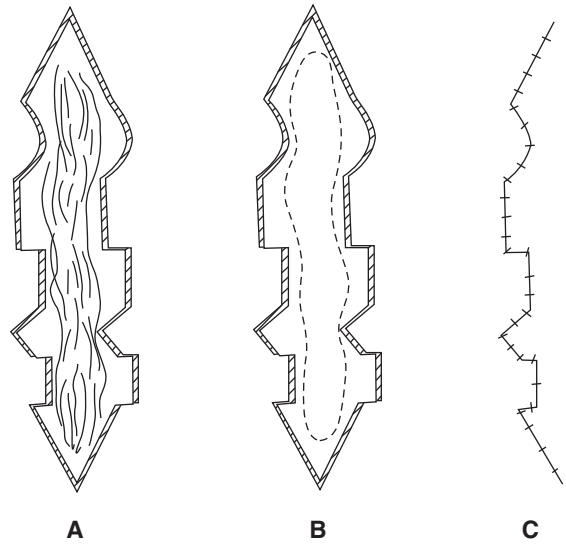
1. Primary excision and straight-line closure—The most common technique in the revision of scars 2 cm or shorter is primary excision and linear closure. Typically, with this procedure, a small margin of normal skin in the periphery of the scar is excised with the scar in a fusiform fashion, and the defect is closed in a linear fashion. The optimal length-to-width ratio to prevent standing cone deformities while maintaining the minimum length of the new scar is 3:1. The wound edges should be undermined to reduce the tension on the closure line. The defect is then closed in two layers, with subdermal absorbable sutures to minimize tension and fine monofilament sutures, such as 5.0 or 6.0 nylon or polypropylene, for the superficial layer. Wound eversion should be meticulously achieved.

With large scars, where total excision of the scar is not practical, serial excisions of the central portion of the scar with advancement of the peripheral tissue can be useful. A minimum period of 6 weeks should be allowed between each two excisions.

Small and pitted or depressed scars, such as deep acne scars, can be revised by punch excision and primary closure with wound eversion. As an alternative, small, full-thickness skin grafts can be placed into the defects and secured in position with sutures, bolstering techniques, or both.

2. W-plasty—The W-plasty is a series of connected, triangular advancement flaps mirrored along the length of the scar. A W-plasty, unlike a Z-plasty, incorporates shorter limbs and does not result in an overall change in the length of the scar. Unfavorable scars that are short and located in forgiving locations, such as the forehead or cheeks, scars that lie perpendicular to RSTLs, pretrichial scars, and scars over curved surfaces such as the inferior mandibular border are particularly good indications of W-plasty. This procedure can make the scar less conspicuous by making it irregular and thus more difficult for the observing eye to track. It also disrupts wound contracture with its irregular pattern.

In designing a W-plasty, dots representing the apices of the triangles are placed 3–5 mm from the scar edge. These dots should be spaced 5–6 mm apart, and each limb of the triangle should be 3–5 mm in length. The angle of the apex of each triangle should be determined by its relationship to the RSTLs, making one of the limbs of the triangle parallel with these lines. The ends of the W-plasty should be less than 30° to avoid standing cone deformities. Alternately, an M-plasty can be used at the ends to prevent extending the excision. The scar is excised, the adjacent tissue is undermined, and the wound is closed with a two-layer closure. Horizontal mattress sutures can be used to enhance wound eversion.

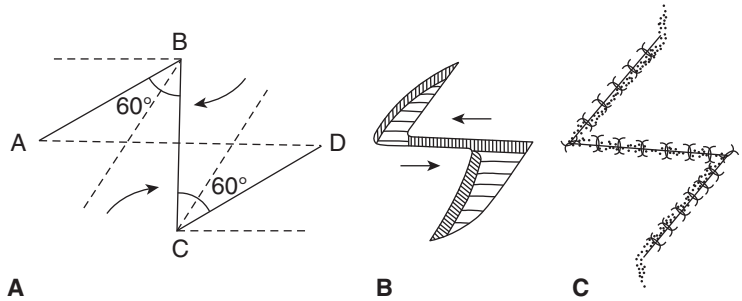


▲ **Figure 72–1** Geometric broken-line closure. **(A)** Random geometric patterns in mirror images are marked around the scar. **(B)** The scar is excised. **(C)** Wound edges are advanced and closed with appropriate sutures.

3. Geometric broken-line closure—Geometric broken-line closure (GBLC) differs from W-plasty in that, instead of using a series of triangles, it includes other alternating geometric shapes, such as squares and semicircles, along with triangles (Figure 72–1). Scars that respond well to GBLC are those that are relatively long and 45° or greater from RSTLs. Scars that are perpendicular to these lines have the best cosmetic result using GBLC. GBLC is slightly more challenging than W-plasty, but the principles and techniques are otherwise identical.

4. Z-plasty—The Z-plasty consists of two transposition-advancement flaps designed to accomplish three goals: (1) change scar direction, (2) interrupt scar linearity, and (3) lengthen scar contracture (Figure 72–2). Z-pasty is particularly beneficial if it can reorient a scar with RSTLs or in a natural junction between facial esthetic units. Similarly, with this technique, a long scar can be broken up into several smaller components to allow better camouflage (Figure 72–3). Finally, scars that cause distortion of facial features due to scar contracture are good candidates for revision using Z-plasty.

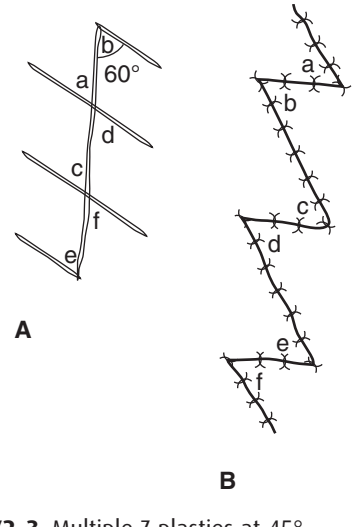
A main advantage of Z-plasty over other techniques, such as W-plasty, is that usually no additional normal skin needs to be removed. A properly planned Z-plasty results in minimal distortion of surrounding structures. Moreover, it can counter the forces of scar contracture, thus correcting webbed or contracted scars that distort anatomic landmarks.



▲ **Figure 72–2** 60° Z-plasty.

Precise preoperative planning of this technique is an essential requirement for its success. In its classic description, Z-plasty consists of one central and two peripheral limbs in the shape of a Z, such that two triangular flaps of equal size are created. All three limbs are of equal length, and the central limb consists of the scar that is to be lengthened and realigned. The orientation of the final scar can be determined by the direction in which the lateral limbs are placed and by varying the angles of the lateral limbs in relation to the central limb. The most commonly used angles are 30°, 45°, and 60°, which produce lengthening of the scar of 25%, 50%, and 75%, respectively. For long scars for which a single Z-plasty may produce long, linear scars, multiple Z-plasties can be used along the scar.

In performing this technique, the scar is excised along the central limb and the peripheral limbs are incised. The two triangular flaps and the surrounding tissue are mobilized, and the flaps are transposed and advanced. After meticulous hemostasis, the flaps are closed using tension-reducing techniques and eversion. A passive drain with pressure dressing may be necessary to reduce the dead space and the chance of fluid accumulation under the flaps.



▲ **Figure 72–3** Multiple Z-plasties at 45°.

5. Skin grafts—Full-thickness skin grafts can be used in a variety of ways in scar revision. Scars can be simply excised and grafted with a full-thickness graft. Skin grafts can also be used to fill skin defects after punch excision of deep or depressed scars. Contracted scars in the lower eyelid that lead to ectropion often require replacement of the anterior lamellar defect using a full-thickness graft. Defects in the upper eyelid causing lag ophthalmus can be repaired in a similar fashion using skin grafts.

6. Flaps—Flaps can be beneficial in a variety of ways in scar revision. In general, they can be used when the best option in scar revision is complete excision of the scar and reconstruction of the defect with a local flap. For example, a small scar of the nasal tip may be excised and repaired using a bilobed flap, just as one might repair a defect after ablation of a malignant growth in the same area. (For a more comprehensive discussion of local flaps, see Chapter 77, Local & Regional Flaps in Head & Neck Reconstruction.)

Prognosis

Most scars may be improved using a variety of scar revision techniques. Essentials of wound care are as important after the revision to achieve optimal outcomes. However, a scar may require several revision procedures before an outcome acceptable to the patient is achieved. The need for multiple procedures should be clearly discussed with the patient.

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Cohen IK, McCoy BJ, Mohanakumar T et al. Immunoglobulin, complement, and histocompatibility antigen studies in keloid patients. *Plast Reconstr Surg.* 1979;63(5):689. [PMID: 432336] (This study suggests that a localized immune response is involved in keloid pathogenesis, one that is not related to either the HLA-A or B histocompatibility loci.)

Cohen SR, Henssler C, Horton K et al. Clinical experience with the Fraxel SR laser: 202 treatments in 59 consecutive patients. *Plast Reconstr Surg.* 2008; 121:297e–304e. [PMID: 18453942] (Patients reported high satisfaction rates for improvements in scars, as well as skin texture and dyschromia, after Fraxel laser treatments.)

Cohen IK, McCoy BJ, Mohanakumar T et al. Immunoglobulin, complement, and histocompatibility antigen studies in keloid patients. *Plast Reconstr Surg.* 1979;63(5):689. [PMID: 432336] (This study suggests that a localized immune response is involved in keloid pathogenesis, one that is not related to either the HLA-A or B histocompatibility loci.)

Ehrlich HP, Desmouliere A, Diegelmann RF et al. Morphological and immunochemical differences between keloid and hypertrophic scar. *Am J Pathol.* 1994;145(1):105. [PMID: 8030742] (An extensive, comparative study of hypertrophic scars and keloids, suggesting that several morphologic and immunohistochemical differences exist between hypertrophic scar and keloid that are useful for the biological and pathologic characterization of the two lesions.)

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73 The Aging Face: Rhytidectomy, Browlift, Midface Lift

Richard Zoumalan, MD, Douglas Leventhal, MD, & W. Matthew White, MD

PATHOGENESIS OF FACIAL AGING

Facelift surgery or rhytidectomy, browlifts, and midface lifts are performed in an effort to redrape and suspend facial soft tissues to gain a more youthful appearance to the face. Facial aging has traditionally been attributed to the force of gravity causing soft tissue ptosis of the face as patient ages. The actual causes of facial aging are incompletely understood at this time, but the pathogenesis of the aging face continues to be a fascinating, hotly debated topic among physicians. In general, facial aging tends to occur in three dimensions and involves all tissue components of the face: skin, muscle and soft tissue, facial fat pads, and the bony facial skeleton.

Facial aging can be thought of occurring from superficial to deep, and tends to begin in the late twenties and thirties in the skin. Photodamage is defined as the functional and structural damage that occurs to skin after chronic exposure to ultraviolet radiation from the sun. The structural changes involve gradual thinning of the epidermis, flattening of the epidermal-dermal border, loss of collagen and thickness in the dermis, decrease in collagen Type I to Type III ratio, and reduction in the skin cellular and protein components. Lax skin with decreased collagen manifests through sagging and increased propensity to be wrinkled and furrowed.

Deeper into the facial soft tissues, muscle laxity and atrophy, as well as bony remodeling and resorption can potentiate the loss of facial, mandibular, and neck definition. These anatomic changes manifest clinically as brow ptosis, deepening of the nasolabial fold, jowling, blunting of the cervicomental angle, and platysmal banding (Figure 73–1). These features of the aging face are particularly amenable to correction with a rhytidectomy, platysmaplasty, midface lift, and/or browlift.

However, there are limitations to these surgical procedures. The surgeon must know that there are options to deal with aspects of the aging face for which a facelift or a browlift is not as effective. Although photodamage from the sun or tanning beds can increase the process of skin thinning, it causes fine skin wrinkling which may be more amenable to a skin treatment such as laser resurfacing or a chemical peel. Also, there is a gradual volume loss in the face which occurs over the time from change in facial fat pads and bony remodeling of the facial skeleton. Fat pads in the temporal and malar area lose volume, and the malar fat pad descends. Although a facelift may elevate the malar fat pad, additional augmentation of facial volume may be necessary with injections of autologous fat, fillers, or even implants.

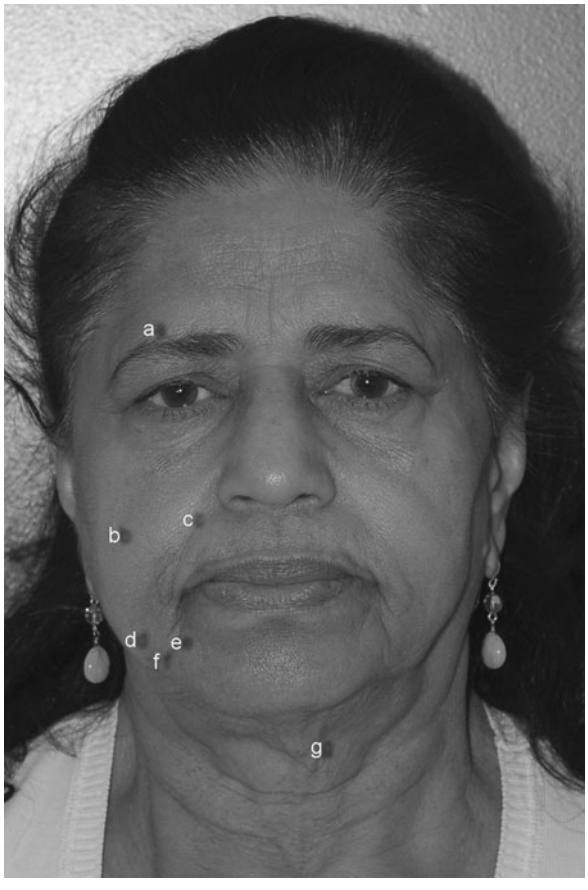
ANATOMY

SMAS

The key to understanding facelift surgery is understanding the anatomy of the superficial muscular aponeurotic system (SMAS) (Figure 73–2). The SMAS is a fibromuscular fascial layer that invests and interlinks the muscles of facial expression. It maintains consistent relationships with the vessels and nerves. The SMAS is contiguous with the platysma inferiorly and the temporoparietal fascia superiorly. In the temporal region, the frontal branch and the superficial temporal artery pierce this layer and become superficial. Inferior to this, the nerves and vessels are all deep to the SMAS, with motor innervations coming from the undersurface. Around the eye, the SMAS interdigitates with the orbicularis oculi. Medially, it has attachments to the zygomaticus major and minor as well as the dermis of the upper lip. The SMAS also has fascial condensations which are adherent to the overlying dermis and underlying muscle and bone. While not true ligaments, they are termed as such and act as support for the soft tissues of the cheek. The major osseocutaneous ligaments include the zygomatic ligament (McGregor's patch) and mandibular ligament and the fascia–fascia retaining ligaments include the parotid and masseteric ligaments.

Platysma

The platysma is innervated by the cervical branch of the facial nerve, a branch deep to platysma, and assists the



▲ **Figure 73–1.** Characteristics features of facial aging: **(a)**—brow ptosis, **(b)**—descent of the midface, **(c)**—nasolabial fold, **(d)**—excessive jowling, **(e)**—Marionette line, **(f)**—prejowl sulcus, and **(g)**—platysmal banding

depressor anguli oris in depressing the lower lip. As mentioned previously, the SMAS and platysma are contiguous; however, the location of the superior extent of the platysma is controversial and can be found up to 4 cm above the mandibular line and 3 cm below the malar eminence.

Medially, at the level of the thyroid cartilage, the platysma fibers interdigitate forming an inverted "V." The apex can be at the level of the chin, or slightly below at the level of the thyroid cartilage. Because of this, the submental area may or may not be covered by the muscle fibers. If there is laxity or dehiscence of the anterior borders of the muscle, it creates banding in the midline, which occurs with age. Patients may then also have a chin droop, as the submental area lacks tissue. Laxity of the platysma can lead to "turkey gobbler" deformity and a more obtuse cervicomental angle. Flaccidity of superolateral fibers of the platysma muscle may be a contributing factor to chin droop and submental laxity.

Facial Nerve

The facial nerve exits the stylomastoid foramen and courses through the parotid gland. It branches into five branches: temporal (or frontal), zygomatic, buccal, (marginal) mandibular, and cervical rami. (Figure 73–3) within the parotid gland, the main trunk usually divides a superior (temporofacial) and inferior (cervicofacial) branches. From there, the branching pattern becomes variable. There is frequent anastamosis between the zygomatic and buccal branches. After exiting the parotid gland in the face, the nerve branches are just deep to the parotideomasseteric fascia, which is a barely appreciable thin facial layer just deep to the SMAS.

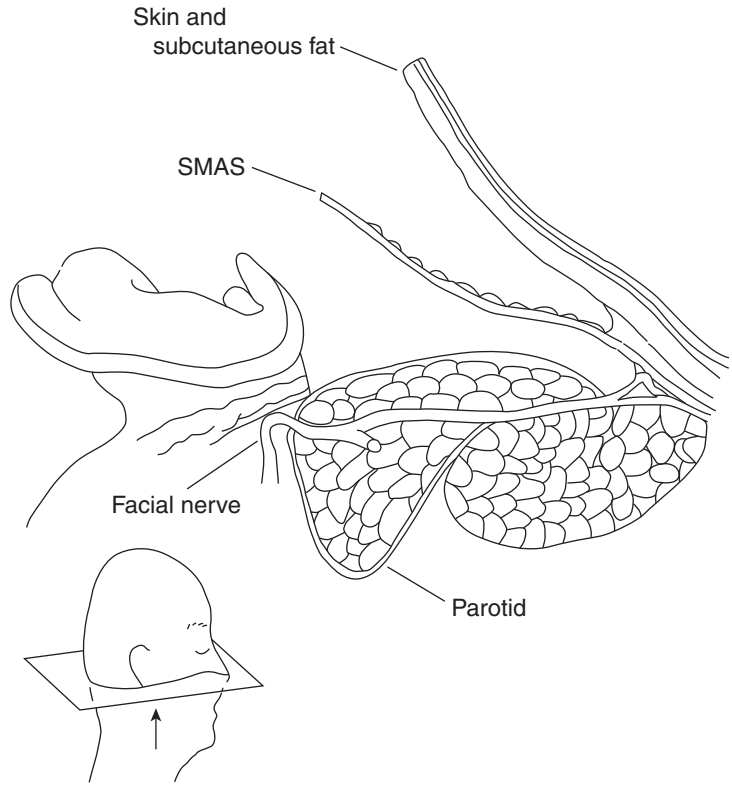
Knowledge of the anatomy of the facial nerve is essential to avoiding nerve injury. The frontal and marginal branches are the most commonly injured branches in facelift. The frontal branch runs within the temporoparietal fascia and is superficial to the superficial layer of the deep temporal fascia. It crosses the zygoma midway between the tragus and lateral canthus of the eye. The marginal mandibular branch runs just deep to the platysma and can be found as low as the level of the hyoid bone, usually two fingerbreaths below the mandibular line.

Greater Auricular Nerve

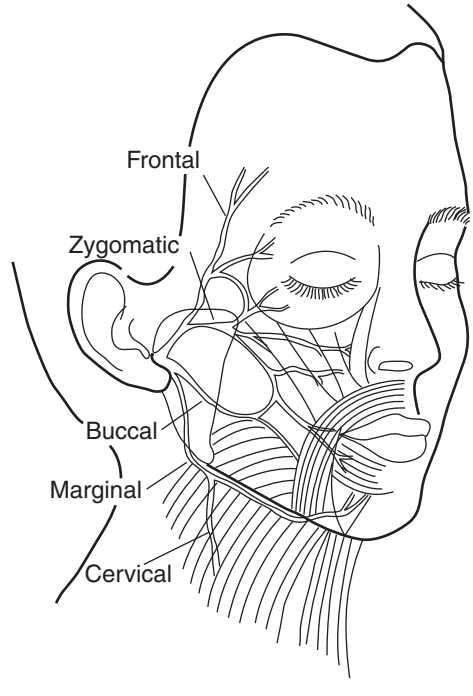
Derived from second and third cervical nerves (C2 and C3), the greater auricular nerve provides sensation to the upper lateral neck and ear lobule. It emerges at the posterior border of the sternocleidomastoid muscle 6 cm inferior to the external auditory canal, wraps around this border, and ascends in the neck on the surface of the SCM. Eventually it gives off a small postauricular branch then pierces the parotid gland to provide its sensory innervation.

HISTORY OF FACELIFT TECHNIQUES

Prior to the 1970s, much of facelift surgery involved a superficial skin dissection with the excision of excess skin. While this technique was popular at that time, skin excision did not provide a long-term benefit nor does it have any effect on the midface. Additionally, the technique tended to make patients look "over-pulled" and unnatural look. In the 1970s, facelift techniques changed dramatically with the description of the SMAS layer by Mitz and Peyronie. Skoog is credited with the development of SMAS manipulation. This began an era of different strategies to attain optimal vector pull for lax soft tissue and fat pad repositioning. The field is constantly evolving as evidenced by the push for minimally invasive techniques using smaller incisions and endoscopic instrumentation. The surgeon's armamentarium is vast and the choice of which technique to use depends on a variety of factors.



▲ **Figure 73–2.** The superficial musculoaponeurotic system is a distinct layer between the parotid gland, skin, and subcutaneous fat.



▲ **Figure 73–3.** Facial nerve anatomy.

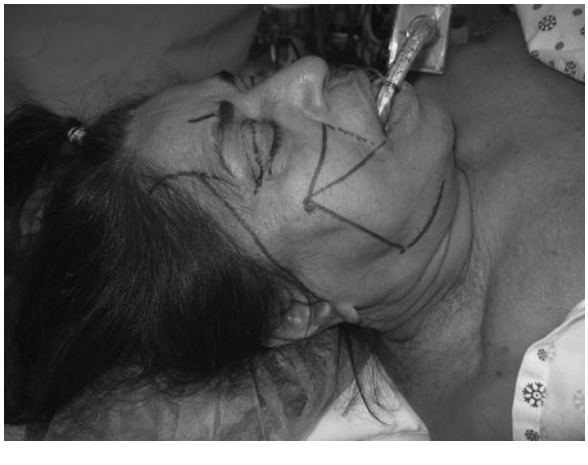
Patient Evaluation

Each patient is entirely different and requires a unique, individualized approach. The surgeon must thoroughly discuss the patients concerns and expectations. In addition, a full medical history and physical exam must be performed. A careful bleeding history should be taken to rule out need for hematologic consultation. A full list of medications, including over the counter and herbal supplements, must be obtained as many drugs can increase the risk of bleeding with surgery.

All patients should be photographed preoperatively. Standard photographic views include: frontal, right and left oblique, and right and left lateral. The reliability and consistency of the photographer is essential to the preoperative consultation. During the initial aesthetic consultation, each patient is evaluated for signs of facial aging, as well as intrinsic anatomic imbalances. A thorough facial analysis should be performed, and the surgeon should be prepared to diagnose photoaging of the skin, volume loss, bony abnormalities, and soft tissue deformities. Specifically, the signs of facial aging identified in patients who proceed to facelift surgery are jowling, neck laxity (with or without platysmal diastases), and midface descent. Patients are given options for treatment and counseled on expected outcomes. The surgeon must be certain that the patient has realistic expectations. The full surgical plan is discussed, including proposed areas of incisions and the reasoning behind placement of these incisions. Patients should also be counseled on all the risks of the surgery, which are discussed later.

Preoperative Preparation

Markings are made on the patients face in the holding area while sitting upright. This allows the surgeon to mark anatomical sites, which he or she needs to identify locations of the face during surgery. In Figure 73–4 it also allows the surgeon one last time to communicate with the patient about the surgical plan.



▲ **Figure 73–4.** Preoperative markings.

Once the patient is in the operating room, the patient's hair is combed away from incision lines and rubber bands or petroleum jelly are used to keep hair away from the incisions. Preoperative hair rinse with betadine or chlorhexidine has been shown to decrease the rate of surgical site infections, as one dose of intravenous antibiotics has been given before surgery and within 1 hour of incision.

ANESTHESIA

Rhytidectomy can be performed with local anesthesia and sedation; however, many surgeons prefer to use general anesthesia because of the length of the procedure and meticulous dissection needed to prevent facial nerve injury. The airway can be secured with either a laryngeal mask airway or an endotracheal tube. Muscle paralytics should be avoided during any procedure that may necessitate intraoperative facial nerve identification.

With either sedation or general anesthesia, local infiltration of tissues is necessary for hemostasis, anesthesia, and enhanced tissue dissection planes. Knowledge of the maximum weight-based dose of the local anesthetic, either with or without epinephrine, is essential and the amount used should be communicated with the anesthesiologist.

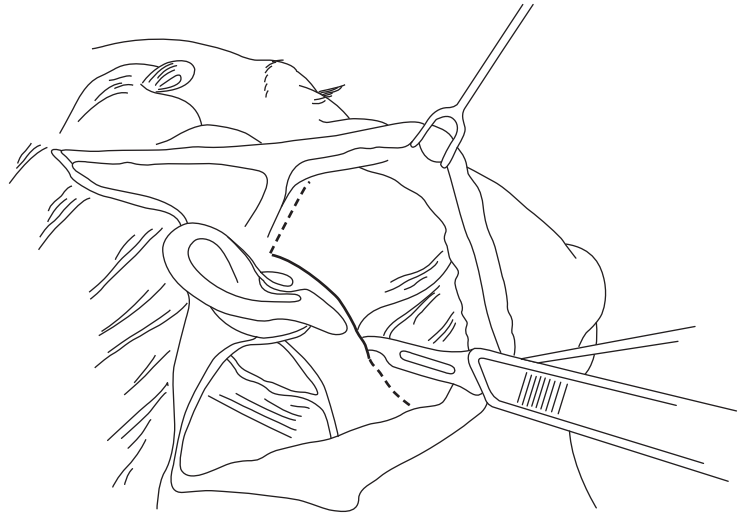
SURGICAL TECHNIQUES

Skin Excision

Subcutaneous rhytidectomy has the lowest complication rate of facial nerve injury. The flap is elevated superficially to the SMAS and platysma in the subcutaneous plane. There is no risk of injury to the facial nerve in the subcutaneous plane; however, inferiorly, one must be preserve the great auricular nerve. The extent of dissection depends on the surgeon's comfort. A shorter flap may be used in patients with comorbidities that have propensity toward flap ischemia. As with other types of lifts, meticulous hemostasis with bipolar electrocautery are performed, excess skin is excised, and skin is closed under minimal tension.

Sub-SMAS Rhytidectomy

Techniques which address the SMAS-Platysma complex tend to have long-lasting and more favorable results than a simple skin excision. The SMAS can be addressed by plication or imbrication. SMAS plication allows the surgeon to mobilize the SMAS without exposing the facial nerve to potential injury. In this technique, the SMAS is sutured to itself without performing any sub-SMAS dissection. The imbrication technique involves incising the SMAS and dissecting in the sub-SMAS plane. A portion of the SMAS is then excised and the edges are sutured together in a superior and posterior direction. Since the SMAS layer is penetrated,



▲ **Figure 73–5** Incision of the SMAS.

there is theoretically a greater risk of facial nerve injury with the imbrication technique as compared to a SMAS plication. However, plication does not free up the SMAS or platysma to allow it to mobilize as freely as elevating a sub-SMAS flap. In the imbrication flap, incision is made into the SMAS just anterior to the ear and carried anteriorly in the plane just immediately deep to the SMAS (Figure 73–5). This dissection must be stopped just inferior to the zygomatic arch, and while it can be carried anterior to the parotid gland and inferior to the mandibular angle, facial nerve branches lie here. Excess tissue is excised and flaps are sutures posteriosuperiorly. The inferior part of the flap is sutured to the mastoid periosteum. The superior portion of the flap is sutured to the temporalis fascia. In the temporalis fascia, a horizontally placed suture is a stronger fixation point than a vertically placed suture, due to fibers of the fascia being vertical.

Deep Plane Rhytidectomy

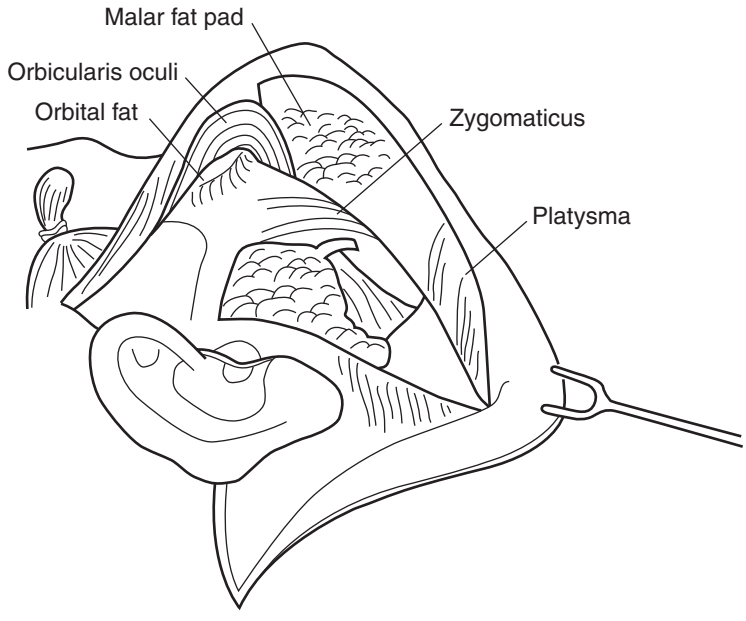
In the deep plane rhytidectomy, the surgeon dissects under the temporoparietal fascia in the temporal area, subcutaneously and sub-SMAS in the midface region, and subcutaneously in the neck. In the midface, the flap is initially raised in the subcutaneous layer but at the level of the malar eminence, the SMAS is incised and dissection proceeds beneath the SMAS and above the masseter, zygomaticus major, and zygomaticus minor muscles. Bridges of tissue are left intact between the temporal and midface regions to prevent injury to the frontal branch and between the midface and neck to prevent injury to the marginal branch. In the neck and midface, the platysma/SMAS layer is sutured posterosuperiorally to the mastoid soft tissue and periosteum. In the temporal area, the temporoparietal fascia is sutured posterosuperiorally to the deep temporalis fascia. The excess skin is then excised making sure that the remaining skin can be closed under no tension. The composite rhytidectomy is a variation of a deep plane technique. The dissection is the same as in the deep plane rhytidectomy, but there is an additional supraperiosteal dissection beneath the orbicularis oculi muscle (Figure 73–6). Since these dissections are carried anteriorly into the midface, this technique is thought to elevate the malar fat pad and soften the nasolabial fold. This technique has the highest risk of injury to the branches of the facial nerve, but has been shown in some studies to have superior, long-lasting results.

THE MINILIFT

The minifacelift or minilift has evolved to describe a variety of facelifts which utilize smaller incisions than the aforementioned standard techniques. Typically, candidates who are excellent candidates for a minilift are younger patients with limited skin laxity and patients requiring "tuckups." The advantages of the minilift are: limited incisions, shorter surgical time, avoidance of general anesthesia, lesser risk of facial nerve injury, and quicker recovery. The disadvantages are: limited access to the neck, limited access and improvement in the midface, and difficulty for visualization which is required for suture placement and hemostasis. Currently, two techniques commonly used and described are the short scar lift, and the Minimal Access Cranial Suspension lift (MACS-lift).

Short Scar Lift

The short scar facelift uses a short incision that does not extent postauricularly beyond 2–3 cm from the lobule. There are no incisions in the temporal area or postauricular



▲ **Figure 73–6** Composite rhytidectomy with dissection of the orbicularis oculi and zygomaticus muscles.

hair-bearing region. The SMAS is addressed either with resection, plication, or anterior imbrication. As with other minilifts, the use of the short scar has the potential complications of skin bunching at the temporal and postauricular regions. This technique also provides minimal access superiorly into the temporal region and inferiorly into the neck.

Minimal Access Cranial Suspension Lift (MACS-lift)

The MACS lift described by Tonnard is geared toward patients in a younger age range (40s–50s) who require a more vertical lift compared to the posterosuperior lift of most facelifts. This lift uses a short incision and skin flap to place a pretragal purse-string suture that is anchored to the deep temporalis fascia. The suture continues inferiorly in a narrow U-shaped, incorporating the SMAS overlying the parotid gland and ending in the platysma at the angle of the mandible before returning to the starting point 1 cm anterior to the first leg of the suture. The second, more O-shaped, purse-string suture is then placed from the same starting point is used to elevate the jowls and nasolabial grooves. The skin is then elevated superiorly, and excess skin is excised.

NECKLIFT

In conjunction with facelift, a necklift or platysmaplasty can restore the youthful appearance of the neck and jawline. The youthful neck is comprised of a strong chin, smooth and defined mandibular border, minimal submandibular gland ptosis, and a cervicomental angle of 90° with a gentle indentation of the thyroid notch.

To achieve the attributes of a young neck, there are a variety of approaches. Submental lipectomy can remove excess fat that allows for a thin flap to be redraped over the underlying bony framework. Suction lipectomy can also help dissect preplatysmal tissue planes before a necklift to allow quicker dissection. Submentoplasty or platysmaplasty is the central suturing of the medial platysma edges to eliminate the platysma banding. Lateral dissection of the platysma with posterosuperior suturing drapes the skin and platysma over the neck structures to improve the cervicomental angle. There are also those that perform submandibular gland and digastric muscle excision to further improve the submental area and jawline.

COMPLICATIONS

Facial Nerve Injury

The most commonly injured nerve during facelift surgery is the great auricular nerve, occurring in up to 7% of the patients. This can cause anesthesia of the earlobe. For some patients, this is permanent and bothersome, as they have a hard time with earrings and using the telephone. The nerve must be protected when elevating the postauricular flap over the sternocleidomastoid muscle as the surgical plane in that region is not well defined.

An injury to a branch of the facial nerve is less common. Sub-SMAS dissections have a higher chance of injury as compared with skin only or SMAS plication techniques. The most common injuries are to the frontal and marginal branches. The buccal branch may also be a commonly injured branch, but because of the large number of anastomotic branches, it may not be clinically evident. The likelihood of a branch being injured depends on surgical technique and areas of dissection. The frontal branch has a superficial course at the level of the zygomatic arch and in order to avoid injury, dissection must be either subcutaneous or subperiosteal. Both the cervical and marginal branches often consist of multiple branches that anastamose before reaching target muscles. In order to avoid injury to both branches, dissection should be performed in a plane superficial to the platysma toward the anterior neck. The most crucial location to avoid injury is the area 2 cm posterior to mandubular angle and the area immediately adjacent to the lateral commissure of the mouth. This area must be dissected carefully, and often a branch of the facial nerve can be seen superficial to the plane of dissection.

When evaluating patients in the recovery room, it is important to note that a temporary paralysis may be caused by use of anesthetic injection. Furthermore, most cases of paralysis beyond the immediate postoperative period are temporary and usually due to local trauma from retraction and not necessarily from a transected nerve.

Hematoma

Hematoma formation is the most common and major complication after facelift, occurring in 0.2% to 8.1% of patients. Factors associated with an increased risk of hematoma formation include male gender, hypertension, smoking, and aspirin or NSAID use. Hematomas can lead to tissue ischemia, prolonged facial edema, hyperpigmentation, and if untreated, skin necrosis. If dissection occurs into the neck, life-threatening airway obstruction can occur. Large expanding hematomas require immediate evacuation. The incidence of hematoma ranges from 0.2% to 8.1%, and it is much more common in males. Smaller hematomas or seromas are more common and are easily treated with needle aspiration in the office setting. The best way to prevent hematoma formation is meticulous hemostasis. Pressure dressings, drains, and fibrin glue may be used to minimize the risk of hematoma formation. In the early postoperative period, it is imperative to prevent hypertension and nausea and vomiting.

Infection

Surgical site infection occurs in facelifts in less than 1% of cases and typically involves the incisions. Early culture and treatment is important, as there is an increasing incidence of methicillin-resistant staphylococcus aureus. If there is a purulent collection under the flap, the incision should be partially or completely opened, irrigated, and left open to drain. Large infections may require hospitalization with administration of intravenous antibiotics.

Scars

As with any surgery, scarring is to be expected along the incision lines. Scars may become more visible if they become hyper- or hypo-pigmented or hypertrophic. It is imperative that the incisions are closed in a meticulous, tension-free manner. If hypertrophic scarring does result, intralesional steroid injections may be used. If there is persistent scarring, patients may benefit from excision and primary closure.

Allopecia

Hair loss is a complication of rhytidectomy that may be temporary or permanent. Alopecia can be secondary to compromised hair follicles or from elevation of the temporal hairline from poorly planned incisions. In addition, if there is a widened scar in the hair-bearing scalp, hair cannot grow from the area. Allopecia can be avoided by the following: carefully planning surgical incisions taking into account the patient's temporal hair tuft, raising a thick flap in hair-bearing areas, avoiding the cauterization of hair follicles in the skin flap, and minimizing tension when closing incisions.

Parotid Injury

Aggressive undermining of the SMAS and suction lipectomy can cause injury to the parotid gland and lead to a sialocele. Fluid may drain externally through incisions, through a fistula, or internally through the mouth via buccal mucosa.

1. Flap necrosis—Lack of optimal blood supply and tissue tension can lead to flap necrosis. In a facelift, the area which is most susceptible to flap necrosis is the superior aspect of the postauricular skin flap. Factors which increase the likelihood of such a complication are systemic diseases such as diabetes, peripheral vascular disease, and connective tissue disorders. Other factors that increase the chance of flap necrosis are infection, excessive skin tension, and poor flap design. Nicotine use increases the risk of flap necrosis by over tenfold. Smoking is a relative contraindication to rhytidectomy and it is recommended that patients abstain from smoking for at least 4 weeks before and after surgery.

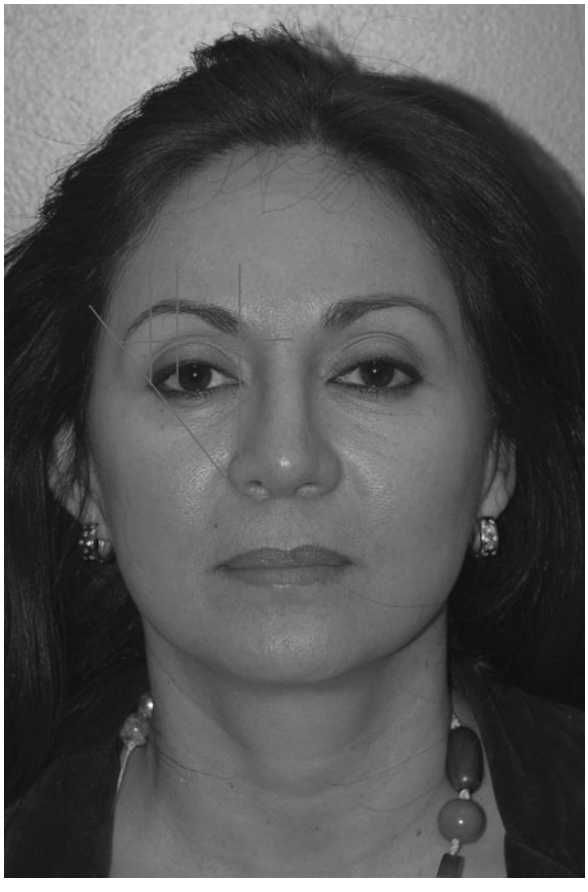
2. Earlobe deformity—A pixie or Satyr's ear (devil's ear) deformity can occur due to excessive skin tension at the inferior aspect of the lobule. If too much skin is excised from the flap and the closure at the inferior part of the lobule is under tension, over time, the earlobe will get pulled inferiorly. This is a tell-tale sign of facelift surgery and repair can be difficult. A V–Y plasty can improve the appearance, but repair should be delayed 6 to 8 months after surgery.

REJEUVENATION OF THE BROW AND MIDFACE

While many think of rejuvenation of the aging face as rhytidectomy, the face ages in other areas that are not addressed by a facelift alone. Over time, descent of the brows and midface occurs in a fashion that requires a combination browlift or midface lift. These operations can also be performed alone, if the patient only requires rejuvenation in a specific location. Browlifts and midface lifts are now often performed endoscopically.

Browlift

A browlift in conjunction with blepharoplasty can improve both cosmesis as well as any functional visual field deficits a patient may have. The "classic" brow has a medial origin along a vertical line drawn through the alar-facial grove and lateral canthus. The lateral aspect should be at a line drawn from the nasofacial groove to the lateral canthus. In a female, the high point of the arch should be at the lateral canthus or lateral limbus (Figure 73–7). In a male, the high point should be at the lateral limbus but the overall shape is more horizontal as compared to females



▲ **Figure 73–7** Aesthetic anatomy of the brow.

Anatomy

The frontalis muscle originates from the galea and inserts in the forehead skin. Its motor innervation is the frontal branch of the facial nerve, and it is the primary elevator of the brow. The depressor muscles of the brow are the paired corrugators supercilii, the obicularis oculi, and the procerus muscle. The corrugators create the vertical rhytides of the glabella. The procerus, which originates from the nasal bones, produces the transverse rhytides in the glabella.

Sensory innervation of the brow is provided by the trigeminal nerve. The supratrochlear and supraorbital branches emerge from the skull deep to the eyebrow. They exit from the supraobrital notch or foramen. In 10% of cases, one or both of the nerves may arise from a true foramen which is found 1–2 cm superior to the orbital rim.

Approaches

There are variety of procedures, both surgical and nonsurgical, that may be used to elevate the eyebrow (Table 73–1). The coronal approach is the classic approach for browlift procedures. It involves making a large incision approximately 4–6 cm posterior to the hairline and elevating subgaleally down to the brow. Once all the tissues are released, the brow is then suspended in a more superior direction. The pretricheal browlift is performed in a similar fashion, but instead, the incision is placed at the anterior hairline. This offers the advantage that when the brow is elevated, the position of the hairline will remain unchanged. The midforeahead lift is performed by placing the superior incision in a deep, horizontal furrow. Incisions should be placed at different levels on each side so that there is not one long horizontal scar. The direct browlift is a skin excision technique that acts to pull the brow vertically upward. The incision cannot be carried deeper into the orbicularis muscle due to the risk of damage to sensory nerves. The inferior incision is placed just above the superior aspect of the eyebrow and the superior incision is placed more superiorly depending upon the extent of elevation needed. The transblepharoplasty browlift or brow pexy, also called the supratarsal browlift, is a great technique that can be used in combination with an upper lid blepharoplasty. It allows superior elevation of the brow complex as well as access to the eyebrow depressor muscles.

With the advent of endoscopic equipment and the push toward minimally invasive procedures, the endoscopic browlift has become the most popular technique today. During the procedure, small incisions are placed in hear-bearing scalp which allow access for a wide release of the brow complex as well as good visualization of the eyebrow depressor muscles. In the central forehead, the dissection plane is subperiosteal while lateral to the temporal line, the dissection occurs deep to the temporoparietal fascia or

Table 73–1. Variations in Browlift Techniques

Type	Incision	Dissection Plane	Indications	Advantages	Disadvantages
Coronal	Above hairline	Subgaleal	Low anterior hairline	Incision hidden in hairline, good exposure to eyebrow depressors	Elevation of hairline, scalp anesthesia, difficult to correct eyebrow asymmetries
Pretrichial	At anterior hairline (irregular and beveled)	Subgaleal	High anterior hairline with long vertical forehead height	Does not elevate hairline, good exposure to eyebrow depressors, improved scar if closed meticulously	Scalp anesthesia (larger than coronal), possible scar visibility
Midforehead	In forehead crease	Subcutaneous	Male pattern baldness with prominent forehead creases/deep furrows	Precise eyebrow elevation, no hairline distortion	Possible scar visibility, minimal lateral eyebrow elevation
Direct	In forehead crease just above eyebrow	Subcutaneous	Unilateral eyebrow ptosis, facial paralysis patients, bushy eyebrows	Precise eyebrow elevation, no hairline distortion, potential long-lasting effect	Possible scar visibility, no improvement of forehead or glabellar rhytids, possible distortion of existing rhytids
Transblepharoplasty	Upper blepharoplasty	Sub-orbicularis	Younger patient with mild-mod eyebrow ptosis	Well concealed incision, no hairline distortion, less dissection than other techniques	Difficult to use in patients with severe eyebrow ptosis, possible eyebrow anesthesia
Endoscopic	4-5 small incisions above hairline	Subperiosteal centrally, beneath temporoparietal fascia laterally	Normal to low anterior hairline	Smaller incisiosn, less scalp anesthesia, allows correction of forehead and glabella rhytids, faster recovery	Requires specialized training, elevation of hairline
Chemical (Botulinum toxin)	None	None	Patients who desire a non-surgical alternative	Quick, easy to perform, minimal morbidity compared with surgery	Short-term effects based upon longevity of Botulinum toxin effect (3-4 months)

superficial temporal fascia. This avoids injury to the frontal branch of the facial nerve as the dissection is deep to the nerve. During the lateral dissection, a series of bridging vessels including the sentinel vein is identified which represents the close proximity of the facial nerve. The brow is released widely and the periosteum and galea is secured to the skull using a variety of drill-assisted securing techniques and devices. As compared to the coronal browlift the endoscopic approach does not require excision of hair-bearing skin while still allowing the surgeon to widely release the tissues necessary to achieve long-term brow elevation.

Botulinum toxin may be used to achieve eyebrow elevation as well, eliminating the need for an extensive surgical procedure. Botulinum toxin may be injected into the eyebrow depressors (procerus, corrugators, and orbicularis oculi) to temporarily paralyze them and allow the frontalis to elevate the eyebrow unopposed. This is a good technique for individuals who do not wish to undergo surgery; however, the duration is temporary.

MIDFACE LIFT

Midface Anatomy

The malar prominence is the upper lateral mound of the cheek. It is composed of a subcutaneous malar fat pad with overlying orbicularis oculi. Deep to the orbicularis oculi is the suborbicularis orbital fat (SOOF). Motor supply is from

the zygomatic and buccal branches of the facial nerve and sensation is from the infraorbital nerve and zyomaticotemporal branch of the trigeminal nerve. During the aging process, the cheek descends inferomedially, which consequently deepens the nasolabial crease. A midface lift intends to resuspend the cheek prominence and thus decrease the depth of the nasolabial crease.

There are two basic planes via which the midface lift may be accomplished. The approach can be either superficial to the investing fascia of the zygomaticus major muscle or deep to the periosteum. The choice of dissection plane depends on the patient's anatomy. Incisions to access the midface include the standard rhytidectomy incision, blepharoplasty incision, transoral incision, and endoscopic temporal incisions.

In an endoscopic midface lift, the midface is approached via the temporal or forehead area. Endoscopic forehead approach with midface suspension can be performed either with or without a browlift. A lower eyelid procedure is usually performed in conjunction with a midface lift because elevation of the malar tissue causes bunching of skin under the eye. Dissection is carried in a subperiosteal plane from the temporal line to the superior orbital rim. Dissection in the temporal region is over the deep temporal fascia to the bone of the zygomatic arch. Tissue over the arch is released and the dissection is continued inferomedially in a subperiosteal plane. The medial extent of the dissection is to the nasal bones and piriform aperture. As with the browlift, the midface/SOOF is suspended via sutures or absorbable suspension systems.

Patients typically experience edema of the midface region that may last for up to 6 weeks. In addition, they may experience masticatory tenderness postoperatively due to the dissection around the masseter and temporalis muscles.

CONCLUSION

There are many tools in the facial plastic surgeons armamentarium to combat the natural aging process. Each procedure and approach must be tailored to the individual patient. A thorough evaluation with appropriate diagnosis of the areas of concern, coupled with a well thought out plan of treatment should be discussed. Most importantly, communication with the patient to understand their goals and desires is an essential element in achieving an optimal result in aging face surgery.

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We would like to acknowledge Anil R. Shah, Eugene J. Kim, MD and Corey S. Maas, MD for their contribution to this chapter in the previous editions of CDT.

74 Blepharoplasty

Eugene J. Kim, MD & Corey S. Maas, MD

ANATOMY

Eyelid Surface

Eyelid skin is the thinnest in the body with relatively sparse subcutaneous fat. This allows free movement of the lid in closure and blinking. The upper eyelid skin is thinner than that of the lower lid. The skin itself has many fine hairs as well as sebaceous and sweat glands. Healing occurs quickly in this area and scarring is usually minute.

The lid crease of the upper eyelid is formed by the insertion of the levator aponeurosis fibers into the skin and the orbicularis oculi muscle. It is approximately 8–12 mm superior to the lash line and lies just at the level of the upper edge of the tarsal plate. Medially and laterally, the crease is closer to the lid margin and has an arc shape across the lid. The Asian eye usually lacks this crease due to the lower insertion of the levator aponeurosis on the tarsus.

The lid fold describes the tissue above the lid crease and may extend throughout the length of the upper lid or it may be more localized. Excess tissue may develop in the aging face and sag over the lid crease, sometimes obscuring vision. A combination of excess skin, hypertrophied orbicularis oculi muscle, and herniated fat can be responsible for this process.

Orbicularis Oculi Muscle

The orbicularis oculi muscle provides the main mimetic function to the eyelid. It receives its innervation from the temporal and zygomatic branches of the facial nerve. The muscle is elliptical and divided into three bands (the pretarsal, preseptal, and preorbital), which attach to the bony orbit at the medial and lateral canthal tendons. The muscle can become hypertrophied over time and result in a full appearance of the eyelids.

Orbital Fat

Orbital fat cushions the globe and its associated structures, and its anterior limit is the orbital septum. In the upper eyelid, the fat separates the levator aponeurosis posteriorly and the orbital septum anteriorly. Here it is divided into two fat compartments: central and medial. In the lower lid, there are three fat compartments: lateral, central, and medial (Figure 74–1).

LEVATOR PALPEBRAE SUPERIORIS MUSCLE

The levator muscle acts to elevate the upper eyelid and has its origin in the periorbita posteriorly. The muscle runs above the superior rectus and fans out anteriorly to become the levator aponeurosis. Insertion occurs at the level of the tarsus, as previously described, forming the lid crease (Figure 74–2). Its innervation is by cranial nerve III (the oculomotor nerve).

TARSAL PLATE

The tarsi are composed of fibrous tissue and provide the general shape and firmness to the eyelids. The upper and lower tarsi measure approximately 10 and 5 mm in height, respectively. Many meibomian glands are present in both tarsi and open into the ciliary margin.

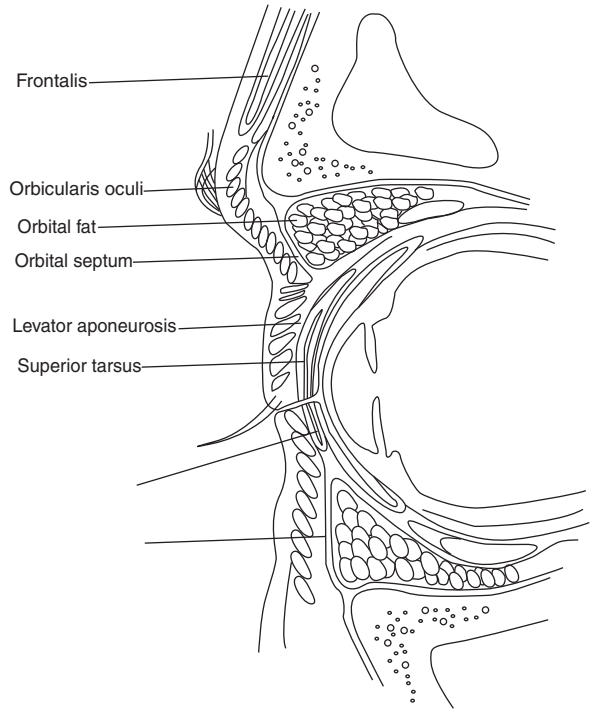
Conjunctiva

This mucus membrane is attached to the tarsal plate and covers the tarsus and Muller muscle. Due to its firm tarsal attachment, the conjunctiva does not have to be sutured following incision. The gray line marks the border between the conjunctiva and skin. Histologically, there is columnar epithelium posteriorly and stratified squamous epithelium anteriorly. This landmark is frequently used in eyelid surgery.

PREOPERATIVE ASSESSMENT

A thorough history and physical, especially an ophthalmologic history, should be performed on every patient. Schirmer testing will help screen patients who are prone to dry eye postoperatively. The snap test allows for the determination of the laxity of the lower lid skin. The lower lid is pulled away from the globe and its snap back to the normal

▲ **Figure 74–1.** The orbital fat is divided into the upper medial and central compartments, and the lower medial, central, and lateral compartments.



▲ **Figure 74–2.** Coronal view of the orbit and its structures.

position is observed. If the lid is slow to snap back, lower lid laxity is a concern and the patient may be at risk for postoperative ectropion. A full-thickness shortening of the horizontal lid can help prevent this complication at the time of blepharoplasty.

Close attention to any degree of scleral show should be made; scleral show occurs when the lid margin does not reach the cornea. Also, any asymmetries should be documented and discussed with the patient. Patients with proptosis are poor candidates for blepharoplasty because of the risk of lagophthalmos and ectropion. In addition, blepharoplasty in patients found to have dry eye should be done very conservatively.

Aspirin should be discontinued at least 2 weeks before and after surgery to decrease the risk of bleeding. Preoperative photography is mandatory and involves the frontal view with eyes open, closed, and in upward gaze; a lateral view should also be taken. These photographs are reviewed with the patient and realistic goals and limitations are discussed.

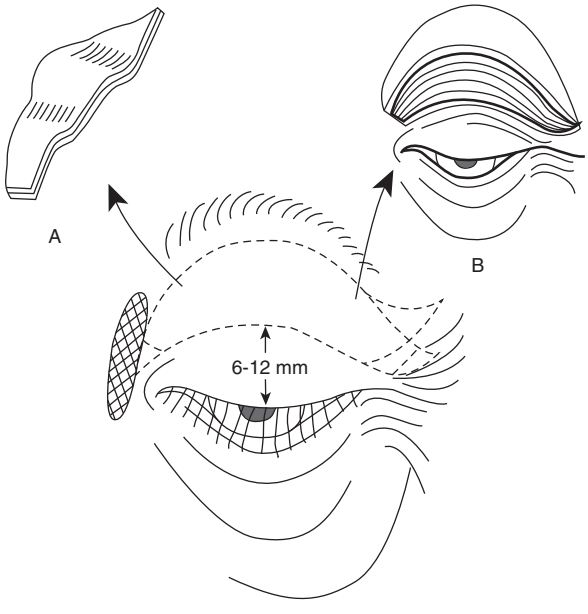
ANESTHESIA

Local anesthesia with or without intravenous sedation is usually perfectly adequate for blepharoplasty. Injection with 1% lidocaine with 1:100,000 epinephrine is made in the surgical field just underneath the skin surface and superficial to the orbital septum.

UPPER BLEPHAROPLASTY

The skin incision in upper blepharoplasty should follow the natural lid crease. This is measured approximately 8–12 mm above the ciliary margin along the upper edge of the tarsal plate. Laterally, the incision is carried toward the orbital rim and curves slightly superiorly. The exact extent is determined by the amount of excess tissue in that area. Medially, the incision extends to an area above the level of the medial canthus and never onto the nasal skin.

The superior skin incision is determined by the amount of skin to be excised. One method to determine this is by grasping the excess skin with forceps. Another method involves incising the lid crease only and then redraping the lid skin downward. This allows just enough skin to be excised. A simple elliptical skin excision may also need to be modified both laterally and medially by a Z-plasty or M-plasty closure.



▲ **Figure 74–3.** The extent of excision in upper blepharoplasty is demonstrated by the dotted line. **(A)** Skin and muscle are excised as one unit and **(B)** skin is elevated first, followed by muscle excision.

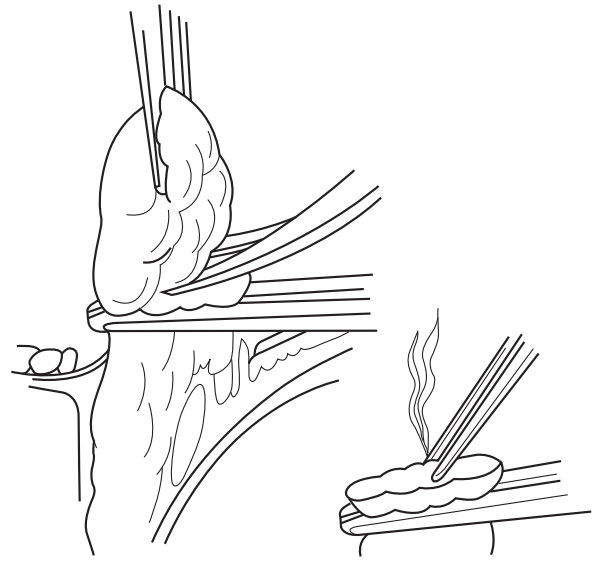
The orbicularis oculi can be addressed following the skin excision or excised with the skin flap (Figure 74–3). Some surgeons advocate the excision of muscle varying from 2 mm in width to a width just 2-mm short of the skin excision. Regardless, care should be taken when tenting the muscle as the septum and levator can be accidentally cut. Hemostasis is obtained with the use of bipolar electrocautery.

Fat excision addresses the process of herniation. The orbital septum is carefully opened above the insertion of the levator aponeurosis. Gentle pressure on the globe can help identify the location of the relevant fat compartments prior to incision. The central and medial fat pads will herniate with globe pressure. They are excised anterior to the septum and meticulous attention is made to hemostasis (Figure 74–4). The central compartment may appear darker in color than the medial compartment. Care should be taken to avoid excessive resection of fat as it can create a hollowed eye look.

The incision is then closed initially via the principle of "halves" using a 6-0 nylon suture. It is completed with a 6-0 fast-absorbing gut suture in a running fashion.

LOWER BLEPHAROPLASTY

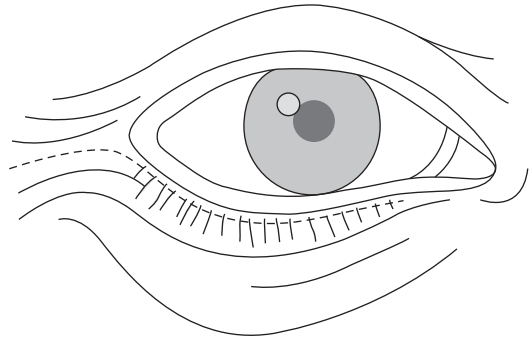
Lower blepharoplasty can be approached via several techniques, including a skin flap, a skin-muscle flap, and a transconjunctival technique.



▲ **Figure 74–4.** Orbital fat is delivered and then carefully excised with the use of cautery.

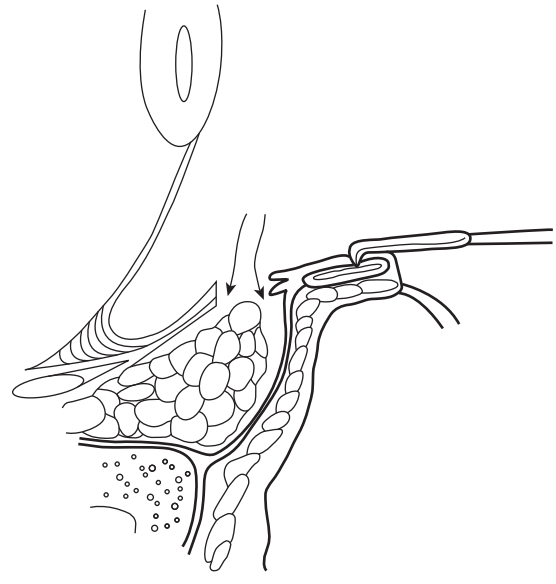
Skin Flap

The use of the skin flap technique is most appropriate in patients who have a significant excess of loose skin but evidence of good orbicularis oculi muscle tone. A subciliary incision is made just inferior to the lash line. Medially, it extends to the punctum and laterally to the canthus with a slight curve inferiorly (Figure 74–5). The plane of dissection is between the skin and the orbicularis muscle down to the level of the orbital rim. Gentle globe pressure will then allow localization of areas of fat herniation. The muscle and septum are incised and the fat delivered and excised from all three compartments. Meticulous hemostasis is achieved. The skin flap is then retracted superiorly and laterally. A thin strip of hyper-



▲ **Figure 74–5.** Lower blepharoplasty incision.

▲ **Figure 74–6.** An open mouth and upward gaze allows for the precise excision of lower lid skin.



▲ **Figure 74–7.** Transconjunctival incision below the lower tarsus.

trophied orbicularis muscle may need excision at this point, followed by closure of the muscle edges. Finally, the skin flap is trimmed underneath the lid margin, taking exquisite care not to place any tension on this area. The patient must open his or her mouth and look upward to insure excessive skin in not removed (Figure 74–6). A combination of interrupted and running sutures can then be used to close the incision.

skin-muscle flap

The skin-muscle flap is developed in a plane between the orbital septum and the orbicularis muscle and is easier to develop than the skin flap. The incision is made as in the skin flap approach and dissection is carried through the orbicularis muscle and directed inferiorly toward the orbital rim. From there, the fat excision proceeds in the same fashion as with the skin flap. Excess skin and muscle is also trimmed in the same manner.

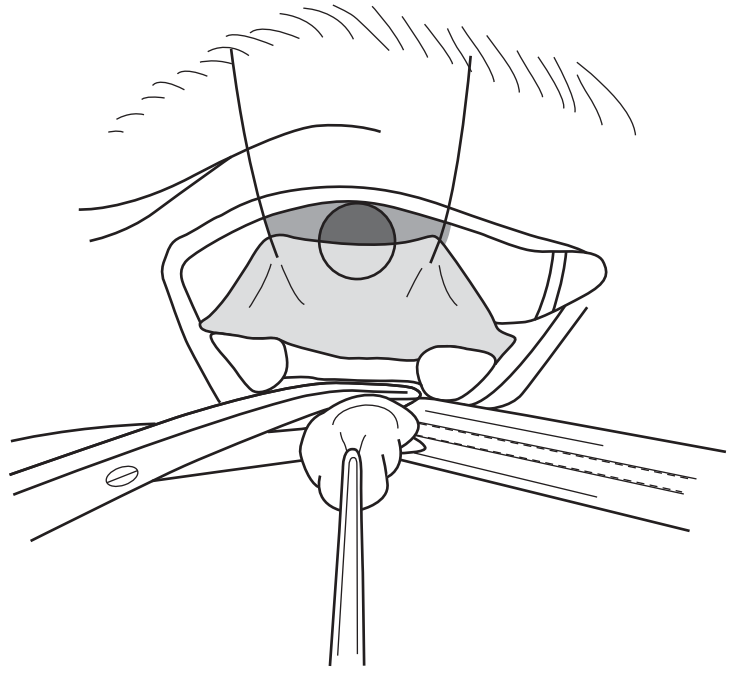
Transconjunctival Blepharoplasty

Transconjuctival blepharoplasty does not directly address the lid skin but, rather, only the orbital fat. However, advocates of this approach argue that the main problem is fat herniation rather than excess skin. By remaining postseptal, the orbital septum and muscle are left intact, which decreases the chance of lid retraction. In addition, external scarring is avoided. However, some surgeons believe that this approach is more likely to result in inadequate fat removal secondary to more limited exposure.

In performing a transconjunctival blepharoplasty, the conjunctiva is first anesthetized with topical tetracaine, followed by a direct injection of lidocaine with epinephrine. The globe is protected with a shield during the procedure. The technique itself utilizes an incision in the lower sulcus of the conjunctiva near the orbital rim (Figure 74–7). This can be made with electrocautery and the fat should be immediately encountered as it is located just under the surface. Gentle pressure delivers the fat and it is excised and cauterized in the usual fashion (Figure 74–8). As stated before, the incision does not need to be sutured close secondary to the tight adherence of the conjunctiva to the tarsal plate. If there is some mild redundant skin, some surgeons advocate the use of a CO_2 laser to tighten the skin in conjunction with the transconjunctival blepharoplasty. Another excellent resurfacing option is chemical resurfacing (ie, phenol peel) which is easily performed at the same time and can achieve nice tightening of the lower lid skin. The "pinch" technique, in which excess skin is pinched up with a forcep and sharply excised with a sharp scissor, is also effective.

POSTOPERATIVE CARE

Antibiotic ointment is applied to the incisions. Ice packs or cool compresses are applied to decrease edema and ecchymosis. Pressure dressings are not necessary as they hinder the ability to assess the presence of bleeding or vision changes. Pain is usually minimal and many patients may require no medication at all. Instructions are given to return immediately if there is an onset of pain, bleeding, or visual



▲ **Figure 74–8.** The excision of orbital fat in the transconjunctival approach.

disturbance. Patients are again reminded to refrain from aspirin or NSAID use. Sutures are removed in 3 or 4 days.

COMPLICATIONS

Loss of Vision

Isolated visual loss is the most serious complication of blepharoplasty and is fortunately a rare occurrence, with a reported rate of 0.04%. In the absence of intraorbital hemorrhage, the exact mechanism is unclear.

Retrobulbar hemorrhage is a surgical emergency. This increases the intraocular pressure and causes an ischemic optic neuropathy, the occlusion of the central retinal artery, or both. The onset of bleeding may often be related to postoperative vomiting or coughing. Clinically, the patient will have a rapid onset of pain and proptosis with associated eyelid ecchymosis. Return to the operating room is mandated with clot evacuation and control of any bleeding sites. Lateral canthotomy may also be necessary for immediate decompression. With a visual loss, the intravenous administration of mannitol and steroids is recommended to decrease intraocular pressure. A consultation with an ophthalmologist should also be made.

Ectropion

Ectropion is the most common complication of lower blepharoplasty. It occurs after excessive skin removal and is due to the rotation of the lid margin inferiorly with separation from the globe. It usually requires surgical correction either with horizontal lid shortening, muscle suspension, or full-thickness skin grafting.

Milia

The development of milia is the most common complication of upper blepharoplasty. This can easily be addressed by "unroofing" the lesions with a needle in the office.

Lagophthalmos

In the initial postoperative period, lagophthalmos is present in many patients secondary to lid edema. It may be permanent in patients with excessive skin resection or scarring. If lubrication, massage, and taping of the lid fail to correct the problem, surgical correction is necessary with a full-thickness skin graft.

Additional Complications

Some other complications of blepharoplasty are scleral show, lid asymmetry, ptosis, corneal injury, and dry eye. The incidence of all these complications can be minimized with careful surgical attention, a preoperative screening, and a detailed anatomic knowledge.

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We would like to acknowledge Minas Constantinides, MD, FACS for him contribution to this chapter in the previous editions of CDT.

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Rhinoplasty

Douglas D. Leventhal, MD &
Minas Constantinides, MD, FACS

HISTORY

The term rhinoplasty is derived from the Greek word "rhinos" which means nose and "plastikos" which means "to shape." Rhinoplasty is surgery that changes the appearance of the nose. More recently, the term "functional rhinoplasty" has been used to describe surgery that, in addition to changing appearance, also improves the function. Nasal reconstruction was first described in Ancient India by Sushruta in his text *Sushruta Samhita* circa 500 BC. Sushruta, considered to be the father of plastic surgery, used a variety of techniques to reconstruct nasal amputations, a common form of capital punishment at the time. These included pedicled, rotation flaps of the cheek and forehead. In the late 1500s, Professor Gaspare Tagliacozzi published a surgical textbook in Bologna showing nasal reconstruction using a flap from the upper arm. In the mid-1800s, Johann Freiderich Dieffenbach further refined the plastic surgical procedures of his time in his textbook titled *Operative Surgery*. He described techniques to reduce the size of the nose, such as excising a portion of abnormally enlarged nasal ala and making cruciate excisions of skin and cartilage. Aesthetic rhinoplasty though an intranasal approach was first described by American otolaryngologist John Orlando Roe in 1887 in his landmark article "The deformity termed 'pug nose" and its correction by a simple operation." In the late 1800s, Jacques Joseph arose as one of the most important figures in facial plastic surgery and was the pioneer of modern rhinoplasty. Joseph gave numerous lectures and practical courses on rhinoplasty that were attended by surgeons like Gustave Aufricht, Joseph Safian, Jacques Maliniac, John Maurice Converse, and Samuel Fomon. Fomon then began teaching a rhinoplasty course based upon Joseph's techniques. Two notable otolaryngologists who attended the courses were Maurice Cottle and Irving Goldman. As these surgeons trained other surgeons and surgical techniques became more refined, modern rhinoplasty was developed.

ANATOMY

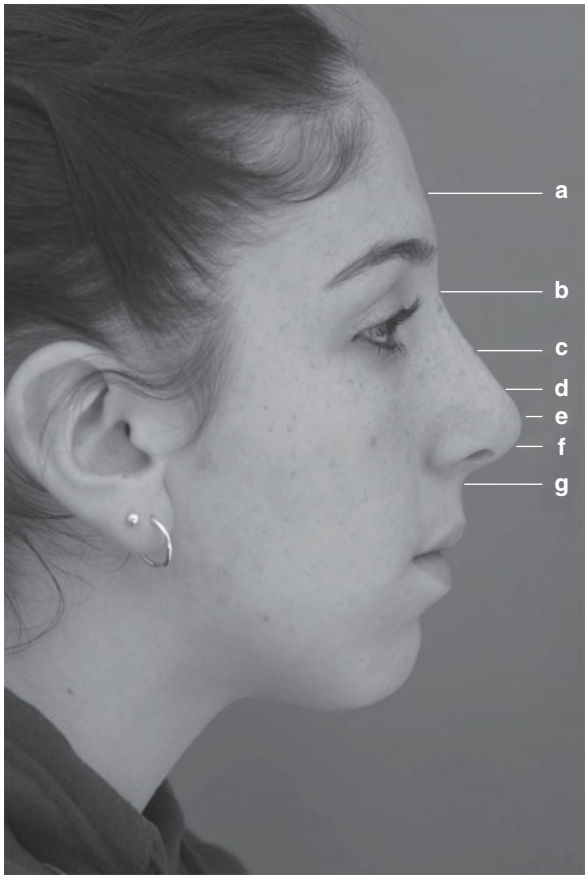
ESSENTIALS OF DIAGNOSIS

- The nose is made up of nine subunits—nasal dorsum, tip, columella, the paired nasal sidewalls, ala/sills, and soft triangles
- The three major tip support mechanisms are the strength and integrity of the lower lateral cartilages, and their attachments to the septum and to the upper lateral cartilages
- The internal and external nasal valves account for much of the nasal resistance to airflow and must be accounted for when performing rhinoplasty.

Surface Anatomy

The external surface of the nose is divided into nine subunits. They consist of the nasal dorsum, tip, columella, the paired nasal sidewalls, ala/sills, and soft triangles. The subunit principle described by Burget and Menick is based upon the notion that the human eye detects the shadowed valleys and lighted ridges of the nasal surface. This principle applies equally in nasal cosmetic surgery and in nasal reconstruction. In cancer or trauma, if more than 50% of a nasal subunit is lost, the remainder of the subunit should be removed. Thus, the whole subunit is replaced with scars designed to lie in the shadowed borders between subunits.

There are numerous facial and nasal anatomic landmarks that must be understood prior to performing an appropriate analysis (Figure 75–1). The ideal facial height divides the face into equal thirds between the trichion, glabella, subnasale, and menton. The ideal facial width divides the face into equal fifths. Thus, the width of one eye should be one fifth of the



▲ **Figure 75–1.** Topography of the nasal profile. Glabella **(a)**, Nasion **(b)**, Rhinion **(c)**, Supratip **(d)**, Tip **(e)**, Infratip **(f)**, and Subnasale **(g)**.

total facial width and equal to the intercanthal distance and nasal base width. Deviations from these ideals due to racial and ethnic differences are common.

Skin-Soft Tissue Envelope

The nose is composed of a bony-cartilaginous framework that is enveloped by a skin-soft tissue covering. This covering is thick at the nasion and tip and thin over the rhinion. This is important when reducing the bony and cartilaginous nasal dorsum as the varied skin thickness will influence the ultimate dorsal contour. Deep to the dermis, there are five soft-tissue components: a superficial fatty panniculus, a fibromuscular layer, a deep fatty layer, a longitudinal fibrous sheet, and an interdomal ligament. The fibromuscular layer consists of the nasal mimetic muscles that are encased and interconnected by the nasal superficial musculoaponeurotic system (SMAS). This nasal SMAS is continuous with the SMAS of the face. The proper plane when elevating nasal tissue whether for a rhinoplasty or nasal reconstruction is in the sub-SMAS plane.

The Bony/Cartilaginous Skeleton

The upper third of the nose consists of the paired nasal bones. These bones articulate superiorly with the frontal bone at the nasofrontal suture, superolaterally with the lacrimal bone, inferolaterally with the frontal process of the maxilla, and inferoposteriorly with the perpendicular plate of the ethmoid bone. The nasion refers to the bony nasofrontal suture, whereas the sellion denotes the soft tissue overlying that area. The radix is the root of the nose that encompasses both the nasion and sellion. The glabella is the prominence of the frontal bone between the eyebrows and is above the radix.

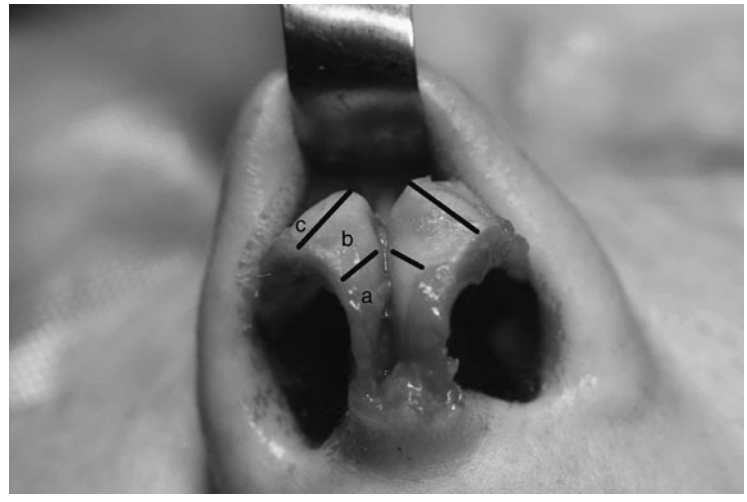
The cartilaginous septum makes up the middle third of the nasal dorsum. It is quadrangular in shape and articulates posteriorly with the bony septum (perpendicular plate of the ethmoid bone and vomer) and inferiorly with the maxillary crest. The caudal aspect of the cartilaginous septum has a defined anterior septal angle and posterior septal angle that play a significant role in the position of the nasal tip.

The upper cartilaginous vault is composed of the paired upper lateral cartilages (ULCs). These structures are triangular or trapezoidal in shape and fuse in the midline to the cartilaginous dorsum. The ULCs are also supported cephalically by their attachments to the nasal bones. The region where the ULCs attach to the under-surface of the nasal bones is called the keystone area. The cephalic aspect of the ULCs may overlap the caudal part of the nasal bones by up to 11 mm. It is imperative to maintain this relationship to prevent collapse of the ULCs and subsequent nasal obstruction. Caudally, the ULCs articulate with the lower lateral cartilages (LLCs) at the scroll.

The lower cartilaginous vault consists mainly of the paired LLCs or alar cartilages. The LLCs, which are extremely variable among individuals, determine the shape and configuration of the nasal tip. The refined tip is described by the double-break appearance, which consists of a supratip and infratip break. The supratip is defined by the junction of the nasal dorsum and the nasal tip, and the infratip is defined by the junction of the tip and columella.

The LLCs are C-shaped and may be divided into three parts: the medial crus, intermediate or middle crus, and lateral crus (Figure 75–2). The medial crura are the narrowest segment of the LLC. Each consists of a footplate segment that flares posterolaterally and an anterior segment that defines the contour of the columella. The medial crura are attached to the caudal septum by fibrous tissue and are separated from each other by loose connective tissue.

The intermediate crura join the medial crura to the lateral crura. The intermediate crura flare posterolaterally away from each other at the angle of divergence. The angle of divergence contributes to the infratip lobule and normally measures approximately 50–60°. Angles greater than 60° typically lead to a wide or boxy tip. The dome is a point where the intermediate crus joins the lateral crus and is the highest and most



▲ **Figure 75–2.** Lower lateral cartilage—Medial crus **(a)**, Intermediate crus **(b)**, and lateral crus **(c)**. The dome is at the junction between the intermediate crus and lateral crus.

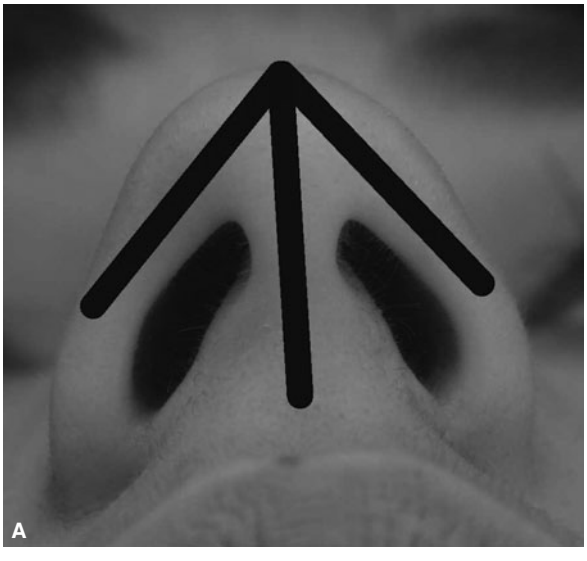
anterior point of the tip. The domes are joined medially by the interdomal ligaments. The domes correspond topographically to the tip-defining points and as such, surgical maneuvers to modify the domes are used to refine the nasal tip.

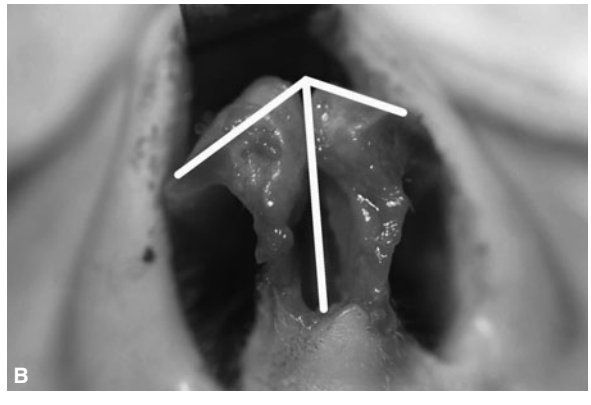
The lateral crura are typically convex in shape and extend posteriorly from the intermediate crura. The lateral crura initially parallel the alar rim, but then turn posteriorly, superiorly, and laterally toward the pyriform aperture. There is a variety of anatomic relations between the cephalic margin of the lateral crura and the caudal margin of the ULCs at the scroll region. Variations in width, shape, and strength of the lateral crura influence both the appearance and strength of the nasal tip.

Tip Support Mechanisms

Many surgeons would argue that the key to rhinoplasty is controlling the nasal tip. It is imperative to understand tip support and dynamics in order to achieve predictable results. Two related models have developed to help explain the complexities of the nasal tip cartilages: the tripod theory and the tip support mechanisms.

In the tripod concept, the anatomy of the LLCs is compared to that of a tripod where the conjoined medial crura formed one leg and each of the lateral crura represented the remaining two legs (Figure 75–3). Hence, in theory, changes in the length of the limbs of the tripod lead to predictable





▲ **Figure 75–3.** Nasal tripod shown topographically on base view **(A)** and intraoperatively through open rhinoplasty **(B)**.

changes in the nasal tip position. Decreasing the lengths of all three limbs equally results in tip deprojection whereas increasing the lengths would increase projection. Shortening the length of the medial crura and/or lengthening the lateral crura would result in caudal tip rotation, whereas the opposite maneuvers would lead to cephalic tip rotation.

The nasal tip classically has nine support mechanisms: three major and six minor. The major tip support mechanisms are: (1) the size, shape, and resiliency of the LLC; (2) the attachment of the LLCs to the caudal septum; (3) the attachment of the LLCs to the ULCs at the scroll region. The minor tip support mechanisms are: (1) the interdomal ligament; (2) the cartilaginous dorsal septum; (3) the sesamoid complex; (4) the attachment of the LLC to the overlying SMAS and skin; (5) the nasal spine; (6) the membraneous septum. When performing nasal surgery, tip support mechanisms need to be respected, and if weakened must be reconstituted to ensure a good functional and aesthetic outcome.

Nasal Valves

The nose is responsible for about two-third of the body's total resistance to airflow during breathing. There are two main valves in the anterior aspect of the nose that account for the majority of resistance: the internal nasal valve (INV) and the external nasal valve (ENV).

The INV is the narrowest segment of the nasal cavity and is the greatest resistance to nasal airflow. The INV is bordered by the septum, the head of the interior turbinate, the caudal edge of the ULC, and the pyriform aperture. The attachment of the ULC to the septum normally occurs at an angle of 10–15° in Caucasians. A connection at a more acute angle may lead to nasal obstruction. INV static narrowing or dynamic collapse and subsequent nasal obstruction may be caused by previous surgery, trauma, septal deviation, inferior turbinate hypertrophy, scarring, synechiae, or congenital malformations. The ENV is formed by the nasal floor/sill, the columella, and the caudal border of the LLC. ENV static narrowing or dynamic collapse may be caused by prior surgery, weak LLCs, a widened columella, thick skin-soft tissue envelope, deviated caudal septum, or nasal stenosis due to trauma or burns.

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PREOPERATIVE PLANNING

ESSENTIALS OF DIAGNOSIS

- There are numerous ideal aesthetic proportions that are used in the preoperative evaluation
- The standard views for preoperative rhinoplasty include: frontal, three-quarters, lateral, and base.

Nasal Analysis

Although beauty is truly in the eye of the beholder, various formulas and calculations have been derived to determine the ideal aesthetic nasal proportions. Preoperative analysis of the nose and how it relates to the rest of the facial units is the cornerstone of rhinoplasty. Table 75–1 shows the parameters that may be evaluated and analyzed in the frontal, lateral, and basal views.

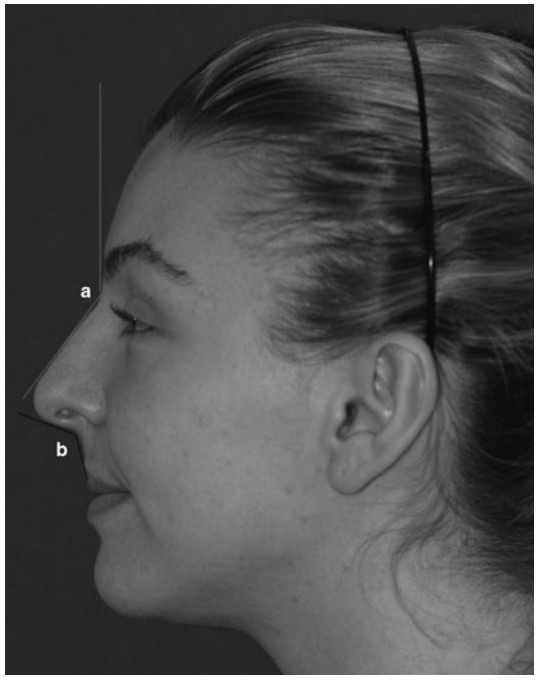
In the frontal view, the brow-tip esthetic line is a gently curved line from the medial eyebrow along the nasal dorsum to the ipsilateral light reflex. In a refined, symmetric nose, the two lines should form an hourglass figure. Also in the frontal view, the columella should be slightly inferior to the alar rims, the contour of which resembles a "gull in flight" silhouette. The frontal view is the most difficult view to achieve perfect symmetry. As such it is the most useful view in evaluating preoperative asymmetries and postoperative results. A useful supplement to the frontal view is the frontal smiling view. With this view, dynamic changes with smiling will often highlight asymmetries that are hidden in the unsmiling, the standard frontal view.

The lateral view is taken keeping in mind the Frankfort horizontal, an imaginary line from the top of tragus to the malar eminence. This line should be horizontal for the lateral view to best be used in interpreting the various aesthetic angles. In the lateral view, there are four aesthetic angles that are determined based upon the geometry of the

Table 75–1. Nasal Analysis on Various Views.

Frontal View	Lateral View	Base View
Nasal length	Nasal length	Columella/lobule relationship
Nasal deviation from the midline	Dorsal hump	Angle of divergence
Tip-defining points/light reflexes (5–10 mm apart)	Radix position	Shape of nasal tip
Tip shape/contour	Nasofrontal angle	Shape of nostrils
Brow-tip aesthetic line	Tip rotation	Position of caudal the septum
"Gull in flight" configuration	Tip projection	Width of ala
Lateral crural positioning ("Parentheses deformity")	Nasolabial angle	
Length of upper lip	Ala/columellar relationship	
	Angle of divergence (double-break)	
	Columellar show (2–4 mm)	
	Chin/malar projection	

nasal dorsum: nasofrontal angle (Figure 75–4), nasofacial angle, nasolabial angle (Figure 75–4), and nasomental angle. The nasofrontal angle is defined by the intersection of a line connecting the glabella and nasion and a line tangent to the nasal dorsum. The ideal measurement is 115° to 130°.



▲ **Figure 75–4.** Nasofrontal angle **(a)** and nasolabial angle **(b)**.

The nasolabial angle is determined by the intersection of a line tangent to the columella and a line from the subnasale to the upper vermilion border. The ideal measurement is 90° to 95° in men and 95° to 110° in women. A caudally rotated tip is often associated with a more acute angle and a cephalically rotated tip, a more obtuse angle. However, absolute tip rotation is determined by the angle of rotation of the dome off the Frankfort horizontal and so is *not* equivalent to the nasolabial angle.

The nasofacial angle is determined by the intersection of a line tangent to the nasal dorsum with a line from the glabella to the soft tissue pogonion. The ideal measurement is 36° to 40°. The nasomental angle is defined by the intersection of the line from the tip-defining point to the soft tissue pogonion and a line tangent to the nasal dorsum. The ideal measurement is 120° to 132°.

Nasal projection is best quantified on the lateral view. Numerous methods have been described to calculate nasal projection, but the three most commonly used are Goode's method, Crumley's method, and Simon's method. Goode's method states that a line from the alar-facial groove to the nasal tip equals 0.55–0.6 of the length of the nasal dorsum. Crumley related the nasal profile to a right triangle with vertices at the nasion, alar crease, and tip-defining point. The sides of the triangle should have a 3:4:5 ratios with a resultant nasofacial angle of 36°. Simon's method related nasal tip projection to the length of the upper lip. He determined that the distance from the subnasale to the upper vermilion border should equal the distance from the subnasale to the tip-defining point.

On the base view, the surgeon may assess the width of the ala that ideally equals the intercanthal distance. Alar flare, or the widest point of the mid-ala, can also be assessed. The relationship between the columella and the infratip lobule, ideally 2:1, is also easily seen. This is also the best view to

assess any deflection of the caudal septum and the effect it has on the columella and nasal tip.

The oblique (or ¾) views can enhance the overall evaluation by assessing the relationships between the dorsum, tip, and sidewalls and adding to the three-dimensional insight of the nose. On this view, if the dorsum is deviated from the midline, it will appear higher when photographed from the opposite side. In other words, a dorsum that is deviated to the right will appear higher on the left oblique view and lower on the right oblique view.

Initial Consultation

It is imperative to take a thorough history with all patients who are operative candidates. In addition to the standard medical/surgical history, questions regarding nasal obstruction, allergic rhinitis, and chronic sinusitis should be included. If the patient has signs and symptoms of chronic sinusitis warranting sinus surgery, this may be done in conjunction with rhinoplasty. In addition to the standard medical history, cosmetic patients may be asked about their motivations, goals, and expectations for surgery. Understanding patient's motivations will give the surgeon a better chance of insuring a successful outcome. In particular, patients who are overly preoccupied with trivial aspects of their appearance and who overstate what the surgery will do for their lives might best be screened for body dysmorphic disorder by a psychiatric professional.

Physical examination begins with the skin quality and texture. Although thick skin makes it more difficult to achieve tip definition, it does help to conceal cartilaginous tip irregularities. Furthermore, patients with thick skin tend to have more postoperative edema. A great deal of information regarding nasal anatomy can be gained via palpation. Nasal bones should be palpated both for irregularities and to assess bony length in relation to ULC length. Special care should be taken of patients with short nasal bones and long ULCs as they are predisposed to nasal valve collapse. The LLCs are palpated to evaluate size, shape, and strength. The tip recoil test is done by pressing the fingertip against the nasal tip and releasing it to determine the degree of resilience. If the tip resists retrodisplacement or springs back to its prior position, then the LLCs are probably able to retain satisfactory support following surgical manipulation. The caudal septum should also be palpated to assess deflection as well as to confirm the presence of septal cartilage in any secondary rhinoplasty.

In addition to examining the nasal anatomy in a static form, it is also imperative to perform a dynamic nasal examination. Classically, the Cottle maneuver is used to assess nasal valve incompetence. The standard Cottle maneuver is performed by distracting the cheek laterally; the modified Cottle maneuver supports the external and internal nasal valves using a cerumen curette during inspiration. This may be quantified by having the patient rate his nasal patency on each side independently on a ten-point scale at baseline, with support of the internal nasal valve, and with support of the external nasal valve.

Intranasal examination is performed using a speculum, headlight, and endoscope if indicated. It is necessary to evaluate for septal deviation or perforation, inferior turbinate hypertrophy, synechiae, and nasal valve scarring or stenosis. These abnormalities should be identified preoperatively and addressed in combination with rhinoplasty.

Photographs are taken of all patients as a guide to preoperative planning, as a teaching tool, and for medicolegal purposes. Pictures are typically taken in front of a blue background to provide a nice contrast to the human face. Standard views for preoperative rhinoplasty include: frontal, three-quarters, lateral, and base. Frontal and lateral smiling views help assess dynamic tip movement and asymmetries. Overhead views of the dorsum and tip may highlight dorsal deviations. Numerous computer programs are available that can morph these images to show patients how a realistic surgical result may appear.

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SURGICAL TECHNIQUES

ESSENTIALS OF DIAGNOSIS

- The incisions used in rhinoplasty include: intercartilaginous, intracartilaginous, marginal, and transcolumellar
- Rhinoplasty may be performed through an open, or external, approach or through a closed, or endonasal, approach
- Rhinoplasty surgery addresses the bony and cartilaginous dorsum, nasal valves, tip, and nasal base
- Cartilage grafts may be taken from the septum, ear, or rib.

Intraoperative Considerations

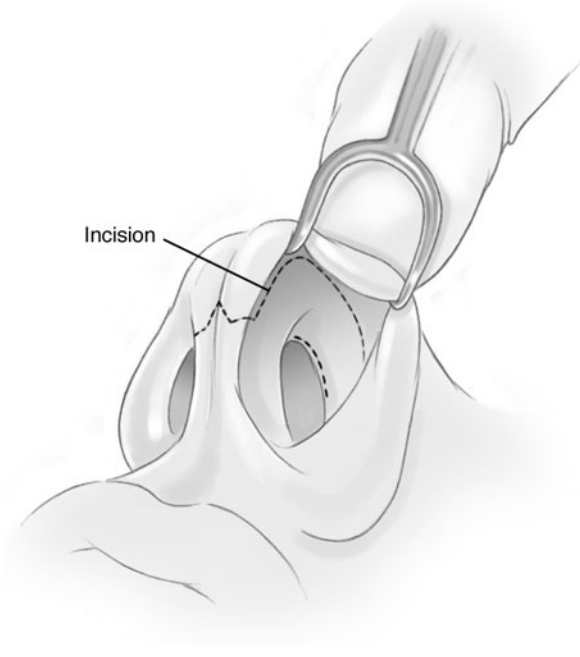
Rhinoplasty surgery may be performed either under sedation or general anesthesia. Once the patient is asleep, cocaine soaked pledgets are placed intranasally under the nasal bones, against the septum, and in the vestibule. A mixture of 1% lidocaine with epinephrine 1:100,000 on a 1.5-inch 27-gauge needle is injected regionally for infraorbital, supratrochlear, and pyriform aperture blocks. The septum, columella, tip, and nasal sidewalls are then injected. Injection is

given paradorsally to prevent any distortion of the midline dorsum. During the surgery, the medial and lateral surfaces of the frontal processes of the maxillae are injected prior to performing osteotomies.

Incisions

There are a variety of incisions that vary with the approach that allow the surgeon to access the septum, LLC, ULC, and nasal bones.

Incisions with the endonasal (closed) approaches: to expose the cartilaginous and bony septum, a hemitransfixion incision, (placed at the caudal septum) or a Killian incision (placed more posteriorly) may be used. An intercartilaginous incision is placed between the LLC and ULC (Figure 75–5). The incision begins posterior-laterally between the two cartilages and is carried anteromedially over the anterior septal angle. When exposure of the nasal tip is warranted, the incision is connected with a transfixion incision. A transcartilaginous or intracartilaginous incision is placed more caudally than the intercartilaginous incision and splits the cartilage of the lateral crus longitudinally. A marginal incision follows the caudal margin of the LLC (Figure 75–5). The marginal incision differs from the rim incision which is along the skin of the alar rim. Rim incisions are rarely performed since they may cause visible scars and alar retraction.



▲ **Figure 75–5.** Incisions used for rhinoplasty—transcolumellar, marginal, and intercartilaginous.

Incisions with the external (open) approach: the transcolumellar incision is through the skin of the midcolumella (Figure 75–5). Typically, the incision is made at the narrowest part of the columella, since the skin is thinnest and closely approximated to the underlying medical crural cartilage at this point. An inverted-V, stair-step, or other broken line incision is used to minimize scar visibility and contracture. The incision continues as a marginal incision intranasally. Some surgeons make a separate hemitransfixion incision to access the septum, while others will access it either by dissecting between the medial crura through the membranous columella, or by separating the ULCs from the dorsal septum and accessing it from above.

Approaches

There are two standard approaches to performing rhinoplasty surgery—endonasal/closed or external/open. Each has its own advantages and disadvantages. The approach that allows the surgeon to achieve the best outcome in his or her hands is the one that is best employed.

Endonasal rhinoplasty may be divided into the nondelivery and delivery approaches. There are two nondelivery approaches: the cartilage splitting and the retrograde. The cartilage splitting approach utilizes an intracartilaginous incision while the retrograde approach utilizes an intercartilaginous incision. Either of these approaches may be used when minimal tip refinement is needed since there is limited exposure of the LLC. The delivery approach employs an intercartilaginous and marginal incision and allows delivery of the LLC as a bilateral pedicled chondrocutaneous flap. This approach yields good visualization of the entire LLC without producing an external scar. Grafts are typically placed in perfect pockets rather than being sewn into position. However, this approach does compromise tip support since it disrupts the attachment of the LLC to the ULC and between the LLC and the septum (when a full transfixion is made).

External or open rhinoplasty approach affords the surgeon maximal exposure of the nasal skeleton and allows for accurate placement and suturing of grafts. Additionally, the nasal cartilages are operated upon in their natural anatomic position, allowing greater accuracy in establishing relationships between the various parts of the nose. The exposure of the underlying nasal anatomy is invaluable in resident education. The disadvantages of open rhinoplasty are that it takes longer to perform and may result in more postoperative edema. The external columellar scar, much maligned in the past, is not visible when executed and closed properly.

Bony Dorsum

Most surgeons prefer to adjust the nasal dorsum first and then make the necessary tip refinements; however, the opposite may also be done. There are four maneuvers typically performed on the nasal dorsum: reduction, augmentation, narrowing, and straightening.

Over-projection of the nasal dorsum may be due to overgrowth of the cartilaginous dorsal septum and/or the nasal bones. The cartilaginous dorsum is usually addressed first and is resected incrementally using either a #11 or #15 scalpel, or scissors. It is imperative that the surgeon spare the ULC while resecting the cartilaginous dorsum to prevent middle vault collapse. Once the cartilaginous dorsum has been reduced to the desired level, the nasal bones are then reduced to the appropriate height. Reduction of a bony hump may be performed using an osteotome and/or rasps.

Some patients have an insufficient nasal dorsal height and require augmentation. Both autologous and nonautologous graft materials have been developed for this purpose. Nonautologous materials include high-density porous polyethylene (Medpore, Porex Surgical Inc., Irvine, CA, USA), solid silicone rubber (Silastic), expanded-polytetrafluoroethylene (Gore-Tex, W. L. Gore and Associates, Flagstaff, Arizona), and acellular human dermis (Alloderm, LifeCell Corp., Branchburg, NJ). These materials may produce good results but surgeons must be cautious of the potential for infection and extrusion.

The septum is typically the first choice for cartilage graft harvest. Harvesting septal cartilage has little morbidity, requires no external incisions, and can yield a sufficient amount of cartilage. It is important that when removing portions of the quadrangular cartilage, at least 1cm of cartilage is left caudally and dorsally ("L strut") to prevent a saddle nose deformity. Furthermore, careful elevation of the mucoperichondrial flaps but be performed to prevent a perforation. Mattress sutures are usually placed after harvesting septal cartilage to appose the two flaps and decrease the risk of a septal hematoma.

In patients who do not have enough septal cartilage for grafting purposes, ear cartilage is usually the next donor site area. The conchal cartilage is removed, preferably from a postauricular approach, leaving the resultant auricular framework intact. Auricular cartilage possesses a natural curve and is softer and weaker than septal cartilage. Thus, it often needs to be folded on itself to produce a straight graft that may also provide support. Dissolvable mattress sutures through and through the ear are placed to prevent an auricular hematoma.

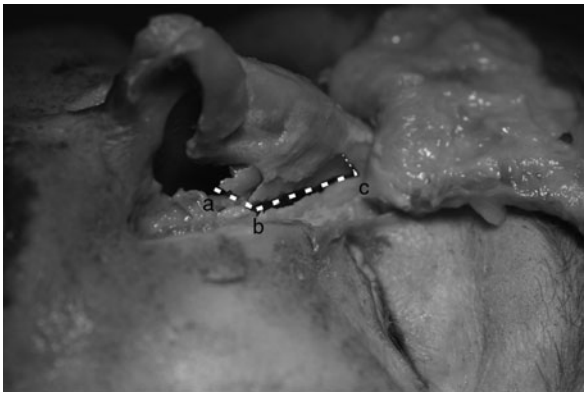
Rib cartilage is typically used either when an abundance of cartilage is required or significant support must be restored. Rib cartilage may be autologous or homologous (irradiated cadaveric costal cartilage). Most authors prefer autologous cartilage, although there is good support for using homologous cartilage in certain cases in the literature. The incision is placed in the inframammary crease and usually the sixth rib is harvested. When harvesting rib cartilage, extreme care must be taken to avoid violating the pleura, which could result in a pneumothorax. Many surgeons advocate getting a postoperative chest X-ray in all patients undergoing rib harvest. Rib cartilage is extremely firm and rigid and is more difficult to carve than septal or auricular cartilage. In addition, rib cartilage is prone to warping over time. All perichondrium should be removed in an effort to reduce this problem.

Any cartilaginous graft used for dorsal augmentation must be precisely contoured by adjusting the shape and thickness, and beveling the edges, of the graft. Over the time, especially in thin-skinned patients, cartilage grafts may become visible under the skin. To combat this problem, some surgeons place temporalis fascia or other soft tissue over the grafts to provide further camouflage. Newer techniques have been developed such as finely dicing the cartilage and wrapping it with temporalis fascia to further minimize the risk of a visible graft.

Osteotomies

Many patients present with a widened nasal pyramid that requires narrowing to obtain a more refined appearance. Narrowing the upper third of the nose is done by making osteotomies along the lateral and medial aspects of the nasal bones. Osteotomes come in various sizes and may be straight or curved. Some osteotomes are guarded in that they have blunted leading edges to assist the surgeon in palpating the location along the nose, and theoretically automatically raise a periosteal tunnel, while others do not. Prior to performing osteotomies, some surgeons elevate the periosteum off the lateral nasal bones to create a tunnel for the osteotome. Some surgeons perform curvilinear osteotomies intranasally by which the osteotome is introduced through an incision just anterior and superior to the head of the inferior turbinate. Other surgeons perform percutaneous osteotomies where a small osteotome (usually 2 mm) is placed through a stab incision at the midportion of the nasomaxillary junction. In this technique, the osteotome is used to perforate or "postage-stamp" the bone in the proposed path of the osteotomy to allow a precise fracture. Some surgeons have adopted a method of doing perforating osteotomies via an intranasal approach.

The most widely accepted path for lateral osteotomies is high (anterior), low (posterior), high (anterior) (Figure 75–6). The osteotome is placed slightly above the pyriform aperture to leave a small triangle of bone intact to maintain the attachments of the lateral alar suspensory ligaments. The osteotome travels posterolaterally, cutting through the pyriform aperture bone until the face of the maxilla. The osteotome is the directed superiorly along the junction of the frontal process of the maxilla and the face of the maxilla. At the nasal bones, the osteotome is then guided anteromedially. In certain patients, a lateral osteotomy alone is sufficient to produce a clean back-fracture of the nasal bones with resultant narrowing. Other patients may require medial osteotomies for a more controlled back-fracture. These are performed by placing the osteotome at the paramedian aspect of the caudal nasal bone, adjacent to the superior septum. The osteotome is then guided in a supero-lateral direction toward the medial eyebrow so as to connect to the superior portion of the lateral osteotomy. Intermediate osteotomies are placed in between the medial and lateral osteotomies and are typically done when one nasal



▲ **Figure 75–6.** High **(a)** Low **(b)** High **(c)** lateral osteotomy (thick dotted line) shown in a cadaver dissection. Backfracture of the nasal bone is shown by thin dotted line.

bone is significantly longer or more convex than the other to make them more symmetric. A transverse root osteotomy is a percutaneous horizontal osteotomy through the root of the nasal bone at the nasion using a 2 or 3 mm osteotome. This is employed when the nasal bone deviation occurs superiorly at the nasal root.

Middle Third and Nasal Valves

The middle third of the nose is composed of the ULC and dorsal septum. As aforementioned, the ULC is a major component of the INV and weakness of the cartilage may lead to collapse and nasal obstruction. Numerous techniques have been described to treat nasal valve collapse depending upon the etiology. Two of the more popular techniques include spreader grafts and flaring sutures. Sheen described the use of spreader grafts, placed between the septum and ULC to lateralize the ULC and increase the cross-sectional area of the INV. Park described the use of flaring sutures, horizontal mattress sutures placed through the caudal/posterior aspects of both ULCs and across the nasal septum. By tightening this suture over the nasal dorsum, the ULCs flare laterally and increase the INV angle. The conchal cartilage "butterfly graft" has also been used successfully to treat INV collapse following rhinoplasty.

Alar batten grafts have been used to treat INV and ENV collapse. These are overlay grafts placed over the posterior lateral crura and spanning to the pyriform aperture. Lateral crural strut grafts are underlay grafts attached to the undersurface of the lateral crura between the cartilage and vestibular mucosa.

Alar rim grafts are used when the ala is weak and dynamic collapse is noted with inspiration. These are nonanatomic grafts as they are placed along the alar rim where there is normally only fibrofatty tissue. These grafts may also be used to correct asymmetries caused by alar retraction.

Asymmetry of the middle third may occur when one side is concave and the other side is convex in shape. This deformity may be corrected by placing a spreader graft or onlay graft on the concave side to create symmetry. Clocking sutures and sidewall-spreading sutures have also been described to align asymmetric ULCs and a deviated dorsal septum.

Nasal Tip

The nasal tip is probably the most complex and variable region of the nose. As such, a myriad of techniques have been developed to alter tip projection and rotation. Table 75–2

Table 75–2. Techniques to Alter the Nasal Tip.

Increase Projection	Decrease Projection	Increase Rotation	Decrease Rotation
Transdomal/Interdomal suture	Full transfixion	Cephalic trim	Shorten medial crura (Lipsett procedure)
Columellar strut	Reduce posterior septal angle	Dorsal reduction	Augment nasal dorsum
Septocolumellar suture	Lateral crural overlay	Anterior septal angle reduction	Caudally positioned tip graft
Lateral crural steal	Vertical lobule division with overlay at medial crura (Lipsett procedure)	Lengthen medial crura	
Medial crural advancement	Augmentation of chin, cheek, lip (relative)	Lateral crural steal	
Tip graft		Lateral crural overlay	
Goldman tip		Vertical dome division with overlay	
		Plumping/premaxillary graft	

shows the various techniques as they relate to projection and rotation. Details of each of the techniques are beyond the scope of this chapter but the reader may refer to the references for more information.

Nasal Base

The nasal base or width of the nose consists of the columella, nasal sill, and ala. This area of the nose is usually addressed at the end of the procedure since changes to the nasal tip may affect the amount of alar flare. A wide alar base is prevalent among certain ethnicities, such as African Americans, and surgeons should not strive to create a Caucasian nose in patients who wish to maintain their ethnicity.

The widened alar base may be a result of a widened nasal sill and/or an excessive amount of alar flaring. A nasal sill excision is indicated when the nostrils are widened and have a horizontal axis whereas a Weir excision is performed when excessive alar flaring is present. Depending upon the etiology, tissue may be excised from either area to narrow the width of the nasal base. Patients must be made aware that the technique requires an external skin excision and meticulous closure is imperative to prevent a noticeable scar.

Postoperative Care

At the end of the procedure, the nose is taped and a cast is placed to stabilize cut nasal bones and to minimize postoperative edema. If there are lacerations of the septal flaps, septal splints may be used to minimize the risk of synechiae.

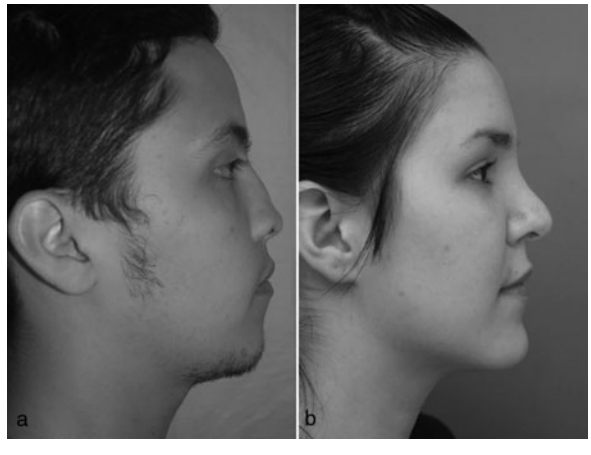
Patients are given postoperative instructions to apply cold compresses for 48 hours, refrain from heavy lifting and nose blowing for 1 week, and to avoid aspirin or ibuprofen products for 2 weeks. The use of postoperative antibiotics is controversial; there is little evidence in the literature that antibiotics play a valuable role postoperatively. An antibiotic ointment applied into the nostrils help incisions to seal more quickly and keep crusts from forming. Saline nasal spray can be used as needed. Patients are evaluated within the first few days of surgery to ensure that there is no early complication of surgery, such a septal hematoma.

The nasal cast, septal splints, and all external sutures are removed after one week. Patients routinely are instructed to perform nasal pressure exercises to ensure the nasal bones heal as straight and narrow as possible. Patients are typically seen again as frequently as needed to ensure an ideal outcome and answer relevant concerns.

Complications

Rhinoplasty is one of the most difficult cosmetic procedures performed today, which is why the revision rate may be as high as 20% in primary cases and 50% in revisions. Consequently, there are numerous complications that can arise from rhinoplasty. General complications include bleeding, scarring, infection, septal perforation, and the need for revision surgery.

Dorsal irregularities may occur if the bony or cartilaginous dorsum was not precisely contoured. A rocker deformity arises when the lateral osteotomy is carried too far superiorly into the thick frontal bone. When the nasal bones are medialized, the osteotomized bony segment protrudes laterally beyond the radix. This can be corrected by performing a percutaneous osteotomy at the point of the bony irregularity. An "open sky" deformity occurs when a dorsal hump is reduced to the point where there is a gap in the midline between the nasal bones. This is both palpable and visible and is treated by performing osteotomies or filling the gap with a soft cartilage graft. A saddle-nose deformity occurs when there is not enough cartilaginous septal support in the middle third of the nose and manifests with a concavity along the dorsum (Figure 75–7(**a**)). It can also occur with over-resection of the cartilaginous septum or loss of septal cartilage as a complication of an untreated infection, hematoma, cocaine abuse, or other inflammatory or autoimmune disorder. The severity of this deformity varies but the mainstay of treatment consists of providing septal support and augmenting the nasal dorsum with the use of cartilage grafts. A pollybeak deformity is a convexity of the cartilaginous dorsum/supratip region that may be categorized into cartilaginous or soft tissue etiologies (Figure 75–7(**b**)). A cartilaginous pollybeak arises when the cartilaginous dorsum has been relatively underresected compared to the bony dorsum and is treated by reducing the cartilaginous dorsum. A soft tissue pollybeak occurs when there is excessive scar formation in the supratip region, often from overresection of the dorsum or tip in a patient with thick skin, and may be treated with steroid injections. An inverted-V deformity can occur along the nasal dorsum when the ULCs lose their attachments to the nasal bones and/or the septum and collapse inward. The collapse exposes the contour of the caudal edge of the



▲ **Figure 75–7. (A)** Saddle nose deformity and **(B)** Pollybeak deformity.

nasal bones, which is in the shape of an upside down V. The placement of spreader grafts assists in resuspending the ULC to the septum and opening the nasal valve area.

The nasal tip being the most complex region of the nose may also be fraught with complications in the hands of inexperienced surgeons. Nasal bossae are irregular knoblike protuberances of the LLCs that cause asymmetries of the nasal tip. Bossae may occur from irregularities of the cartilages themselves or from contractive scar forces acting on weakened cartilages. A pinched tip can result when the domes are excessively narrowed via a dome division or aggressive interdomal/transdomal suturing techniques. Alar retraction may occur secondary to scarring or aggressive cephalic excision and treatment typically requires supporting the LLCs with grafts. Severe alar retraction may warrant an auricular composite graft that consists of skin and cartilage to replace the scarred vestibular mucosa.

Conclusion

Rhinoplasty is one of the most challenging and rewarding procedures performed by facial plastic surgeons. To become a masterful rhinoplasty surgeon, one must possess a profound understanding of nasal anatomy and be able to execute a variety of targeted surgical techniques. In addition, the surgeon must know which technique to implement for each individual situation to achieve consistent, superior results. This process of constantly learning what works and what does not in rhinoplasty is why even the masters observe that it is an operation that takes a lifetime to fully understand.

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Tardy ME. Rhinoplasty tip ptosis: Etiology and prevention. *Laryngoscope.* 1973;83(6):923–929.
Toriumi DM, Checcone MA. New concepts in nasal tip contouring. *Facial Plast Surg Clin North Am.* 2009;17(1):55–90.
Toriumi DM, Josen J, Weinberger M et al. Use of alar batten grafts for correction of nasal valve collapse. *Arch Otolaryngol Head Neck Surg.* 1997;123:802–808.

We would like to acknowledge Alexander L. Ramirez, MD and Corey S. Maas, MD for their contribution to this chapter in the previous editions of CDT.

Hair Transplantation

76

Marc R. Avram, MD & Nicole E. Rogers, MD

Introduction

Hair is one of the few physical characteristics over which we have voluntary control. The length, the color, and how we style our hair are a reflection of our personality and how we project ourselves to the world. When our hair *involuntarily* begins to disappear, it is a source of ongoing emotional and psychological stress for many men and women.

Fortunately, modern techniques in hair transplantation can consistently restore a natural frame of hair around the face (Figures 76–1 and 76–2). The era of large, pluggy, unnatural transplanted hair, which existed from the 1960s until 1990s no longer exists. Currently, the cosmetic standard for transplantation is to create consistently natural appearing transplanted hair for men and women. This chapter will be an overview of state-of-the-art techniques in hair transplantation.

The Consult

As with all surgical procedures, a consultation is vital to the success of the procedure. In addition to a physical examination, a thorough hair loss and medical history should be obtained. Key questions include: How long the hair loss has been going on? What medications have been used to date, and with what success? What is the goal of the patient from the procedure?

On physical exam, the caliber of hair follicles and available donor density are the two most important physical characteristics to determine. Patients with thick caliber, coarse hair and high donor density will be able to create the perception of thick transplanted hair while patients receiving an equal number of fine caliber follicles, with poor to average donor density will appear to have received much less hair.

The physician should review the ongoing nature of male and female pattern hair loss. Patients should be aware that the net perceived density of the procedure equals the number of follicles transplanted minus their ongoing hair loss. For all patients, the role of minoxidil and finasteride for men, and minoxidil for women should be reviewed. Both medications are FDA-approved and are highly effective to help maintain existing hair.

If a patient uses a medication and undergoes hair transplantation, there can be a substantial increase in perceived density, both short and long term. Despite the success of medications, it should also be emphasized that the medications are elective and can be stopped at any time. It is the obligation of the surgeon to plan a transplant anticipating future hair loss. If a patient ever does discontinue the medication and more of their original hair is lost, the transplant should appear natural both short and long term.

An overview of the procedure, preoperative and postoperative instructions should be reviewed.

The key to success is to create realistic expectations based on each patient's physical exam, ongoing hair loss, and individual goals.

Olsen EA, Whiting D, Bergfeld W et al. A multicenter, randomized, placebo-controlled, double-blind clinical trial of a novel formulation of 5% minoxidil topical foam versus placebo in the treatment of androgenetic alopecia in men. *J Am Acad Dermatol*. 2007;57(5):767–774.

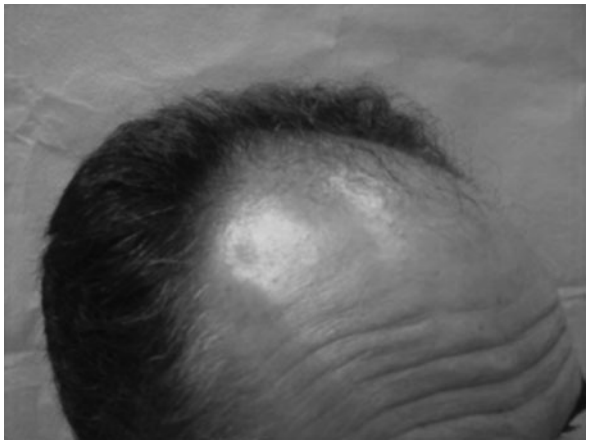
Price VH, Menefee E, Sanchez M. Changes in hair weight in men with androgenetic alopecia after treatment with finasteride (1mg daily): 3- and 4- year results. *J Am Acad Dermatol*. 2006; 55(1):71–74.

Rogers NE, Avram MR. Medical treatments for male and female pattern hair loss. *J Am Acad Dermatol*. 2008;59(4):547–566.

Stough DB, Rao NA, Kaufman KD et al. Finasteride improves male pattern hair loss in a randomized study in identical twins. *Eur J Dermatol*. 2002;12(1):32–37.

Donor Harvesting

Hair transplantation is based on the theory of donor dominance, which states that hair transplanted from the posterior scalp and moved to the front of the scalp will maintain its



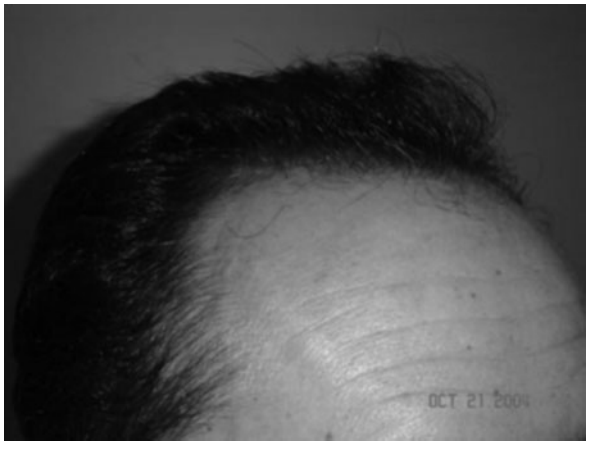
▲ **Figure 76–1.** Before hair transplantation.

natural genetic destiny and *not* to be affected by male or female pattern hair loss. The donor ellipse and follicular unit extraction (FUE) are the two techniques for harvesting hair follicles.

Limmer BL. Elliptical donor stereoscopically assisted micrografting as an approach to further refinement in hair transplantation. *J Dermatol Surg Oncol*. 1994;20 (12):789–793.
Norwood O, Limmer BL. Advances in hair transplantation. *Adv Dermatol*. 1999;14:89–113.
Orentreich N. Autografts in alopecia and other selected dermatological conditions. *Ann NY Acad Sci*. 1959 20;83: 463–479.

Ellipse

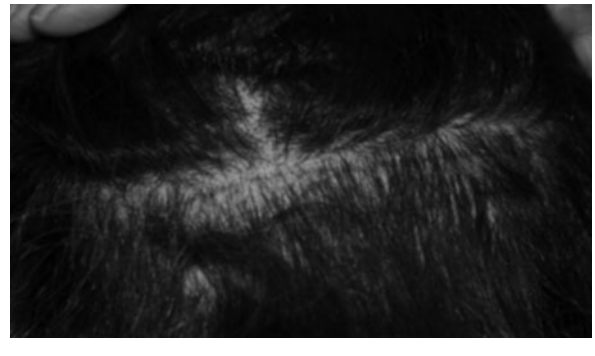
Elliptical donor harvesting is performed in the vast majority of patients. It is comparable to any other cutaneous excision, such as for skin cancer removal. The donor hair is trimmed



▲ **Figure 76–2.** After 900 1-3 hair grafts.

▲ **Figure 76–3.** Trimmed donor region.

to a length of 1–2 mm (Figure 76–3). The patient is placed in the prone position for optimal ergonomics using a special prone pillow. The skin is infiltrated with local anesthesia. To obtain optimal hemostasis the infiltration should be performed in the dermis rather than the subcutaneous area. The ellipse is removed either with an individual scalpel or utilizing double bladed knives with two #10 blades. The width of the donor ellipse should be kept to 1 cm or less in order to have minimal tension on the donor wound. This should result in a 1–3 mm wide donor scar (Figure 76–4). Also, vari-



▲ **Figure 76–4.** Donor scar 7 days postoperatively.

ous techniques exist for minimizing the appearance of the donor scar, so that the underlying hair may "grow through" the scar. The length of the donor ellipse depends on the desired number of hair grafts for the procedure.

Once the ellipse is removed, the donor area is closed with a single layer of either sutures or staples. Extensive undermining and deep sutures are typically not necessary. The staples or sutures are removed in 7–10 days.

The main advantage of elliptical harvesting is its straightforward nature and the ability to harvest hundreds to thousands of follicular groupings with minimal trans-section of the follicles.

The main disadvantage of elliptical donor harvesting is the permanent thin scar that results from the excision as with any excision. For most patients, this is of no practical concern since existing hair on the posterior scalp will easily cover any scar.

FUE

For a minority of patients who like to shave their hair or wear their hair closely cropped on the posterior scalp, FUE is an alternative donor harvesting method. The chief advantage of FUE is the lack of the perceptible donor scar. FUE is performed by utilizing 1 to 1.2 mm steel punches similar to the ones used in dermatology for skin biopsies to harvest individual follicular groupings from the donor scalp (Figure 76–5).

As one would expect this is a more time consuming process, which is of no long-term concern but the potential disadvantage of FUE is greater transection of follicles as they are removed from the donor scalp. To date there are no definitive studies showing whether or not this of any consequence to the yield of hair removed from follicular unit extraction.

Currently, the overwhelming majority of patients opt for elliptical donor harvesting due to the shorter time needed and lower rate of follicle transection, leading to predictably excellent growth. For most patients, the donor scar is not a major issue so long as their hair is long enough to cover. Nonetheless, FUE is an excellent treatment option for those patients who may shave their hair in the future or like to wear their hair closely cropped on the posterior scalp.

Anesthesia

Hair transplantation is performed in the majority of patients using local anesthesia. The challenge with transplantation is the need to keep the scalp anesthetized for several hours as recipient sites are created and then grafts are placed into the area. We use various concentrations of lidocaine with epinephrine to maintain comfort for the patient and hemostasis in the areas of graft placement. Also, a combination of different techniques including nerve blocks of the supraorbital and supratrochlear nerves and field and ring blocks to the scalp as well as the use of longer acting anesthetics such as bupivicaine.

For a minority of patients who request to be sedated, or require cardiac monitoring during the procedure, IV sedation is an excellent alternative. As with all IV sedation procedures, if performed, it should be done only in a certified operating theater with an experienced anesthesiologist present at all times.

Graft Creation

From the 1960s–1990s 10 to 20-hair, 3 to 5 mm plugs were utilized. This unfortunately resulted in the "pluggy, doll's hair" appearance of transplanted hair. This is an unfortunate public legacy of hair transplantation. Contemporary surgery maintains the natural anatomy of 1–3 hair follicular groupings as they grow on the scalp. Once the donor ellipse is removed, it is placed in chilled saline and carefully dissected into these 1–3 hair follicular units. The majority of hair transplant teams use magnification to aid in the dissection of the follicular groupings from the donor ellipse (Figure 76–6).

▲ **Figure 76–5.** FUE in posterior scalp.

▲ **Figure 76–6.** Graft creation using magnification.

The key to success is to have excellent ergonomic conditions, which include plenty of light, good room temperature, and comfortable seating and counter space for separating the grafts.

Avram MR. Polarized light emitting diode magnification for optimal and recipient site creation during hair transplantation. *Derm Surg*. 2005;31(9):1124–1127.
Bernstein RM, Rassman WR. Follicular unit transplantation. *Dermatol Clin*. 2005;23(3):393–414.
Bernstein RM, Rassman WR, Stough D. In support of follicular unit transplantation. *Dermatol Surg*. 2000;26(2):160–162.

Hairline Design

Unfortunately, for decades, hair transplant surgeons took the meaning of hair *line* literally. Besides using unnaturally large plugs, they were placing the hairs in very straight, "picket fence" lines across the frontal scalp. Hairlines are actually irregular transition zones from glabrous to hair bearing scalp. Contemporary transplantation mimics this with irregular, "feathered" hairlines in both the frontal, temporal, and posterior scalp in men (Figure 76–7). The frontal hairline should be placed at least 7–9 cm above the glabella and have a natural temporal recession. In addition, the surgeon should avoid placing grafts in the vertex of very young male patients (twenties to thirties) given the difficulty of predicting his future hair loss. Precious donor hairs may be used up to fill a continuously expanding "bald spot" otherwise grafts placed in the center can look very unnatural when isolated by lost surrounding hairs.

Stough DB, Bondar GL. The Knudson nomenclature. Standardizing terminology of graft sizes. *Dermatol Surg*. 1997;23(9):763–765.

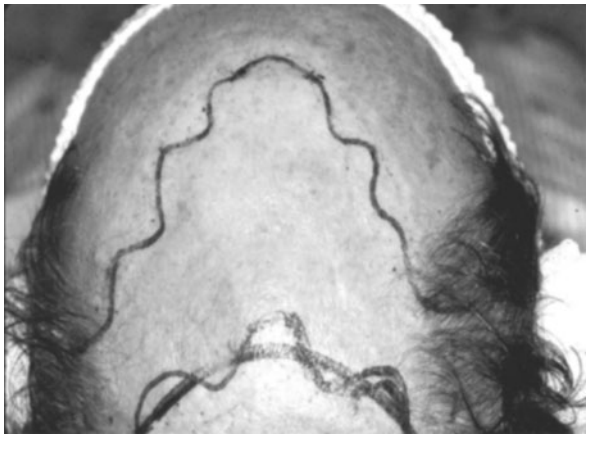
Recipient Site Creation and Placement of Grafts

Recipient sites are created using a variety of instruments, ranging from #18 to # 21 gauge needles to specialized spear points or chisel tips. When making the incisions, it is important to follow the natural angle of hair growth and avoid transecting existing hair follicles. The depth of the sites should be 4–5 mm, to mimic the natural depth of hair follicles in the skin. Depending on the density of existing follicles, 10–30 recipient sites per cm^2 are made for optimal density.

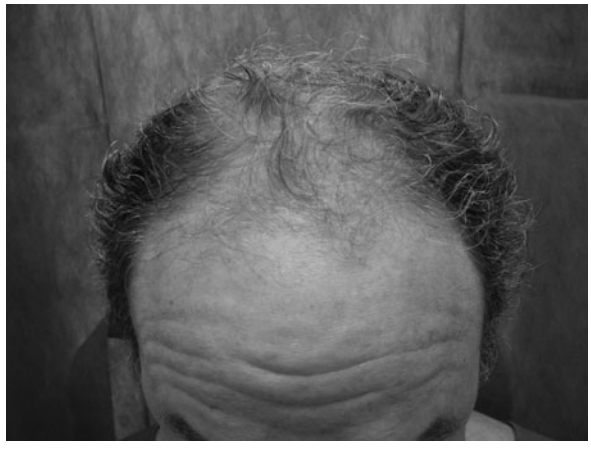
Grafts are placed into the recipient area utilizing microvascular forceps. All grafts should, at all times, remain chilled and never desiccate while being transferred from the chill saline Petri dish into the scalp.

Postoperative Care

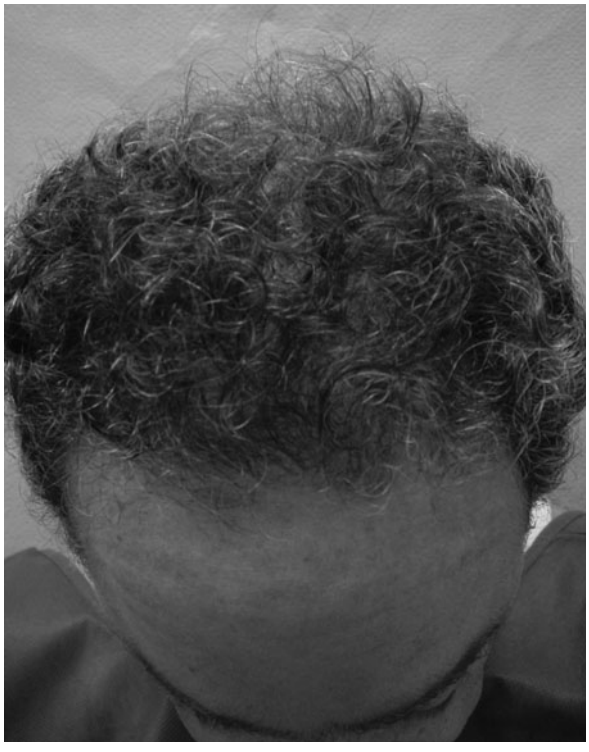
An experienced hair transplant team can place an average of 500–1500 grafts, over a period of takes three to 6 hours. After the last graft is placed, a dressing is applied to protect the grafts while they heal overnight. Patients return home and may resume regular activities, but should avoid heavy exercise for 3–4 days. A short course of prednisone to prevent frontal edema and extra strength acetaminophen can be used as needed during the first few days after the procedure if there is any discomfort or headache. The day after the procedure, the dressing is removed at home by the patient. The patient should feel well and should be encouraged to shower. This will help remove hemorrhagic perifollicular crusting. Most of our patients with existing hair elect to do the procedure at the end of a work week, so they have the weekend to convalesce. Sutures or staples are removed in 7–10 days. Transplanted hair begins to grow 3–6 months after the procedure and the full cosmetic impact occurs approximately 1 year after the surgery (Figures 76–8–76–13).



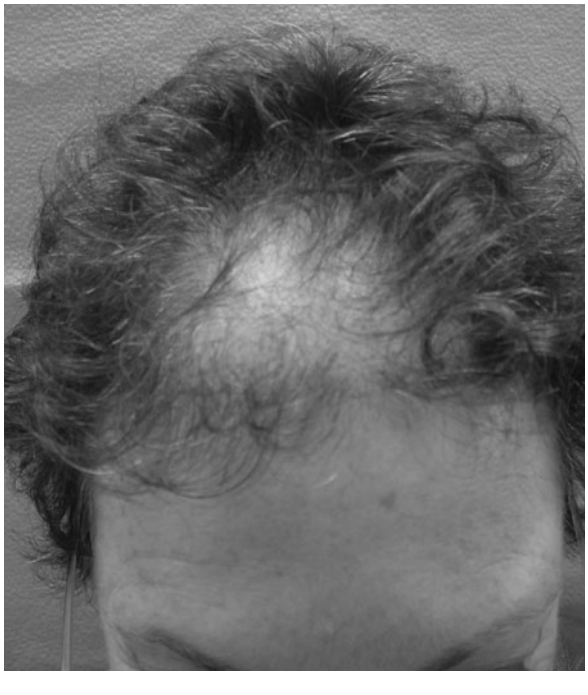
▲ **Figure 76–7.** Hairline drawn on scalp.



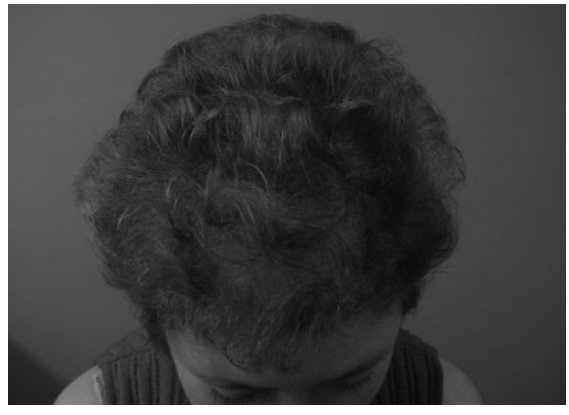
▲ **Figure 76–8.** Before hair transplantation.



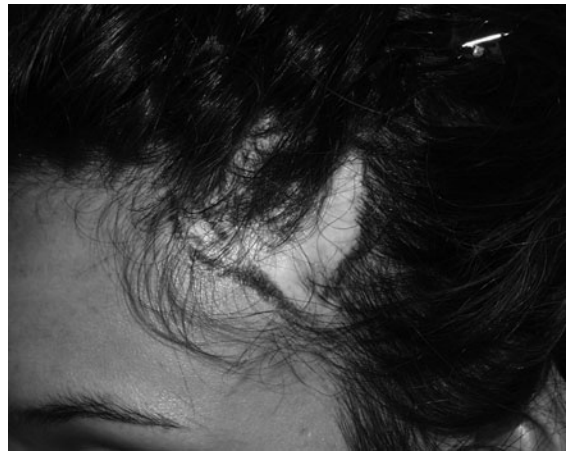
▲ **Figure 76–9.** After 850 1-3 hair grafts.



▲ **Figure 76–10.** Before hair transplantation.

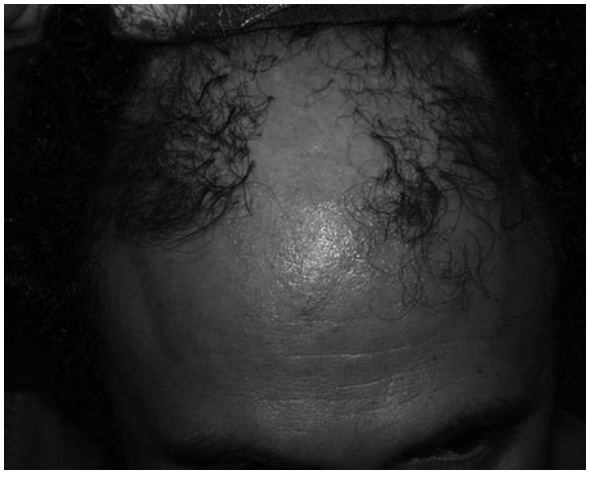


▲ **Figure 76–11.** After 650 1-3 hair grafts.



▲ **Figure 76–12.** Before hair transplantation into scar secondary to trauma.

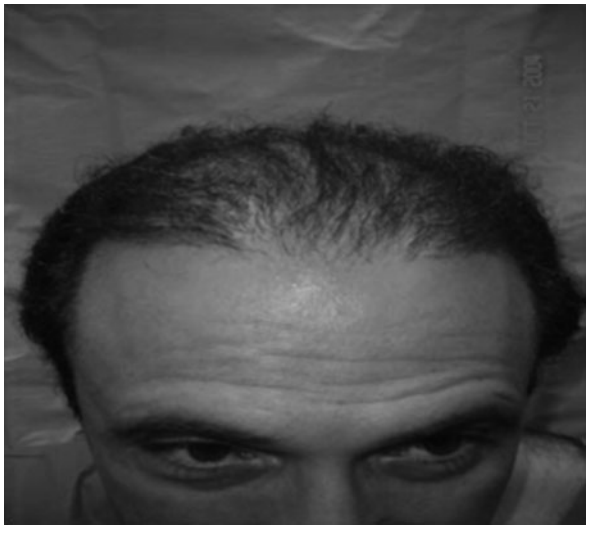
▲ **Figure 76–13.** After 350 1-3 hair grafts.



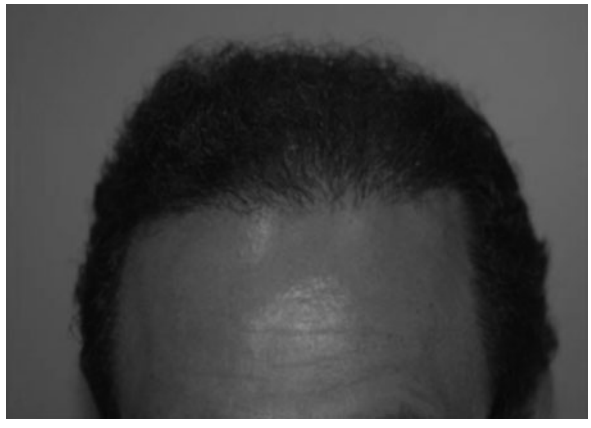
▲ **Figure 76–14.** Large pluggy grafts.

Corrective Hair Transplantation

Patients with unnatural hairlines and /or inappropriately placed grafts can be substantially improved through a variety of techniques. Patients who received large "pluggy" grafts in the past can be improved by adding one to three hair follicular groupings between the existing plugs. This is similar to filling in gaps between trees with bushes to make it a more natural and softer appearance (Figure 76–14–76–16). If the large grafts were placed in the scalp where they never should have been, such as the vertex, they can be removed using a 3–4 mm punch biopsy. When the plugs are removed, they are redivided and placed back into the scalp as follicular groupings. Significant emotional and psychological distress can be relieved by simple corrective techniques.



▲ **Figure 76–15.** After one procedure.



▲ **Figure 76–16.** After three hair transplant procedures show major cosmetic improvement.

Unger W et al. The surgical treatment of cicatrical alopecia. *Dermatol Therapy*. 2008;21(4):295–311.

Future

Contemporary transplantation offers a consistently natural appearing result for both men and women. Well-trained teams utilizing large numbers of one to three hair follicular groupings are able to produce natural short and long-term results when done appropriately. The future may offer cloning. Cloning of follicles will not affect the aesthetic result but will give an unlimited donor density and eliminate the need for donor harvesting from the scalp. Presently, there is privately funded research in the area, but it will be many years before we can offer this to our patients.

We would like to acknowledge Min S. Ahn, MD for his contribution to this chapter in the previous editions of CDT.

77

Local Skin Flaps in Facial Reconstruction

Judy Lee, MD, & W. Matthew White, MD

This chapter presents a basic overview of the approach to reconstruction of cutaneous facial defects with local skin flaps. Emphasis is placed on the understanding of the anatomy, evaluation of a defect, and design of an appropriate local skin flap.

ESSENTIALS OF DIAGNOSIS

For successful local flap reconstruction of facial defects, the surgeon must have a thorough understanding of thefollowing.

- Biomechanics of soft tissues
- Vascular supply to the face and given skin flap
- Aesthetic subunits and the relaxed skin tension lines of the face (RSTL)
- Dimensions and depth of the defect
- Inherent structural characteristics of the native skin in the area of the defect (ie, thickness and sebaceous character).

Introduction

Successful reconstruction of facial defects requires a thorough understanding of skin anatomy and physiology, careful analysis of the defect, and meticulous soft tissue techniques. Options for reconstruction should generally proceed from least invasive to most invasive in terms of morbidity. This approach is termed the "reconstructive ladder." Most facial defects that are too large for primary closure are amenable to local flaps. When planned and executed properly, local flaps allow for rapid reconstruction with a reliable blood supply, minimal morbidity, and excellent cosmesis. This chapter reviews the classification of commonly used local skin flaps and outlines the use of local flaps for facial reconstruction.

In considering the appropriate surgical approach for a given defect, the surgeon should not forget that secondary intention healing is a viable option for concave areas of the face.

Principles in Flap Design

When possible, local flaps should be designed in the same aesthetic unit as the initial defect. Lines of excision should usually be made parallel to relaxed skin tension lines (RSTL) or along aesthetic borders to optimize scar camouflage. If the defect involves multiple aesthetic subunits, it may be necessary to use a separate flap for each subunit. If more than 50% of a subunit is involved, the defect may be enlarged to reconstruct the entire unit with a flap. Placing incisions parallel to RSTLs reduces tension on wound closure by placing maximal tension into lines of maximal extensibility (LME). Skin tension and its distribution are important to avoid distortion of key facial landmarks such as the eyelid, lip, and the nasal ala.

Burget GC, Menick FJ. The subunit principle in nasal reconstruction. *Plast Reconstr Surg*. 1985;76:329–347. (Classic article describing the subunits of the nose.)

Zitelli JA. Secondary intention healing: an alternative to surgical repair. *Clin Dermatol*. 1984;2:92–106. (This paper describes secondary intention healing and the areas of the face that are most amenable to this technique.)

Classification

Local skin flaps can be classified either by their blood supply or by the method of transfer. (Table 77–1)

A. Flap Blood Supply

Surgeons must be familiar with the vascular supply of a local flap, either random (supplied by the dermal and subdermal vascular plexuses) or axial (supplied by a named artery and vein). Most axial flaps have some random blood supply at their distal ends.

Table 77–1. Classification of Local Flaps by Tissue Movement.

Pivotal Flaps
Rotation
Transposition
Interpolation
Advancement Flaps
Single pedicle
Bipedicle
Y–V
Hinged Flap

The blood supply to a random skin flap is derived from musculocutaneous perforating arteries near the base of the flap. The distal portion of the flap is perfused by interconnecting subdermal plexuses located at the junction between the deep reticular dermis and subcutaneous fat. These vessels communicate with more superficial dermal plexuses located at the papillary ridge to the dermal–epidermal junction. Rhombic and bilobed flaps are examples of random pattern flaps.

Axial (arterial) pattern skin flaps are perfused by a direct cutaneous artery within the longitudinal axis of the flap. Axial flaps typically have improved survival lengths compared to random pattern flaps due to this vascular supply. The surviving length of axial flaps is related to the length of the cutaneous artery. Flap necrosis secondary to ischemia can occur at the distal portion of the flap if the length exceeds the arterial length, where the flap is dependent on random pattern blood supply. A common example of an axial flap is the paramedian forehead flap, which is supplied by the supratrochlear artery.

Method of Flap Transfer

This chapter will classify local flaps according to classic transfer methods. In reality, many local flaps actually are combinations of these classifications.

A. Advancement Flaps

Advancement flaps have a linear configuration where an adjacent tissue is advanced linearly to cover a primary tissue defect. Advancement flaps are subclassified as simple, single pedicle, bipedicle, and V–Y flaps. These flaps are particularly useful in reconstructing forehead, lip, and eyelid defects.

1. Single-pedicle advancement flaps—These rectangular flaps are created by making two parallel incisions extending from the border of the defect, ideally along RSTLs when possible (Figure 77–1). A length-to-width ratio of 1:1 to 2:1 is ideal and should not exceed 3:1. The flap and its pedicle are then advanced into the defect. The tension in these flaps is in the direction of the advancement. Undermining around the defect minimizes tension and promotes better scarring along the incisions. Burow's triangles may be used to remove standing cone deformities, which may be excised anywhere along the longer side.

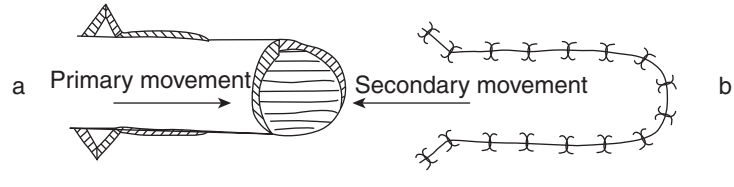
2. Bipedicle advancement flaps—These flaps are designed to allow advancement into the adjacent defect in a vector that is perpendicular to the flap axis (Figure 77–2). These flaps are generally used to close a defect in an area of high visibility by moving the defect into an area of low visibility (eg, from the forehead to the scalp).

3. The V–Y advancement flap—This flap is unique among advancement flaps in that it is pushed rather than stretched into the defect. The donor flap, which is usually triangular, is advanced, and the resulting donor defect is closed in a straight line. This approach results in a suture line with a Y configuration. A skin island advancement flap is an example of a V–Y advancement flap.

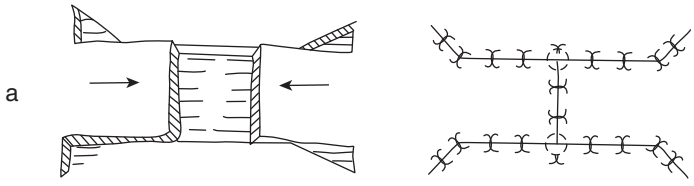
B. Pivotal Flaps

Pivotal flaps are transferred about a pivotal point from the donor site to the defect. Pivotal flaps include rotation, transposition, and interpolation flaps.

1. Rotation flaps—In rotation flaps, tissue is moved curvilinearly about a pivot point into an adjacent defect. These flaps are designed so that the leading edge of the flap is also a border of the defect. By doing so, a facial defect is filled by creating another defect that may be closed with less tension or distortion. Burow's triangle at the base may be excised to assist in rotation and closure. Rotation flaps are usually based inferiorly to promote lymphatic drainage. Rotation flaps are commonly used for medium to large defects involving the cheek, neck, and scalp.



▲ **Figure 77–1.** Single-pedicle advancement flap.



▲ **Figure 77–2.** Bilateral advancement flap.

2. Interpolation flaps—The interpolation flap is similar to the transposition flap in that the flap is moved about the pedicle and transposed across intervening tissue; however, with an interpolation flap, the pedicle rests over the intervening tissue. The pedicle must be divided and inset at a second stage after neovascularization occurs. A common interpolation flap is the paramedian forehead flap.

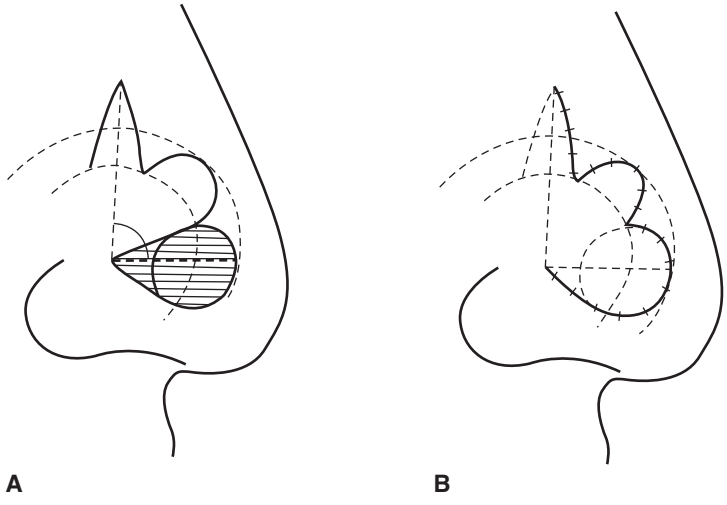
3. Transposition flaps—A transposition flap is created so that the donor site is remote from the defect, while the base of the flap is immediately adjacent to the defect. The flap is moved about the pedicle and transposed over the intervening tissue into the defect. Like rotation flaps, transposition flaps exploit skin laxity at a site distant to the surgical defect and redirect the tension of closure. Examples of the transposition flap include the bilobed flap, Z-plasty, and rhombic flap.

4. Bilobed flap—The bilobed flap is a double transposition flap consisting of two lobes based on a single pedicle. It is designed to recruit adjacent skin from areas of more laxity to areas of deficiency. The primary lobe is adjacent to the defect and designed to have a diameter equal to that of the defect. The secondary flap is used to repair the primary flap donor site and is approximately one-half the diameter or more of the primary lobe. The secondary donor site is closed primarily.

The traditional design of the bilobed flap was described with a 90° angle of transfer between each lobe, for a total transposition of 180°. Zitelli modified the arcs of rotation to an angle of 45° between each lobe, limiting transposition to 90°, in order to minimize dog ear and trapdoor deformities that can occur with the larger angles (Figure 77–3). The bilobed flap is ideal for reconstructing cutaneous defects <1.5 cm or less in size. These flaps are particularly useful in nasal tip reconstruction. Defects of the nasal ala are generally approached with medially based bilobed flaps, whereas tip defects are closed with laterally based flaps.

Disadvantages of the bilobed flap include the curved, complex incision lines, disruption of nasal subunits, and limitation to relatively small defects.

5. Z-plasty—Z-plasty is a double transposition flap consisting of two triangles, each with independent pivot points. One triangular flap is transposed about its pivotal point in a clockwise direction, while the other flap in a counterclockwise direction, to its triangular recipient site. Wide undermining at the base of each flap is necessary to achieve proper flap movement. For scar revision, the scar should be positioned in and oriented along the central long limb of the Z (Table 77–2).



▲ **Figure 77–3.** Zitelli modification of bilobe flap, resulting in a 90° rotation, minimizes standing cutaneous deformities, and trapdoor deformities. **(A)**—skin defect and flap design. **(B)**—rotation of flap and closure of the defect.

Table 77–2. Angle Design for Z-Plasty Influences Scar Length.

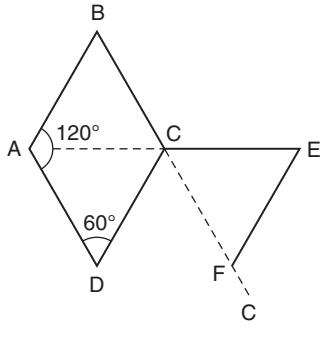
Angle Size	Length Increase
30°	25%
45°	50%
60°	75%
75°	100%
90°	120%

Z-plasty is used to change the direction of the scar to relieve scar contracture at the expense of lengthening the final length of the scar. The wider the angle of the triangular flaps, the greater the length of the final scar, but this also results in larger standing cutaneous deformities. Flaps with angles of 30°, 45°, and 60° result in elongation of the final scar by approximately 25%, 50%, and 75%, respectively.

While relatively large Z-plasties can be used in the neck, those on the face ideally should be designed so that the limbs are 0.5 cm or less. If the scar being revised is longer than 0.5 cm, multiple Z-plasties should be used. Z-plasty can help reorient scars to be more parallel to RSTLs.

6. Rhombic flap—The classic rhombic flap originally described by Limberg is a transposition flap used to repair a rhombus-shaped surgical defect with equal side lengths, two opposing 60° angles and two opposing 120° angles (Figure 77–4). This configuration creates a short diagonal (which bisects the 120° angles) that is equal in length to the sides of the rhombus.

The flap is designed by extending the line of the short diagonal a length equal to the diagonal, which is also the same length as the side of the defect. A second line is then drawn of equal length parallel to either adjacent side of the defect. Every rhombic defect has four potential flaps that can be designed due to having two potential lines drawn in either direction. The point of greatest wound closure tension is at the closure site of the donor defect. Donor site closure should be parallel to the LME and perpendicular to RSTLs.



▲ **Figure 77–4.** Classic rhombic flap.

The Dufourmentel flap is a variation of the classic Limberg rhombic flap. This flap is designed to close rhombic defects with any two opposite angles rather than the 60° and 120° angles. It is particularly useful for repair of rhombic defects with acute angles of 60° to 90° where excision of excess skin is undesirable.

A disadvantage of the rhombic flap is a more visible scar than with other flaps because approximately half of the incisions are not parallel to RSTLs. Rhombic flaps are particularly helpful in repairing defects on the cheek and temple, where skin creases are less prominent.

Borges AF. The rhombic flap. *Plast Reconstr Surg*. 1981;67:458–466. (Design and technique of a rhombic flap.)
Larrabee WF. Design of local skin flaps. *Otolaryngol Clin North Am*. 1990;899–923. (Excellent review of the design of local skin flaps.)
Zitelli JA. The bilobe flap for nasal reconstruction. *Arch Dermatol*. 1989;125:957–959. (Classic paper describing the bilobe flap as described and modified by Zitelli.)

Reconstruction of Specific Facial Subunits

A. Nose

For full thickness defects, three-layered reconstruction generally preserves function and minimizes the contraction. The effect of scar contracture is most prominent at the nasal alar subunit and can cause major deformity and nasal airway obstruction. The nasal subunits should be considered when planning reconstruction. The subunit rule states that if more than 50% of the subunit is removed, the entire subunit should be removed for optimal camouflage of incisions.

In general, defects of the upper two thirds of the nose that involve the dorsal and/or sidewall subunits are reconstructed with thinner, less sebaceous skin than that used in the lower third of the nose. The paramedian forehead flap, an interpolation flap supplied by the supratrochlear artery, provides abundant tissue, with excellent color and texture matching, and it can reliably be used to cover the entire nasal surface. Disadvantages of the flap are the vertical forehead scar, and the limited length in nonhair bearing forehead skin, and the need for a second stage procedure to divide the pedicle.

Defects involving the lower third of the nose can be more challenging to reconstruct due to its complex contours and thicker, more sebaceous, skin. The bilobed flap is an excellent flap for defects smaller than 1.5 cm. Alar notching and retraction may occur if the defect is less than 10 mm from the alar margin. If the entire tip subunit is involved, a paramedian forehead flap should be considered. For subtotal tip defects, a full-thickness skin graft or composite auricular cartilage graft is another option, although this may provide a less desirable color and texture match.

B. Cheek

Cheek defects can vary in depth and may present as a challenge to match the contour of the surrounding tissue. The skin of the cheek is relatively thick with reasonable elasticity. Primary closure along RSTLs is the simplest and best reconstructive option for small defects. However, for medium-to-large defects, local flap coverage is required.

Simple transposition flaps, including the rhombic flap can be used successfully in the cheek region, but incisions placed perpendicularly to the RSTLs should be avoided. These flaps are generally limited to the lateral aspect of the cheek.

The most common local flap used for cheek reconstruction is the cervico-facial advancement rotation flap. Large amounts of tissue can be recruited from the cheek and cervical skin to cover large defects, without causing significant secondary deformity. The lower medial area of the cheek near the alar-facial junction is frequently amenable to repair with island pedicled flaps.

C. Forehead

Bilateral advancement, or H-plasty, is a commonly used flap for closing forehead defects. In this procedure, bilateral lateral-to-medial advancement flaps are used to close square or round defects, and the incisions are placed in existing forehead furrows. An O–T flap is a variation of bilateral advancement flaps, which can also be used successfully in the forehead.

Burget GC. Aesthetic reconstruction of the nose. *Clin Plast Surg*. 1985;12:463–480. (Burget describes his technique and approach for reconstructing large nasal defects.)

Cook TA, Davis RE. Cheek reconstruction. *Operative Tech Otolaryngol Head Neck Surg*. 1993:4:31–36.(Excellent review article describing the various methods of cheek reconstruction.)

Quatela VC, Sherris DA. Aesthetic refinements in forehead flap nasal reconstruction. *Arch Otol HNS*. 1995 Oct;121(10):1106–1113. (Tips and methods for excellent results in nasal reconstruction with the paramedian forehead flap.).

Siegle RJ. Forehead reconstruction. *J Dermatol Surg Oncol*. 1991;17:199–204. (Overview of method of reconstructing forehead defects.)

We would like to acknowledge Nathan Monhian, MD, Shan R. Baker, MD, and Jeffrey Wise, MD for their contribution to this chapter in the previous editions of CDT.

78 Microvascular Reconstruction

Vasu Divi, MD &
Daniel G. Deschler, MD, FACS

The basic goal of head and neck reconstruction is to replace soft tissue and bony defects with similar tissue, restoring function, and optimizing cosmesis. Reconstructive surgical options are typically thought of in a hierarchy called the reconstructive ladder. (Table 78–1) Each step on the ladder increases the invasiveness and complexity of the reconstruction. Selection of the appropriate procedure depends on the defect and the goals of reconstruction.

Microvascular free-tissue transfer is a reconstructive technique in which tissue units are separated from their native blood supply and moved from one part of the body to a new location. The donor tissue has an identifiable artery and vein that are reanastomosed to recipient vessels, thus reestablishing blood flow. The potential for sensory reinnervation also exists through the reanastomosis of cutaneous nerves.

Refinements in free-tissue transfer over the last two decades have revolutionized the reconstruction of head and neck defects resulting from trauma, congenital anomalies, and ablative procedures for neoplastic processes. Free-tissue units are custom-designed for defects to provide characteristics similar to those of the original tissue. This versatility allows free flaps to serve multiple purposes, such as lining oropharyngeal defects and providing soft tissue support for maxillary defects. Free flaps offer other advantages because they do not have the anatomic constraints of regional pedicled flaps; they can be completed in a single stage, allow a simultaneous two-team approach, and have allowed ablative surgeons to expand their resection boundaries.

PREOPERATIVE CONSIDERATIONS & PLANNING

Important considerations in patient selection for free-flap reconstruction include age, comorbidities, and functional needs. Older patients are more likely to have comorbid factors that may increase their risk of exposure to prolonged anesthesia, affect wound healing, and decrease their tolerance for donor site morbidity. Some patients may not need the additional functional advantages gained from free-flap reconstruction. The risks and benefits of free-flap reconstruction must be considered for each individual patient.

Preoperative planning and communication with the anesthesia, nursing, and other involved surgical teams facilitate an efficient and well-executed surgical procedure. The tissue defect, functional needs of the patient, or both must be anticipated so that the optimal free flap is selected. Factors to be considered are donor tissue characteristics and composition, the length of pedicle, color match, soft tissue bulkiness, and the functional disability of the donor site. Communication about the patient's intraoperative position and the preservation of adequate recipient vessels in the head and neck for anastomosis should also be relayed with the appropriate teams.

Technical Considerations

Although careful preoperative planning, patient selection, and flap design are important factors in free-tissue transfers, a meticulous microvascular technique is essential for the successful insetting and revascularization of tissue units. Critical to the execution of microvascular techniques are proper instruments, an operating microscope, and the expertise of microvascular surgeons who are trained in the techniques of vessel selection, handling, and preparation.

A. Vessel Preparation

As a rule, vessel handling should be minimal to decrease the risk of trauma or injury. Vessels should be handled by the adventitia because direct contact with the intima may cause spasm, endothelial damage, and thrombosis, all with the potential of compromising blood flow to and from the transferred tissue. Vessels in the donor vascular pedicle are skeletonized, freeing the arteries from the veins within the vascular pedicle. Atraumatic vascular clamps are then placed. The ends of the vessels are transected and irrigated intermittently with dilute heparinized saline solution to prevent thrombosis. Finally, the excess adventitia is removed from the vessels to expose the media; adventitia trapped in the lumen at the suture line may initiate clot formation.

Table 78–1. Reconstructive Ladder

secondary intention
primary closure
split thickness skin graft
full thickness skin graft
tissue expansion
local flap
regional pedicled flap
microvascular free-tissue transfer

B. Microvascular Anastomosis

After both donor and recipient vessels are prepared, arterial anastomosis is followed by venous anastomosis. End-to-end anastomosis is the most commonly used technique, using appropriately sized monofilament sutures (8–0, 9–0, or 10–0). The end-to-side technique is used when there is a significant size mismatch between vessels (>3:1) or when the internal jugular vein is the recipient vessel. Significant tension should not exist at the suture line and vessels should be sutured to lie without twists or kinks.

CLASSIFICATION OF FLAPS

Free-tissue flaps are generally categorized by the types of tissues that are included in the transfer. Flaps most commonly contain skin (cutaneo-), muscle (myo-), bone (osseo-), or fascia (fascio-). For example, a flap that primarily contained bone and skin would be described as a osseocutaneous flap. Enteric flaps contain visceral structures and fall into their own category.

The cutaneous portion of each free-tissue flap is ultimately supplied by the main pedicle through perforating vessels. These small caliber perforators branch off the pedicle in somewhat predictable locations, although anatomic variation can exist. The perforating vessels travel from the pedicle to the skin to ramify in the subcutaneous plexus that then provides the vascular supply to the skin. Each perforator supplies a limited area of skin, therefore including an adequate number of these vessels in the flap design is essential for survival of the cutaneous paddle. Failure to do so can result in total or partial necrosis of the cutaneous portion of the flap. The course of these perforators from the main pedicle to skin must be preserved during flap elevation. They can travel through the fascial septum between muscles (septocutaneous perforators) or through the muscles themselves (musculocutaneous perforators). Similar vessels branch off the main pedicle to supply the periosteum of the osseous flaps.

Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. *Br Plast Surg*. 1987;40:113–141.

FASCIAL & FASCIOCUTANEOUS FREE-TISSUE FLAPS

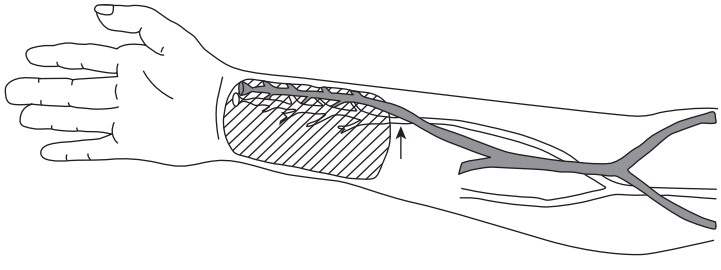
Fascial and fasciocutaneous free-tissue flaps are commonly used flaps in head and neck reconstruction. They are characterized by thin, pliable fascia or skin without the bulk of pedicled myocutaneous flaps. Furthermore, they have the potential for crude sensation through the reanastomosis of an accompanying cutaneous nerve to nerves at the recipient site. They are primarily used for complex intraoral, pharyngeal, and cutaneous defects of the head and neck.

1. Radial Forearm Free-Tissue Flaps

The free-tissue flap of the radial forearm is based on the radial artery, its associated venae comitantes, and the cephalic vein. The skin is supplied by fasciocutaneous vessels in the intermuscular septum between the brachioradialis and flexor carpi radialis.

The main advantages of the radial forearm flap are its thin and pliable tissue characteristics. This flap is an excellent choice to reconstruct oral cavity and oropharyngeal defects without limiting mobility of the tongue or remaining structures. Furthermore, this tissue can be tubed for pharyngeal, laryngeal, and esophageal defects. Crude sensation may be achieved through the reanastomosis of the lateral and medial antebrachial cutaneous nerves to nerves at the recipient site.

Possible ischemic injury to the hand is the main disadvantage to this flap. Preoperatively, the Allen test is performed to verify collateral flow to the hand from the ulnar artery via the palmar arch. Other potential drawbacks include tendon exposure, dysesthesia, motor dysfunction of the hand, and cosmetic results at the donor site from coverage with a split-thickness skin graft (Figure 78–1).



▲ **Figure 78–1.** Radial forearm free-tissue flap (hatched lines) based on the radial artery (open arrow) and cephalic vein.

2. Lateral Arm Free-Tissue Flaps

The fasciocutaneous flap of the lateral arm is supplied by the posterior branches of the radial collateral vessels from the profunda brachii artery. This flap has both a superficial and a deep venous system, the cephalic vein and paired venae comitantes, respectively. The perforators travel to the skin via the lateral intermuscular septum.

The advantages of this flap include a pliable skin paddle, the potential for sensory innervation through the posterior cutaneous nerve, and a donor site that can be closed primarily with minimal functional impairment. The disadvantages of this flap include smaller-caliber vessels and the variability of subcutaneous fat, which depends on the patient's body habitus.

3. Fasciocutaneous Flaps of the Lateral Thigh

The fasciocutaneous flap of the posterior lateral thigh receives its blood supply from the cutaneous perforators of the profunda femoris artery, with the dominating third perforator. Venous drainage occurs through paired venae comitantes that accompany branches from the third perforator. The lateral femoral cutaneous nerve may also provide some sensation to the skin paddle.

The advantage of this flap is the availability of a sizable amount of pliable skin. The long axis of the skin paddle is designed over the intermuscular septum between the long head of the biceps femoris and the vastus lateralis muscles. This flap has been used after laryngopharyngectomy, and the ample subcutaneous tissue is useful in total glossectomy and skull base defects. Donor site morbidity is minimal but may include wound dehiscence and compartment syndrome. Another disadvantage is the potential anatomic variation of the vascular bundle.

The anterior lateral thigh flap was initially described at the time of the lateral thigh flap, but it did not gain widespread acceptance and popularity until recently. This flap is similar to the lateral thigh flap in tissue characteristics, yet in a more favorable position for simultaneous harvest, since the approach is to the anterior thigh. The anterior lateral thigh flap is based on a septocutaneous or septomyocutaneous perforator off the circumflex femoral artery and vein. The vascular pedicle travels between the rectus femoris and vastus lateralis muscles until giving off perforating branches that supply the cutaneous segment. This perforator is situated within a 3 cm circle located midway between the anterior iliac crest and the lateral patella.

Advantages of the flap include the minimal donor site morbidity, since primary closure is usually achievable and minimal muscular loss is required. Disadvantages include the somewhat short vascular pedicle, requirement for delicate perforator dissection, and the somewhat small vessel diameter. The clinical uses of this flap are similar to those of the lateral thigh free flap.

4. Scapular Fasciocutaneous Flaps

The scapular fasciocutaneous flap is based on the circumflex scapular artery and vein and may be harvested either as a fasciocutaneous or an osseocutaneous flap (see the next section "Osseomyocutaneous Free-Tissue Flaps"). The circumflex scapular artery originates from the subscapular artery and terminates into the transverse and descending branches, which may be used to supply two separate skin islands—the scapular and parascapular flaps, respectively. Two skin flaps supplied by a single vascular pedicle offer an excellent choice when both intraoral and external coverage are needed. The scapular region provides a large amount of tissue (14–21 cm) useful for larger defects, large-caliber vessels, and an acceptable color match to facial skin.

The major drawback of this flap is the lateral decubitus position of the patient during flap harvest, which limits a simultaneous two-team approach. Furthermore, no potential for sensory reinnervation exists. Although the donor site can be closed primarily with minimal morbidity, patients may require an arm sling and need physical therapy for a short period of time postoperatively.

5. Temporoparietal Fascial Flaps

The temporoparietal fascial flap derives its blood supply from the superficial temporal artery and vein. The temporoparietal fascia is thin, pliable, and well vascularized, allowing it to mold into complex facial defects and drape over skeletal frameworks such as the ear. This flap also has the unique property of providing a viscous gliding surface that is excellent for tendon excursion. The temporoparietal fascial flap is most often used as a pedicled flap for reconstruction of lateral temporal bone, orbital, limited oropharyngeal, and intracranial defects. As a free flap, it can be used for orbital reconstruction and a nasal lining in the setting of total nasal reconstruction; it has recently been described for laryngeal reconstruction after partial laryngectomy.

Azizzadeh B, Yafai S, Rawnsley JD et al. Radial forearm free flap pharyngoesophageal reconstruction. *Laryngoscope*. 2001;111(5):807. [PMID: 11359159] (Evaluates wound healing, speech, and swallowing outcomes.)

Cheney ML, Varvares MA, Nadol JB Jr. The temporoparietal fascial flap in head and neck reconstruction. *Arch Otolaryngol Head Neck Surg*. 1993;119(6):618. [PMID: 8388696] (Techniques, advantages, and applications are described.)

Hayden RE, Deschler DG. Lateral thigh free flap for head and neck reconstruction. *Laryngoscope*. 1999;109(9):1490. [PMID: 10499060] (Describes favorable outcomes in the largest case series.)

Lueg EA. The anterolateral thigh flap: radial forearm's "big brother" for extensive soft tissue head and neck defects. *Arch Otolaryngol Head Neck Surg*. 2004;130(7):813.

Table 78–2. Anatomy, Advantages, and Disadvantages of Various Fasciocutaneous Flaps.

Type of Flap	Neurovascular Pedicle	Advantages	Disadvantages
Radial forearm	Radial artery Cephalic vein Lateral and medial antebrachial nerves	Thin, pliable Potential sensation	Possible ischemia, tendon exposure, motor dysfunction, and unfavorable cosmesis at donor site
Lateral arm	Radial collateral vessels from the profunda brachii artery Cephalic vein and paired venae comitantes Posterior cutaneous nerve	Thin, pliable Potential sensation Donor site can be closed primarily	Smaller-caliber vessels Variability of subcutaneous fat
Lateral thigh	Perforators off the profunda femoris artery (with dominant third perforator) Paired venae comitantes Lateral femoral cutaneous nerve	Sizable amount of pliable skin Excess subcutaneous tissue useful for large defects	Possible wound dehiscence and compartment syndrome Anatomic variability of vascular bundle
Scapula	Circumflex scapular artery and vein	Large amount of tissue Possibility of two skin islands Large-caliber vessels Acceptable color match with facial skin	Patient lies in lateral, decubitus position No potential for sensory reinnervation
Temporoparietal fascia	Superficial temporal artery and vein	Thin, pliable Rich, vascular capillary network Gliding surface	Donor site scar Potential alopecia

Ninkovic M, Harpf C, Schwabegger AH et al. The lateral arm flap. *Clin Plast Surg*. 2001; 28(2):367. [PMID: 11400830] (Describes the anatomy, surgical approach, advantages, and disadvantages of the lateral arm flap.)

Urken ML, Bridger AG, Zur KB et al. The scapular osteofasciocutaneous flap: A 12-year experience. *Arch Otolaryngol Head Neck Surg*. 2001;127(7):862. [PMID: 11448364] (Describes favorable outcomes for patients with large surface area defects, those with preexisting gait disturbances, and older patients.)

Wei FC, Jain V, Celik N et al. Have we found an ideal soft-tissue flap? An experience with 672 anterolateral thigh flaps. *Plast Reconstr Surg*. 2002;109(7):2219; discussion 2227. (An outstanding review by the author with the single greatest experience with this flap.)

The disadvantages of this flap include a donor-site scar, potential alopecia along the region of flap elevation, and a small-caliber vessel (Table 78–2).

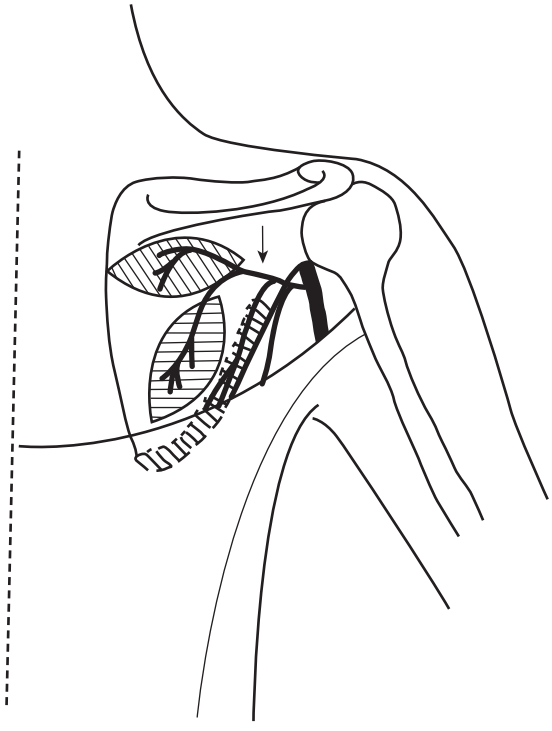
OSSEOCUTANEOUS FREE-TISSUE FLAPS

A variety of composite flaps, comprising both soft tissue and bone, are available for mandibular, maxillary, and palatal defects. Because each flap has advantages and limitations, the surgeon needs to consider the soft tissue characteristics, the length of bone stock and vascular pedicle, and the suitability for osseointegration (ie, the placement of dental implants) of each flap.

The bony components of these composite flaps are vascularized by the periosteum, which in turn receives perforators from the main pedicle. The bone is plated to the viable remaining native bone, allowing primary bone healing. These free-tissue techniques, which include a bone segment, offer advantages over traditional techniques, which use reconstruction plates and myocutaneous pedicled flaps. Free-tissue techniques also provide an advantage to the potential complications of plate fracture and extrusion and wound breakdown associated with traditional techniques.

1. Scapular Osseocutaneous Flaps

As described previously, the circumflex scapular artery divides into the transverse and descending branches. The transverse branch of the scapular circumflex artery travels approximately 2 cm below and parallel with the scapular spine whereas the descending branch parallels the lateral border of the scapula. Approximately 10–14 cm of bone can be harvested from the lateral scapular border, which is suitable for osseointegration. The advantages and disadvantages are similar to the scapular fasciocutaneous flap described earlier. The vascular pedicle allows for significant mobility of the osseous portion of the flap relative to the cutaneous portion (Figure 78–2).



▲ **Figure 78–2.** Scapular fasciocutaneous flap based on the circumflex scapular artery (arrow), which may include bone from the lateral border of the scapular (shaded region).

2. Osseomyocutaneous Flaps of the Iliac Crest

The iliac crest composite flap is based on the deep circumflex iliac artery and vein, which arise from the external iliac system. Perforators from the deep circumflex iliac artery supply the skin overlying the iliac crest and the ascending branch of this artery forms an arcade on the undersurface of the internal oblique muscle.

Although up to 16 cm of the bone stock can be harvested from the iliac crest, this flap is limited by the lack of maneuverability of the soft tissue component. The iliac crest flap was modified to include the internal oblique muscle. An osseomyocutaneous flap of the internal oblique-iliac crest offers increased flexibility of the soft tissue components as well as decreased bulk, making it a more versatile flap for oromandibular reconstruction. The iliac crest also provides a hardy bone stock suitable for osseointegrated implants.

The drawbacks of this flap are a short vascular pedicle, bulky skin island, and morbidity at the donor site. The donor site has an increased risk of abdominal hernias, even with the use of mesh, and gait abnormality.

3. Fibular Osseomyocutaneous Flaps

The fibular composite flap is based on the peroneal artery and vein. Perforators from the posterior intermuscular septum supply the thin overlying skin; sensation to the flap may be restored through the lateral sural cutaneous nerve. This flap offers the longest length of available revascularized bone (24 cm), allowing near-total mandibular reconstruction. Although the height of the fibular bone stock is shorter than the iliac crest, it can still support osseointegrated implants.

Preoperatively, angiography or magnetic resonance angiography is recommended to verify the collateral vascular supply to the foot. Approximately 6–8 cm of fibular bone should be left proximally to prevent injury to the common peroneal nerve and distally to prevent destabilization of the ankle.

Although the skin island is thin and pliable, it is somewhat limited by its linear orientation to the bone. However, technical modifications have made the skin harvest dependable. The donor site can usually be closed primarily, but a skin graft may be required. Functional mobility of the leg is expected postoperatively.

4. Osseocutaneous Flaps of the Radial Forearm

The fasciocutaneous flap of the radial forearm, described in the previous section, may also be harvested as a composite flap. The length of radius that may be harvested is limited to 10–12 cm in length and to 40% of the diameter to prevent donor site complications. The use of this flap has been limited by the risk of pathologic fracture and somewhat limited bone stock available (Table 78–3).

Cordeiro PG, Disa JJ, Hidalgo DA et al. Reconstruction of the mandible with osseous free flaps: a 10-year experience with 150 consecutive patients. *Plastic Recon Surg*. 1999;104(5):1314–1320. [PMID: 10513911]

Genden EM, Wallace D, Buchbinder D et al. Iliac crest internal oblique osteomusculocutaneous free flap reconstruction of the postablative palatomaxillary defect. *Arch Otolaryngol Head Neck Surg*. 2001;127(7):854. [PMID: 11448363] (Describes favorable results for competent oral rehabilitation without the need for a prosthetic obturator.)

Urken ML, Bridger AG, Zur KB et al. The scapular osteofasciocutaneous flap: A 12-year experience. *Arch Otolaryngol Head Neck Surg*. 2001;127(7):862. [PMID: 11448364] (Describes favorable outcomes for patients with large surface area defects, with preexisting gait disturbances, and older patients.)

Werle AH, Tsue TT, Toby EB et al. Osteocutaneous radial forearm free flap: its use without significant donor site morbidity. *Otolaryngol Head Neck Surg*. 2000;123(6):711. [PMID: 11112963] (Internal fixation reduces the incidence of donor radius fractures while preserving excellent function.)

Table 78–3. Anatomy, Advantages, and Disadvantages of Various Osseocutaneous Flaps.

Type of Flap	Neurovascular Pedicle	Length of Bone Stock	Advantages	Disadvantages
Scapula	Circumflex scapular artery and vein	Upto10–14 cm	Large amount of tissue Possibility of two skin islands Large-caliber vessels Acceptable color match with facial skin Suitable for osseointegration	Patient lies in lateral, decubitus position No potential for sensory reinnervation
Iliac crest	Deep circumflex iliac artery and vein	Up to 16 cm	Flexible soft tissue component Suitable for osseointegration	Short vascular pedicle Bulky skin island Risk of abdominal hernia
Fibula	Peroneal artery and vein	Up to 24 cm	Offers greatest length of bone for possible near-total mandibular reconstruction	Little maneuverability of soft tissue around bone May need skin graft to cover donor site
Radius	Radial artery Cephalic vein Lateral and medial antebrachial nerves	Up to 10–12cm	Thin, pliable Potential sensation	Possible pathologic fracture Short bone stock

MYOGENOUS & MYOCUTANEOUS FREE-TISSUE FLAPS

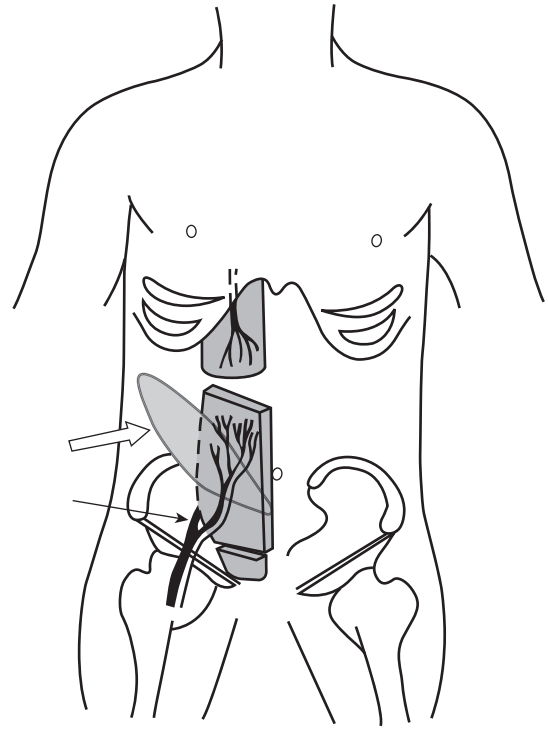
Before the advances in microvascular techniques, pedicled myocutaneous flaps, such as the pectoralis major and latissimus dorsi flaps, were the standard of care for head and neck reconstruction. Pedicle flaps still play an important role, but free-tissue myogenous and myocutaneous flaps offer greater versatility with fewer limitations. The following flaps may be harvested as muscle only or with skin and adipose tissue.

1. Myocutaneous Flaps of the Rectus Abdominis Muscle

Although the rectus abdominis muscle has a dual blood supply from the inferior and superior epigastric arteries, the harvested free-tissue flap is based on the larger caliber inferior epigastric system. These vessels arise from the external iliac vessels and send perforators to the skin through the rectus abdominis muscle.

This flap is used primarily for its significant muscle and soft tissue bulk, long vascular pedicle, and reliability. It is an excellent choice for large maxillary and skull base defects.

The main donor site morbidity is a potential ventral hernia, with the most susceptible region below the arcuate line. To decrease the risk of tissue and viscera herniation, the anterior rectus sheath below the arcuate line must be meticulously closed; mesh may be used as an adjunct to strengthen the abdominal wall (Figure 78–3).



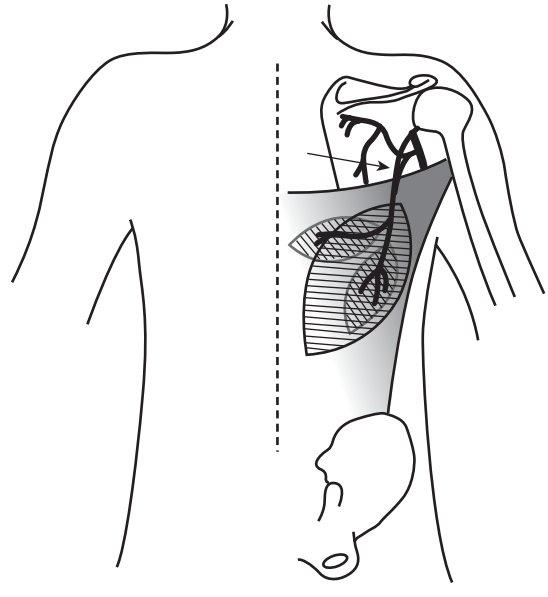
▲ **Figure 78–3.** Rectus abdominis muscle and overlying skin paddle (dark arrow) supplied by the inferior epigastric vascular pedicle (open arrow).

2. Myogenous & Myocutaneous Flaps of the Latissimus Dorsi Muscle

The latissimus dorsi muscle receives its blood supply from the thoracodorsal artery and vein, which are branches of the subscapular system, with innervation from the thoracodorsal nerve. It is potentially the largest flap used in head and neck reconstruction.

An advantage of this flap is the versatility in the amount of muscle that is harvested, ranging from a small amount of muscle under the skin paddle to the entire muscle. Other advantages include its long pedicle length (9 cm), large-caliber vessels, and the ability to design a bilobed flap based on the medial and lateral branches of the thoracodorsal artery. This flap is used for glossectomy, the skull base, and large cervical cutaneous defects. Muscle only may be harvested and used with skin grafting for large scalp defects.

Disadvantages to this flap are the potential for seroma formation and wound dehiscence at the donor site. The lateral decubitus position of the patient, needed for flap harvest, limits the simultaneous two-team approach (Figure 78–4).



▲ **Figure 78–4.** Latissimus dorsi flap based on the thoracodorsal artery (arrow); it is shown here as a single large skin paddle (horizontal lines) or as two separate paddles (vertical lines).

3. Myogenous Flaps of the Gracilis Muscle

The dominant vascular supply to the gracilis muscle is the adductor artery, which arises from the profunda femoris. Venous drainage occurs via accompanying venae comitantes. Motor innervation to the gracilis is supplied by the obturator nerve, which divides into fascicles to different portions of the muscle.

The gracilis muscle is a medial rotator and superficial adductor of the medial thigh whose primary role in head and neck reconstruction is for facial reanimation. The main advantages of the gracilis flap for facial reanimation are the fascicular neuroanatomy of the obturator nerve, the long vascular pedicle (up to 6 cm), and the ability to allow a simultaneous two-team harvest. Donor morbidity is minimal (Table 78–4).

Browne JD, Burke AJ. Benefits of routine maxillectomy and orbital reconstruction with the rectus abdominis free flap. *Otolaryngol Head Neck Surg*. 1999;121(3):203. [PMID: 10471858] (Describes the functional benefits and acceptable cosmesis.)

Papadopoulos ON, Gamatsi IE. Use of the latissimus dorsi flap in head and neck reconstructive microsurgery. *Microsurgery*. 1994;15(7):492. [PMID: 7968480] (Describes the benefits for wide defects of the head and neck.)

Shindo M. Facial reanimation with microneurovascular free flaps. *Facial Plast Surg*. 2000;16(4):357. [PMID: 11460302] (Describes the excellent functional and aesthetic results of free-flap reconstruction for facial reanimation.)

ENTERIC FREE-TISSUE FLAPS

The jejunal enteric free-tissue flap was the first example of head and neck free flap reconstruction in humans (1959). The unique aspect of jejunal and omental-gastroomental tissue in head and neck reconstruction is the availability of a mucosal surface that may be used to reconstruct the

Table 78–4. Anatomy, Advantages, and Disadvantages of Myogenous and Myocutaneous Flaps.

Type of Flap	Neurovascular Pedicle	Advantages	Disadvantages
Rectus abdominus	Inferior epigastric artery and vein	Significant soft tissue bulk Long vascular pedicle	Potential ventral hernia, especially below arcuate line
Latissimus dorsi	Thoracodorsal artery and vein Thoracodorsal nerve	Large amount of available muscle Long vascular pedicle Large-caliber vessels Two soft tissue islands possible	Possible wound dehiscence and seroma formation Patient lies in lateral, decubitus postion for harvest
Gracilis	Adductor artery Venae comitantes Obturator nerve	Fascicular neuroanatomy suitable for facial reanimation Minimal donor site morbidity	Minimal

aerodigestive tract. Both jejunum and gastroomentum flaps may be used as a tubed flap or mucosal patch. In reconstruction of pharyngeal defects that extend into the mediastinum, a gastric pull up procedure is preferred to avoid placing the distal anastomosis within the thoracic cavity.

1. Jejunal Enteric Free-Tissue Flaps

The jejunal enteric free-tissue flap is based on arborizing vessels from the superior mesenteric artery and vein. The antimesenteric border of this flap may be filleted, exposing a mucosal surface and providing a pliable and secretory flap for pharyngeal and oral cavity reconstruction. This tubular flap has been used extensively for pharyngoesophageal defects and the diameter of the jejunum makes it appropriate for this purpose.

The disadvantages of this flap include its fragile vessels, poor tolerance to ischemia, and the risks associated with the laparotomy required for harvest: bowel adhesions, obstruction, and wound dehiscence (Figure 78–5). In addition, voice outcomes with a tracheoesophageal puncture are considered to be inferior as compared to the radial forearm free flap for reconstruction of total pharyngeal defects.

2. Omental & Gastroomental Free-Tissue Flaps

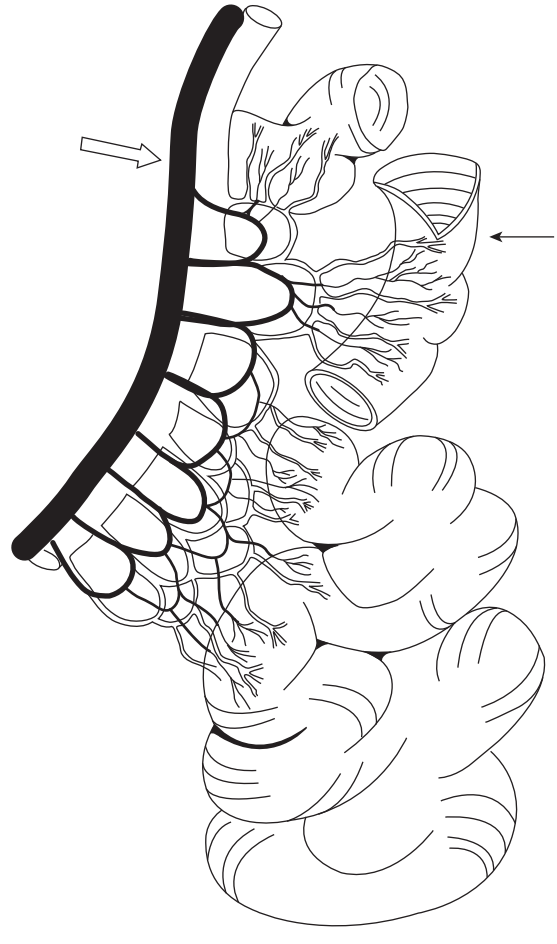
The omental flap derives its vascular supply from the right and left gastroepiploic vessels. This flap includes the double layer of peritoneum that hangs off the greater curvature of the stomach. A segment of the greater curvature is included in the gastroomental flap.

Because of its excellent blood supply, the omentum has a wide variety of uses in the head and neck, including reconstruction of the skull base and large scalp defects, carotid coverage, the management of wounds with osteomyelitis and osteoradionecrosis, and facial contouring. The gastroomental tissue includes gastric mucosa, which provides potential secretions useful for oropharyngeal defects.

Donor site morbidity includes potential intra-abdominal complications such as a gastric leak and gastric outlet syndrome.

Genden EM, Kaufman MR, Katz B et al. Tubed gastroomental free flap for pharyngoesophageal reconstruction. *Arch Otolaryngol Head Neck Surg*. 2001;127(7):847. [PMID: 11448362] (Describes the benefits for patients previously treated with multimodality therapy.)

Theile DR, Robinson DW, Theile DE et al. Free jejunal interposition reconstruction after pharyngolaryngectomy: 201 consecutive cases. *Head Neck*. 1995;17(2):83. [PMID: 7558817] (Describes a large series with excellent swallowing outcome and low morbidity.)



▲ **Figure 78–5.** Jejunal flap showing a segment of bowel (dark arrow) based on the mesenteric branches of the superior mesenteric artery and vein (open arrow).

POSTOPERATIVE CARE

Once the microvascular unit has been successfully transplanted and vessels have been reanastomosed, the viability of the flap depends on the maintenance of arterial and venous flow. Factors that may reduce vascular flow, such as external compression from hematoma and edema, hypotension, vasopressors, and vessel spasm, need to be minimized (Table 78–5).

▶ Postoperative Monitoring

The dreaded complication of microvascular reconstruction is flap loss from vascular compromise. Early detection may mean the difference between flap salvage and flap failure, with most surgeons favoring the frequent monitoring of

Table 78–5. Clinical Applications for Various Microvascular Free-Tissue Flaps.

Type of Flap	Clinical Applications
Fasciocutaneous	
Radial forearm	Oral cavity defects Oropharyngeal and esophageal defects
Lateral arm	Oral cavity and oropharyngeal defects
Lateral thigh	Laryngopharyngectomy, skull base, and total glossectomy defects
Scapula	Intraoral and external defects
Temporoparietal fascia	Dorsal hand and foot defects Auricular defects, nasal defects Laryngeal reconstruction Complex facial defects
Osteomyocutaneous	
Scapula	Maxillary and mandibular defects
Iliac crest	Maxillary and mandibular defects
Fibula	Maxillary and mandibular defects Near-total mandibular defects
Radial forearm	Mandible, orbit
Myogenous-Myocutaneous	
Rectus abdominis	Large maxillary and skull base defects
Latissimus dorsi	Skull base, glossectomy, and large cervical cutaneous defects
Gracilis	Facial reanimation
Enteric	
Jejunum	Pharyngeal, esophageal defects Can be filleted for oral cavity; pharyngeal defects
Omentum	Skull base, large scalp defects Coverage for wounds with osteomyelitis and osteoradionecrosis Carotid coverage Facial contouring
Gastro-omentum	Oropharyngeal defects Cervical, esophageal defects

flap viability for the first 48–72 hours. The vast majority of flap failures occur within this period. Venous congestion usually precedes arterial insufficiency owing to a low-flow system with an increased risk of thrombus formation. The most commonly used monitoring techniques are clinical assessment of the cutaneous paddle and Doppler ultrasound flowmeter.

Clinical evidence of venous congestion includes a purplish, turgid flap with rapid capillary refill (less than 1 second). Arterial insufficiency manifests with a pale, cold flap with prolonged (>3–4 seconds) or no capillary refill. Pinprick of the cutaneous portion of the flap with an 18-gauge needle is also an excellent means of assessing the quality of blood flow to and from the flap. A congested flap rapidly bleeds dark blood, whereas a flap with arterial insufficiency may not bleed at all or may bleed bright blood after a significant delay (>4 seconds).

The Doppler ultrasound flowmeter is also a convenient tool to assess vascular flow. The quality of the Doppler signal can give evidence of the velocity of blood flow. Other monitoring methods, such as temperature probes, oxygen tension measurement, implantable dopplers, and color-flow Doppler, have been used.

Thrombus Prevention

The use of pharmacologic adjuncts to prevent thrombus formation is controversial. However, a variety of agents exist and their use is left to the discretion of the surgeon. Aspirin is an antiplatelet agent that has been used postoperatively to prevent thrombus formation. Heparin can be given as a low-dose intraoperative bolus followed by 5–7 days of intravenous infusion, or as a perioperative, subcutaneous injection of 5000 units three times a day. Dextran has been used for its antithrombin and antifibrin effects. An intraoperative bolus is followed by 5 days of intravenous infusion at 25 mL/h. Numerous other agents have been investigated with varying effects.

Moore MG, Deschler DG. Clopidogrel (Plavix) reduces the rate of thrombosis in the rat tuck model for microvenous anastomosis. *Otolaryngol Head Neck Surg*. 2007;136(4):573-576.

Flap Salvage

If there is evidence of flap compromise due to either arterial or venous insufficiency, the patient is taken back to the operating room for exploration. The cause of problems vary and can include hematoma, clot within the vascular pedicle, or inappropriate vessel geometry. In cases where adequate venous outflow of the flap cannot be established, leech therapy can provide a temporary solution.

Medicinal leeches (*Hirudo medicinalis*) are useful for congested flaps and salvaging areas of marginal viability. Leeches release hirudin, an agent that inhibits the conversion of fibrinogen to fibrin at the bite site. The bite wounds then slowly ooze venous blood for up to 6 hours, relieving venous congestion. Patient hematocrit levels must be monitored to prevent significant blood loss, and an antibiotic, third-generation cephalosporin or ciprofloxacin is given intravenously for prophylaxis against specific gram-negative bacterial infection unique to the leech bite. The leech is removed from its attachment to the tissue after withdrawing approximately 5–10 mL of blood by exposing it to an alcohol swab. Each leech is used only once and disposed of using universal precautions. Frequency and duration of leeching

is variable and must be based on clinical assessment of the flap. Leeching generally continues until the venous drainage of the flap is established through inosculation to the recipient tissue bed.

Chepeha DB, Nussenbaum B, Bradford CR et al. Leech therapy for patients with surgically unsalvageable venous obstruction after revascularized free tissue transfer. *Arch Otolaryngol Head Neck Surg.* 2002;128:960–965. [PMID: 12162779] (Description of a leech protocol and outcomes from use.)

FUTURE DIRECTIONS

Perforator Flaps

Perforator flaps represent an evolving option for further refinement of donor tissue units. These flaps are cutaneous flaps that are created by tracing a single or multiple perforators supplying an area of skin back toward the larger vascular pedicle from which they branched. During the dissection, the muscle through which the perforator travels is separated and not included in flap elevation. The versatility of these flaps is the ability to harvest discrete amounts of skin and subcutaneous tissue from a much larger variety of perforating vessels throughout the body. It avoids the associated tissue bulk and donor site morbidity of harvesting the underlying muscle. These flaps tend to be more technically demanding, and their indications in the head and neck are developing.

BIOMEDICAL & TISSUE ENGINEERING

Biomedical engineering has continued to rapidly evolve and provide reconstructive surgeons with new tools. Computer-aided design and computer-aided manufacturing of stereolith models based on preoperative imaging has given surgeons a template with which to plan and design bony reconstructions. Robotic surgery has been described for assisting with flap inset in patients who have undergone transoral resection of cancers. Tissue engineering uses cells, scaffolds and growth factors to create replacement tissues. Although this modality remains in its infancy, bioengineered structural elements such as bone and cartilage could be used to prefabricate flaps at distant sites, which can then later be transferred to the head and neck using microsurgical technique.

ALLOTRANSPLANTATION

As our experience with and understanding of immunosuppression grows, our ability to transplant non-vital structures has expanded. In 2005, a French group reported the first successful allogenic face transplant for a woman suffering from traumatic soft tissue deficits. Since then, interest in this procedure has continued to grow, with two additional transplants having been performed in the US and one in China. Many new challenges arise in facial transplantation, the most important of which is the need for life-long immunosupression to prevent graft rejection. Balancing the risks of life-long immunosuppression against the outcomes from traditional reconstructive techniques has been a source of debate. Tongue, larynx, and tracheal transplants have been described but also remain experimental. Discovery of new immunosuppressive agents that are more selective and with fewer side effects or induction of tolerance may alter the clinical utility of allogenic transplantation for head and neck defects.

Geddes CR, Morris SF, Neligan PC. Perforator flaps: evolution, classification, and applications. *Ann Plast Surg.* 2003;50(1):90–99. [PMID: 12545116]

Nussenbaum B, Teknos TN, Chepeha DB. Tissue engineering: the current status of this futuristic modality in head neck reconstruction. *Curr Opin Otolaryngol Head Neck Surg.* 2004;12(4):311–315. [PMID: 15252252]

Garfein ES, Orgill DP, Pribaz JJ. Clinical applications of tissue engineered constructs. *Clin Plast Surg.* 2003;30(4):485–498. [PMID: 14621297]

We would like to acknowledge Jeannie Hye-Joon Chung, MD for her contribution to this chapter in the previous editions of CDT.

79 Otoplasty & Microtia

Jeffrey B. Wise, MD, Sarmela Sunder, MD,
Vito Quatela, MD & Minas Constantinides, MD, FACS

OTOPLASTY

ESSENTIAL OF DIAGNOSIS

- Prominauris (prominent ears) occurs in approximately 5% of the population.
- Conchal prominence and the absence of an antihelical fold represent the most common causes of prominence of the ears.
- Although there are hundreds of techniques to correct auricular prominence, the most common are suture techniques for conchal setback (technique of Furnas) and for creation of an antihelical fold (technique of Mustarde).
- Otoplasty refinement techniques exist for deformities such as large earlobes and excessive helical prominences.
- Complication rates from otoplasty range from 7% to 12% and may be subdivided into early, late, and aesthetic/anatomic in etiology.
- Auricular hematoma occurs in 1% of otoplasties. Complaints of unilateral pain or tightness within the first 48 hours postoperatively require prompt removal of dressings to examine the wound site for hematoma collection.

PREOPERATIVE EVALUATION/TIMING OF SURGICAL CORRECTION

The incidence of excessively prominent ears is about 5%. It is inherited as an autosomal dominant trait with 25% partial penetrance; it most commonly results from two anatomic irregularities, specifically the absence of an antihelical fold and excessive depth or projection of the conchal bowl.

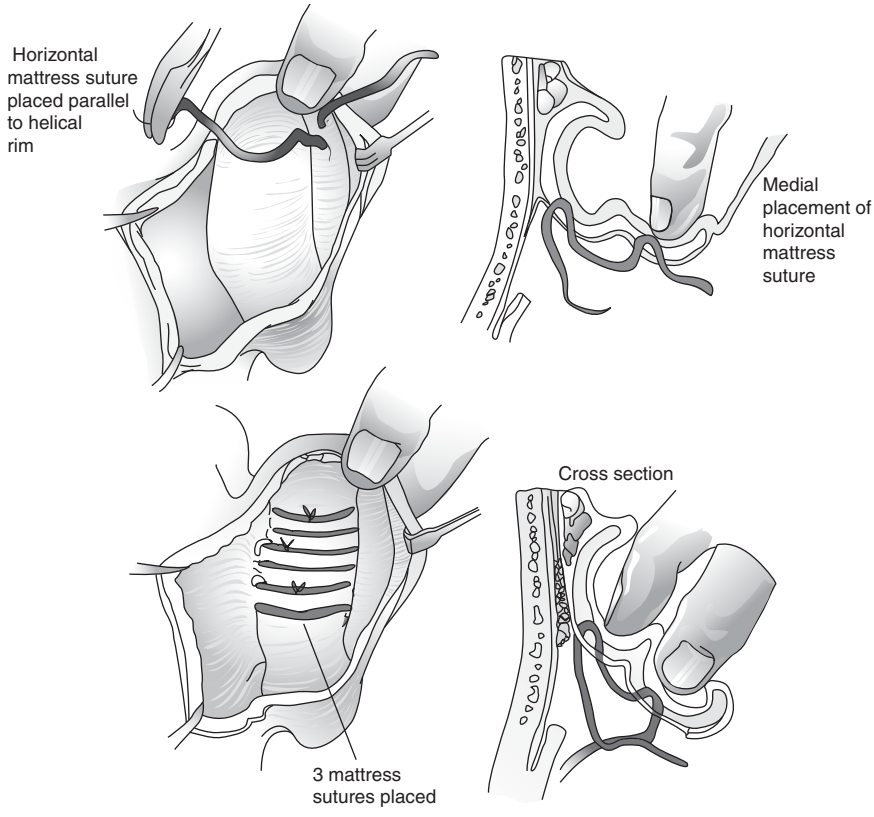
Precise analysis of auricular deformities is paramount to achieving successful outcomes. Surgeons must identify the specific cause of auricular prominence in the formulation of an appropriate surgical plan. Although frequently bilateral, asymmetries in ear protrusion should be noted. As such, standard preoperative photography should be performed, including frontal, full right and left oblique, full right and left lateral, and close-up right and left lateral views.

Although there exist proponents of earlier surgical correction, most authors agree that the ideal age for otoplasty is between 5 and 6 years. Physiologically, the auricle is roughly 90% of adult height by 6 years of age. Psychosocially, correction is undertaken before or soon after a child's entrance to grammar school, where children are subject to peer ridicule. Moreover, by 5 or 6 years, children are able to participate in their own postoperative care (ie, not pulling off bandages or disturbing the wound).

Gosain AK, Kumar A, Huang G. Prominent ears in children younger than 4 years of age: what is the appropriate timing for otoplasty? *Plast Reconstr Surg* 2004;114:1042. [PMID: 15457011] (This article provides a retrospective analysis of the efficacy of otoplasty in patients younger than 4 years of age.)

TECHNIQUES OF SURGICAL CORRECTION

Over 200 techniques have been described for correction of the prominent ear. Conceptually, they can be subdivided into procedures that address an absent antihelical fold, procedures that reduce excess in the conchal bowl, and those that reduce prominent or enlarged lobules. Most of the latter techniques involve reshaping auricular cartilage, which can be accomplished through a number of cartilage-manipulating techniques such as suturing, scoring, and excision/repositioning, to name a few. Herein, the most commonly used technique for correction of an absent antihelical fold, originally described by Mustarde, is discussed in greater detail. In addition, the Furnas technique for reduction of an excessive conchal bowl is described.



▲ **Figure 79–1.** Technique of Mustarde for creation of the antihelical fold—three permanent horizontal mattress sutures are placed parallel with the helical rim. Care is taken to place sutures through the anterior perichondrium without violating the anterior skin. (Reproduced, with permission, from Adamson PA, Constantinides MS. Otoplasty. In: Bailey BJ, Calhoun KH, Coffey AR, Neely JG, eds. *Atlas of Head & Neck Surgery—Otolaryngology.* Philadelphia: Lippincott-Raven, 1996:429.)

Technique of Mustarde

In 1963, Mustarde first described a technique for creating an antihelical fold by using permanent conchoscaphal mattress sutures. Since that time, many subtle refinements of this technique have been described, but the fundamentals of the procedure remain unchanged.

Pediatric patients most commonly undergo general anesthesia for this procedure, and perioperative broad-spectrum antibiotics are administered. The face is prepped into a sterile field such that both ears can be visualized simultaneously. After infiltration with lidocaine 1% with epinephrine 1/100,000, an eccentric fusiform incision is made into the postauricular surface. Typically, more skin is excised from the postauricular surface than from the mastoid, in an effort to camouflage the resultant scar into the postauricular sulcus following setback.

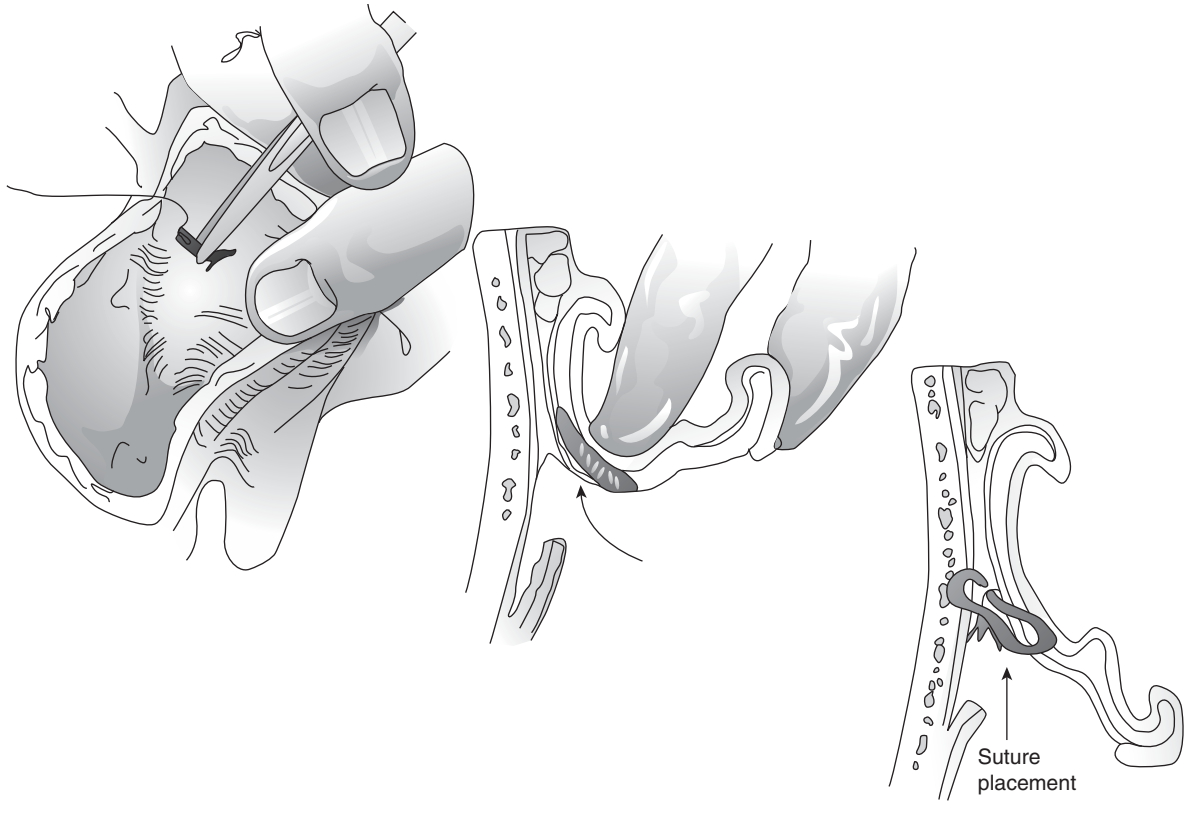
Once the fusiform of skin is excised, the remaining skin of the posterior aspect of the helix, antihelix, and concha is undermined with scissors, leaving perichondrium attached to the auricular cartilage. The extent of antihelical fold creation is determined by pinching the anterior auricle with a thumb and index finger. Alternatively, some surgeons mark cartilaginous landmarks with several ink-dipped fine needles. Permanent horizontal mattress sutures (eg, 4–0 Mersilene [Ethicon, Inc., Somerville, NJ]) are placed into the helical cartilage, parallel with the helical rim at the lateral extent of the desired antihelical fold (Figure 79–1). It is critical that sutures are placed through the cartilage and lateral perichondrium but not the lateral helical skin. The first helical suture is placed at the level of the helical root to create the superior crus. The second suture is typically placed just inferior to the junction of the superior and inferior crura. Third and fourth sutures are placed as needed. Some overcorrection is necessary during placement of the most superior suture, because it has been demonstrated that as much as 40% loss of correction at this site may occur within the first postoperative year.

The wound is irrigated with antibiotic solution and closed with resorbable sutures. Antibiotic ointment, along with cotton impregnated in mineral oil, is applied to the new antihelix and postauricular sulcus, and a mastoid dressing is applied.

The dressing is removed on the first postoperative day to check for hematomas, and replaced for 3–4 more days. Subsequently, a head band is worn continuously for 2 weeks and at night for an additional 4–6 weeks.

Technique of Furnas

In 1968, Furnas popularized a technique of conchal setback using permanent conchomastoidal suturing. This procedure



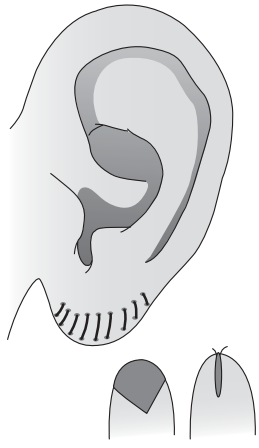
▲ **Figure 79–2.** Technique of Furnas for correction of conchal excess. Permanent conchomastoid horizontal mattress sutures are placed at the lateral third of the concha. A full-thickness bite of cartilage and perichondrium is performed, with care taken to avoid suture placement through the anterior skin. In addition, the sutures must pull the ear posteriorly as well as medially to prevent stenosis of the external auditory canal. (Reproduced, with permission, from Adamson PA, Constantinides MS. Otoplasty. In: Bailey BJ, Calhoun KH, Coffey AR, Neely JG, eds. *Atlas of Head & Neck Surgery—Otolaryngology.* Philadelphia: Lippincott-Raven, 1996:429.)

is often undertaken in conjunction with techniques to correct an absent antihelical fold, as described above.

The patient is prepped and draped in a manner similar to that described for correction of the antihelical fold. After infiltration of lidocaine 1% with epinephrine 1/100,000, a fusiform incision is made in the postauricular region. The width of the incision is estimated by manually pushing the concha toward the mastoid. Care is taken to avoid excessive skin excision, since tension on the wound predisposes to hypertrophic scar formation. Little to no skin excision is required inferior to the level of the antitragus. After excision of skin, soft tissue and postauricular muscle are excised from the postauricular sulcus. Sufficient soft tissue is excised to produce a pocket that will receive the concha during suture placement.

The skin over the helix, antihelix, and concha is undermined with scissors, and permanent horizontal mattress sutures (eg, 4–0 Mersilene [Ethicon, Inc., Somerville, NJ) are placed at the lateral third of the concha cavum and concha cymba parallel with the natural curve of the auricular cartilage (Figure 79–2). The sutures are thrown through cartilage and lateral perichondrium, but not lateral auricular skin. At least three sutures are placed for adequate setback. The sutures are placed on what was the ascending wall of the concha and, when tightened, convert the wall into a longer floor of the concha. For long-term successful conchal reduction, suture bites of mastoid periosteum must be taken. With extremely thick cartilage, as frequently seen in older persons, the cartilage may be weakened by excising small vertical ellipses of cartilage. It is important for the conchomastoidal sutures to allow the concha to be set not only medially but posteriorly. If not, external auditory canal stenosis can result.

The wound is irrigated and closed as after the Mustarde technique. A mastoid dressing is placed, and subsequent postoperative management is the same as that of antihelical fold surgery.



▲ **Figure 79–3.** Fusiform wedge excision for reduction of large ear lobule. (Reproduced, with permission, from Adamson PA, Constantinides MS. Otoplasty. In: Bailey BJ, Calhoun KH, Coffey AR, Neely JG, eds. *Atlas of Head & Neck Surgery—Otolaryngology.* Philadelphia: Lippincott-Raven, 1996:435.)

Otoplasty Refinement Techniques

Frequently, small deformities of the auricle are present that can be corrected by subtle surgical refinements. These techniques are applicable to both congenital irregularities and deformities that are detected after more substantial otoplasty correction (ie, conchal setback and correction of absent antihelical fold). Such refinements include correction of the prominent lobule and reduction of helical prominences.

Reduction of a large ear lobule rarely requires general anesthesia in the adult population. A new earlobe size is designed with a marking pen. After infiltration with local anesthesia, a fusiform incision is made anteriorly and posteriorly in a curvilinear fashion, and a V-shaped, wedge excision of lobule excess is performed (Figure 79–3). The skin is closed with permanent suture (eg, 6-0 nylon), with suture removal occurring on the sixth postoperative day.

Helical prominences, such as superior outer helical rim cartilage excess (ie, elf ears, Spock ears) and superior helical fold cartilage excess (ie, lop ear), may be corrected by a variety of helical reduction techniques. After the infiltration of local anesthesia, a fusiform incision is made on the outer helical rim in the case of helical rim excess and under the helical fold in the case of superior helical fold excess (Figure 79–4). After skin elevation, excess cartilage is shaved using a blade. Skin is trimmed as necessary to ensure appropriate draping over the cartilaginous rim. The incision is closed with permanent suture (eg, 6-0 nylon), with suture removal occurring on the sixth postoperative day. No pressure dressing is required.

Adamson PA, Constantinides MS. Otoplasty. In: Bailey BJ, Calhoun KH, Coffey AR, Neely JG, eds. *Atlas of Head & Neck Surgery—Otohryngohgy*. Philadelphia: Lippincott-Raven, 1996:429.

Furnas DW. Correction of prominent ears with multiple sutures. *Clin Plast Surg* 1978;5:491. [PMID: 359225] (This article describes the author's suture technique for conchal setback using permanent conchomastoidalsuturing.)

Mustarde JC. The treatment of prominent ears by buried mattress sutures: a ten-year survey. *Plast Reconstr Surg*. 1967;39:382. [PMID: 5336910] (This article reviews the author's otoplasty suture technique for correcting a deficient antihelical fold.)

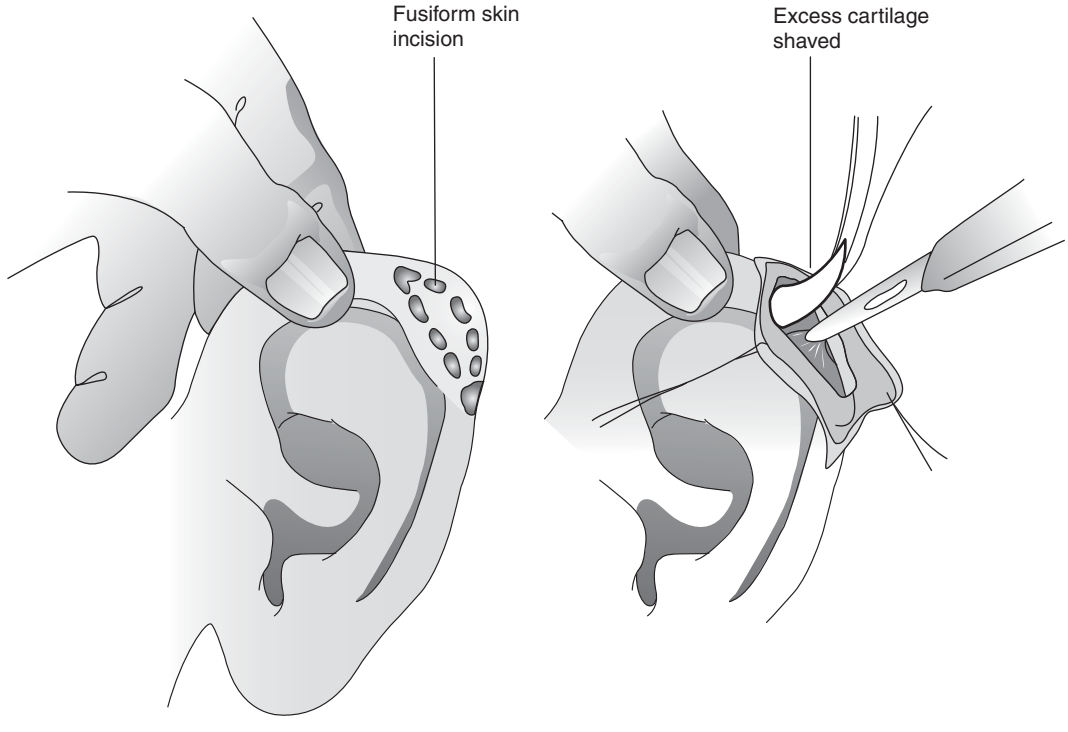
COMPLICATIONS OF OTOPLASTY

Overall, there is a high satisfaction rate among patients who undergo otoplasty surgery (85%). Complication rates range from 7% to 12%, with unsatisfactory aesthetic outcomes accounting for the majority of complications. Complications arising from otoplasty may be subdivided into early, late, and aesthetic/anatomic in etiology (Table 79–1).

Hematoma formation occurs following approximately 1% of all otoplasty procedures. Studies suggest a slightly higher incidence of hematoma formation in cartilage-cutting procedures compared with cartilage-suturing operations. Symptoms include unilateral or bilateral ear pain, usually within the first 48 hours after surgery. Hematoma formation may lead to perichondritis and the devastating sequelae of cartilage necrosis and ear disfigurement. Therefore, complaints of ear tightness or pain should be taken seriously with prompt removal of bandages and inspection of wounds. Infections after surgery typically manifest on postoperative day 3 or 4. Treatment involves systemic antibiotics, with particular emphasis on coverage for staphylococci, streptococci, and *Pseudomonas aeruginosa*.

Late complications include paresthesias of the ear, particularly to cold temperatures, which typically improve over 4–6 months. In addition, suture otoplasty techniques may result in complications surrounding permanent suture placement, such as suture extrusion and suture granuloma formation. These risks are minimized by meticulous placement of sutures. Hypertrophic scars or keloids may form as the wound heals, and conservative treatment with serial triamcinolone acetonide injections is indicated.

Aesthetic complications result from abnormalities in the relationship of the auricle to the scalp or from distortion of the auricle itself. These often stem from over-correction or undercorrection of the initial deformity. Often, an unsatisfactory outcome occurs when there is asymmetry between the left and right ear (typically, less than 3 mm difference in the mastoid-helical distance between left and right ear is satisfactory). Classic deformities include the "telephone ear" deformity that results from overcorrection of the middle third of a prominent ear. "Reverse telephone ear" deformity occurs when the midauricle protrudes after overcorrection of the superior pole and lobule. Alternatively, inadequate conchal setback may produce a similar aesthetic deformity. Isolated antihelical overcorrection, or "hidden helix," produces the suboptimal appearance of the helix positioned



▲ **Figure 79–4.** Reduction of helical prominences. (Reproduced, with permission, from Adamson PA, Constantinides MS. Otoplasty. In: Bailey BJ, Calhoun KH, Coffey AR, Neely JG, eds. *Atlas of Head & Neck Surgery—Otolaryngology.* Philadelphia: Lippincott-Raven, 1996:435.)

medial to the antihelix on frontal view. All of the above aesthetic complications can usually be addressed through revision surgery, if desired by the patient.

Becker DG, Lai SS, Wise JB, Steiger JD. Analysis in otoplasty. *Facial Plast Surg Clin North Am*. 2006;14:63. [PMID: 16750764] (This article reviews otoplasty evaluation and provides a thorough description of potential otoplasty complications.

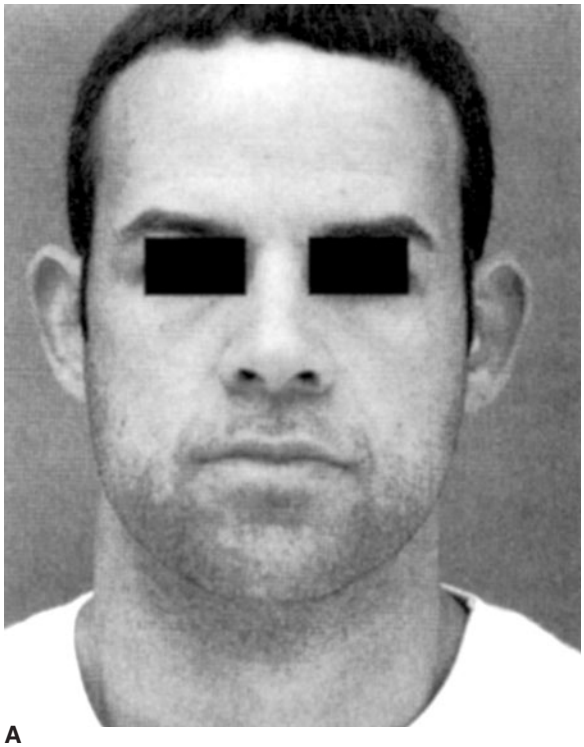
SUMMARY

Protrusion of the ears is a relatively common deformity. Successful surgical correction can relieve both children and adults of the psychosocial distress often associated with these deformities. An understanding of auricular anatomy and aesthetic ideals, plus with accurate analysis and meticulous surgical technique, can yield outcomes that are gratifying to both patient and surgeon (Figure 79–5).

Table 79–1. Otoplasty Complications.

Early Complications	Late Complications	Aesthetic/Anatomic Complications
Hematoma	Paresthesia/hypersensitivity	Inadequate correction
Infection	Suture extrusion	Antihelical overcorrection (ie, "hidden helix")
Chondritis	Suture granuloma formation	Telephone ear
Pruritis	Skin necrosis Hypertrophic scar formation Keloid scar formation	Reverse telephone ear Malposition of the lobule Sharp cartilaginous edges External auditory canal stenosis (from conchal setback)

From Becker DG, Lai SS, Wise JB, Steiger JD. Analysis in otoplasty. *Facial Plast Surg Clin North Am.* 2006;14:63–71.



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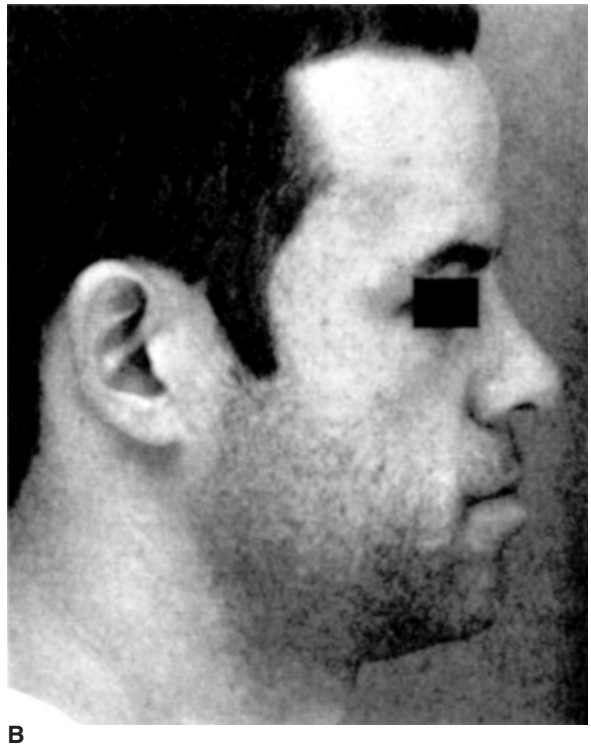

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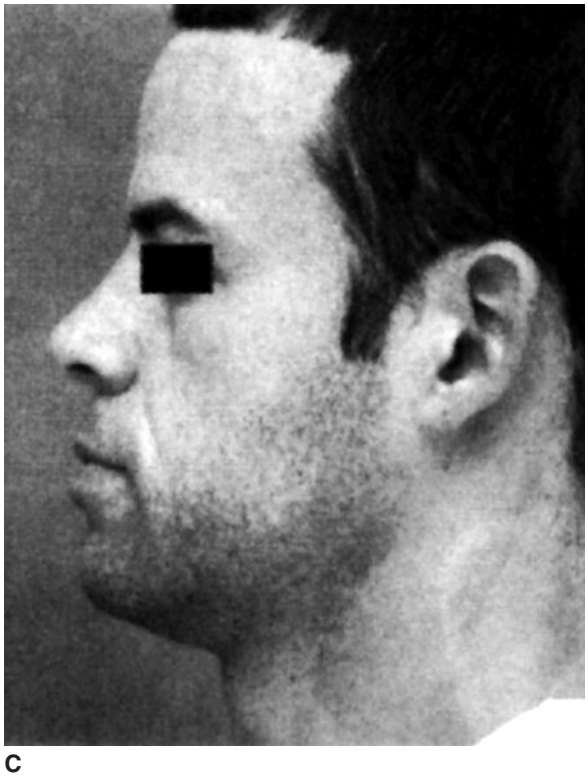
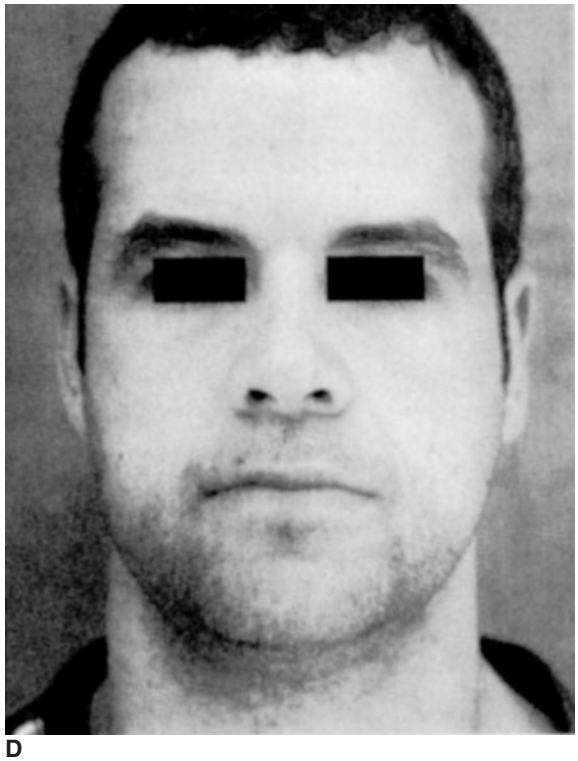


C

▲ **Figure 79–5. (A–C)** Young man with prominauris, specifically conchal excess and an absent antihelical rim. *(continued)*



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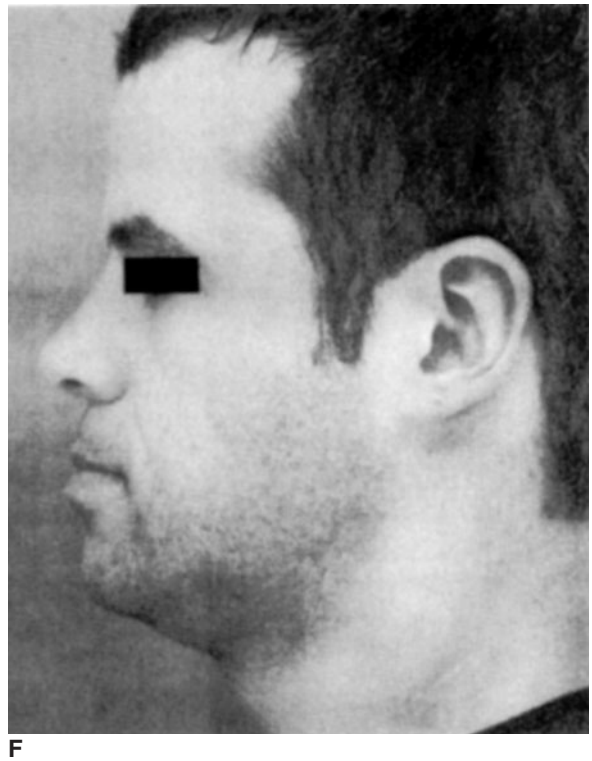

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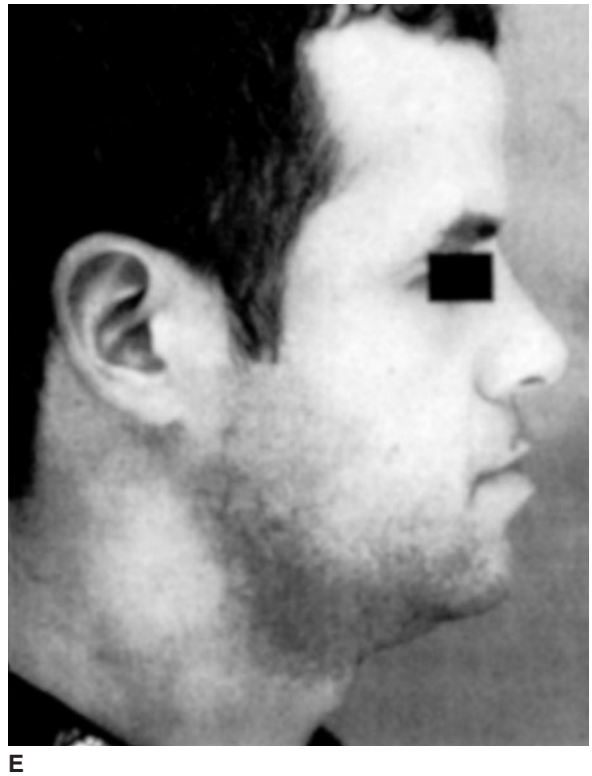


E

▲ **Figure 79–5.** *(continued)* **(D–F)** Patient 4 months postoperative from antihelical fold creation and conchal setback using suture techniques.

MICROTIA

ESSENTIAL OF DIAGNOSIS

- Microtia occurs due to abnormal development of hillocks during weeks 4 to 12 of gestational age
- Microtia is more prevalent in certain ethnic populations, including certain Latin American countries and the Navajo Indian population in the U.S
- Microtia has been linked to teratogens such as isotretinoin and thalidomide, but in the majority of cases the cause is unknown
- Microtia consists of disorganized remnant of cartilage attached to a variable amount of soft tissue lobule
- Microtia is treated by multistage auricular reconstruction starting after age 5 that preferentially utilizes costal cartilage, although alloplasts are preferred by some surgeons.

BACKGROUND

Auricular malformations range from anotia to mild alterations in the external form of the ear. Microtia is a congenital malformation of variable severity of the external ear. The microtic auricle consists of a disorganized remnant of cartilage attached to a variable amount of soft tissue lobule, which often is displaced from a position symmetrical with the opposite normal ear.

Microtia occurs with a frequency of 1 in 5,000–20,000 births. It affects males more than females at a ratio of 2.5:1. Unilateral cases are much more common than bilateral cases with a ratio of 4:1. The right ear is affected more frequently than the left ear with a ratio of 3:2. The reason for this predilection remains unclear.

Microtia occurs with increased frequency in certain populations, such as in several Latin-American countries, and among the Navajo Indian community in the United States. The incidence of microtia is 1 per 900–1200 births in the Navajo population and 1 per 4000 births in the Japanese population.

EMBRYOLOGY

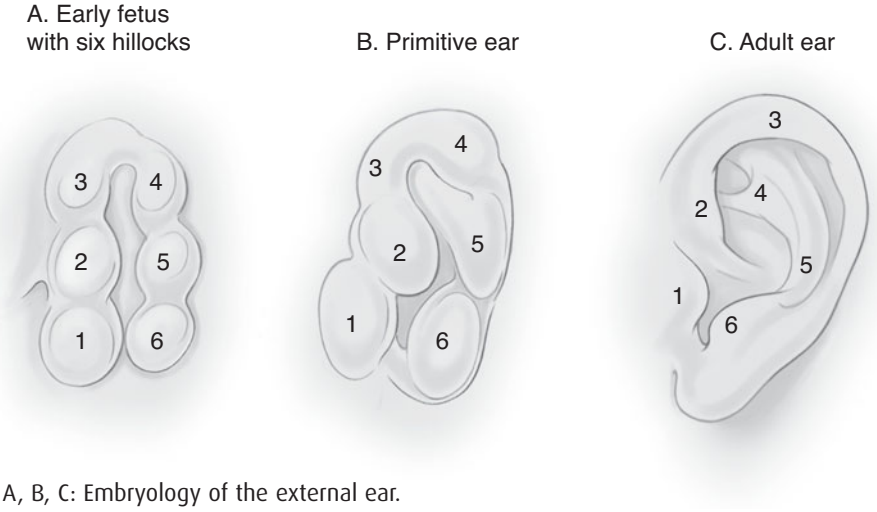
Microtia results from abnormal embryologic development of any of the six auricular hillocks. The six hillocks form the auricle during the sixth week of gestation. Abnormal development of the hillocks during weeks 4 to 12 of gestational age leads to auricular defects. Hillocks 1, 2, and 3 are derived from the first branchial arch and give rise to the tragus, helical crus and helix, respectively. Hillocks 4 and 5 form the antihelix, and hillock 6 forms the antitragus (see Figure 79–6).

While certain teratogens such as isotretinoin and thalidomide have been known to produce microtia, the cause in the vast majority of cases remains elusive.

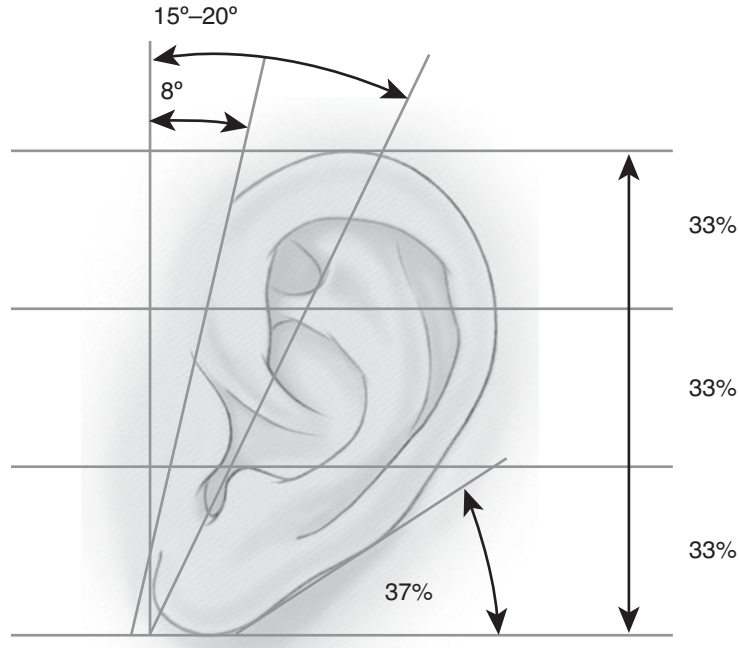
NORMAL ANATOMY

The structure of the auricle can be broken down into its integral elements all of which lend to the natural appearance of an ear. The main components include the helix, antihelix, scapha, triangular fossa, concha cymba, concha cavum, external auditory meatus, tragus, antitragus, and lobule. All these critical facets of the ear need to be present in order to achieve the perception of a normal ear.

The average length of the ear varies between 55 to 65 mm and the average width is 33.4 mm in females and 35.5 mm in males. The width is approximately 55% of the length of the



▲ **Figure 79–6.** A, B, C: Embryology of the external ear.



▲ **Figure 79–7.** Diagramatic representation of the relationships of components of a normal ear.

ear. Conceptually, the ear can be divided into equal horizontal thirds. The first third extends from the superior helical rim to the upper border of the concha cymba. The middle third extends from the upper border of the concha cymba to the superior aspect of the antitragus. The lower third extends from the superior aspect of the antitragus to the end of the lobule (see Figure 79–7).

In the general population, the ear protrusion from the mastoid to the posterior surface of the auricle or auriculocephalic angle is 15°–20°. The inclination of the ear is usually 20° from the Frankfort plane. Many surgeons use the inclination of the nasal dorsum as guide. However, this is not an accurate measure, since the average nasal dorsum usually lies approximately 30° from the Frankfort plane.

TYPES OF MICROTIA

While no universal classification system of microtia prevails, there are several widely used staging systems. Marx described a system based on the degree of deformity and specific anatomic parts.

- Grade 1 microtia is characterized by an abnormal auricle with all identifiable landmarks.
- Grade 2 microtia consists of an abnormal auricle without some identifiable landmarks.
- Grade 3 microtia is recognized by a very small auricular tag
- Grade 4 microtia is anotia.

Weerda described a similar system consisting of only three grades.

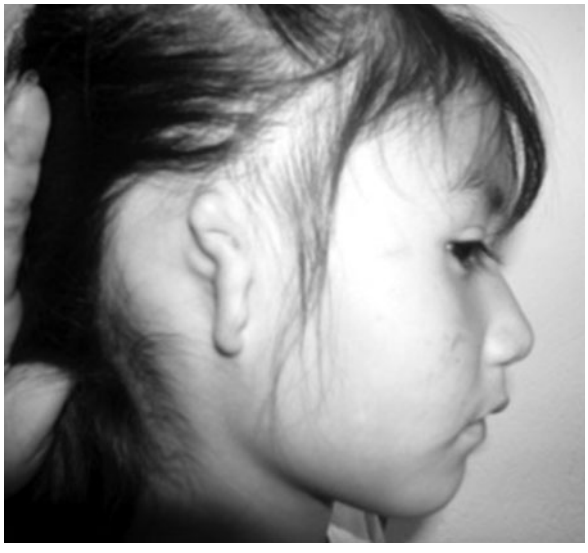
Grade I microtia is characterized by a mild deformity with a slightly dysmorphic helix and antihelix, as depicted in the first image below. All the major structures are present, and no additional cartilage is necessary during surgical repair. Characteristic lop ear and cup ear abnormalities are categorized into this group.

Grade II microtic ear deformities have all major structures present to some degree, but repair requires cartilage or skin. The grade III abnormality has few, if any, landmarks. The lobule, if present, is usually positioned anteriorly. Peanut and anotic ears are examples of grade III malformations (see Figure 79–8).

SURGICAL REPAIR

Various methods of reconstruction have been advocated throughout the years, including the use of autologous rib cartilage versus the use of a prosthesis. Autogenous cartilage is our favored choice because of lower resorption rates, lower extrusion rates, ability to grow and ability to withstand trauma. A relatively new area of research involves using cultured chondrocytes to create a cartilaginous framework. While this continues to be an area of interest, it is beyond the scope of discussion for this chapter and will not be discussed here.

A child with microtia should be evaluated at an early age with appropriate referrals made for audiologic testing and for an otologist, if there is evidence of hearing loss and/or



▲ **Figure 79–8.** Type 3 microtia.

middle ear deformities. Timing of microtia repair is based on physical maturity, psychological development and the patient's social milieu. By the age of 6, the thoracic cavity increases in size and strength such that there is adequate donor cartilage available. As the child grows, more cartilage becomes available facilitating reconstruction. However, the benefit of availability of greater cartilage needs to be weighed against the patient's social situation, such that it is performed at a time when it limits the psychological effects of peer ridicule and teasing. The psychological effects of such teasing generally do not manifest before ages 7–10. If a child does not have the developmental maturity to manage with the critical early postoperative period, surgical repair should be delayed.

Atresia repair needs to be delayed until after all the auricular reconstruction has been completed. This allows for establishing the auricular position before creation of an external canal, ensuring appropriate symmetry. Secondly, it allows auricular reconstruction to occur with an unadulterated blood supply.

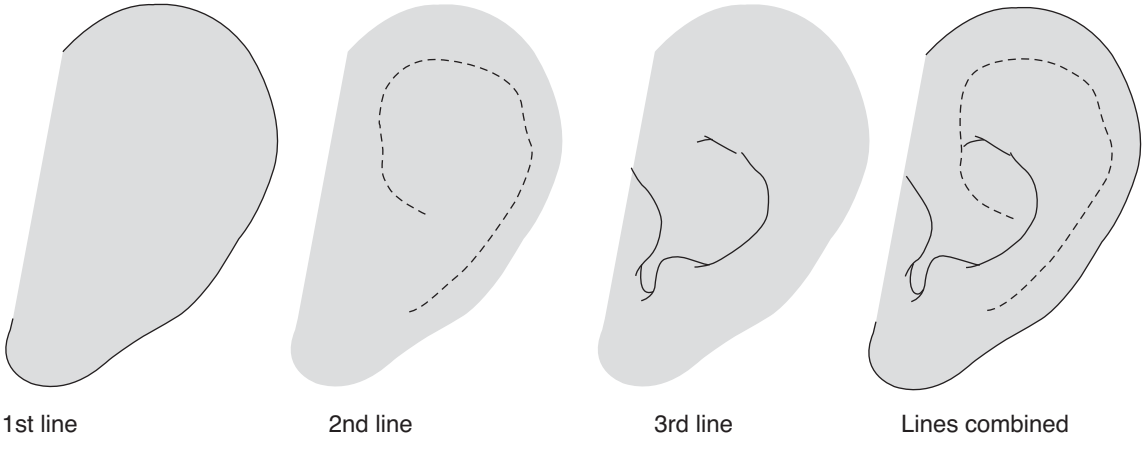
Architecture

The architecture of the auricle is composed of several key components which need to be understood in order to achieve a quality repair. The first defining quality is the general outline of the auricle, which is essentially an oval shape with a slightly flattened area posteriorly. A second defining characteristic is a line that defines the helical rim from its root and the crus helicus. A third line defines the concha, tragus, and antitragus (see Figure 79–9. Finally, the fossa triangularis needs to be highlighted to achieve a realistic appearance to the framework.

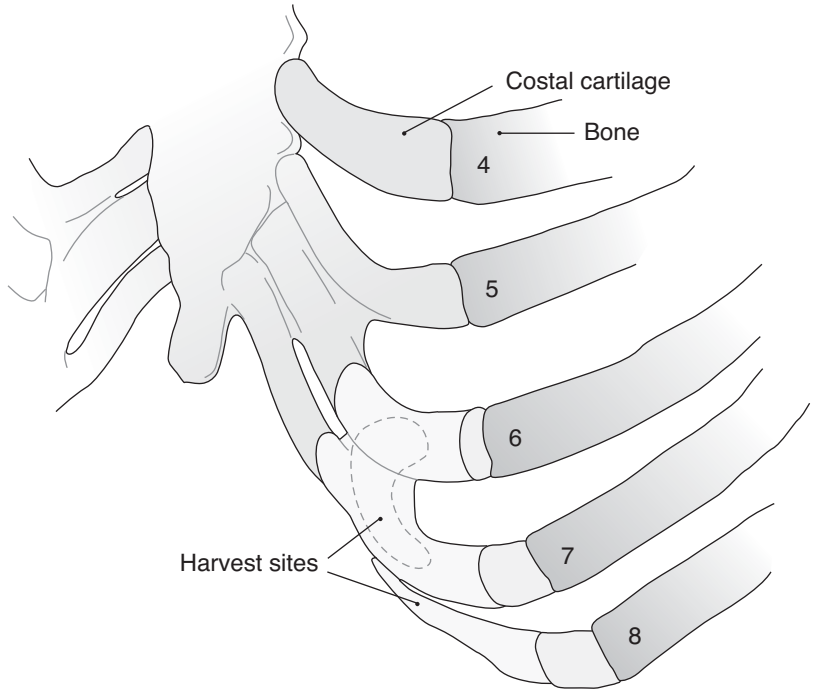
The reconstructed ear should be symmetric with the contralateral ear, especially with respect to vertical position, length, and protrusion, as these are the qualities which can be accessed from an anterior view. Asymmetries of the two sides of the face are noted in up to 88% of microtia patients, due to generalized abnormalities in the development of the branchial arch. As a result, measurements of the lower one-third of the face can be deceptive.

Reconstruction

Traditional microtia reconstruction generally occurs in four stages with each stage-taking place 3 to 4 months after the preceding stage. The first stage involves harvesting the rib cartilage, carving, and creating an auricular framework, and placing it under a subcutaneous pocket. The second stage involves rotating the lobule from the microtia remnant and positioning it inferiorly on the helical rim. The third stage



▲ **Figure 79–9.** Basic structural components of the normal ear. Each line enhances the perception of the typical ear and can be used by the reconstructive surgeon to create a framework.



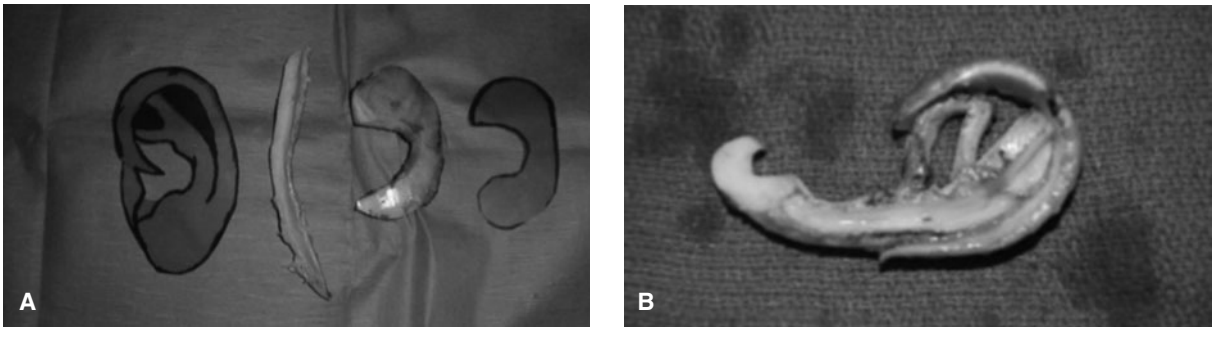
▲ **Figure 79–10.** Harvesting of the contralateral ribs 6, 7, and 8 to create the cartilage framework. The sixth and seventh ribs create the base while the free-floating eighth rib creates the helical rim.

encompasses creating an auriculocephalic angle by elevating the framework off the skull and placing a skin graft on the undersurface of the framework. The fourth and final stage involves forming the tragus, and possibly the conchal bowl. It cannot be overemphasized that no incision should be made until a multistage plan is outlined prior to start of the first stage. Incisions for all subsequent stages should be planned prior to starting the first phase in order to maximize blood supply for all subsequent reconstructions.

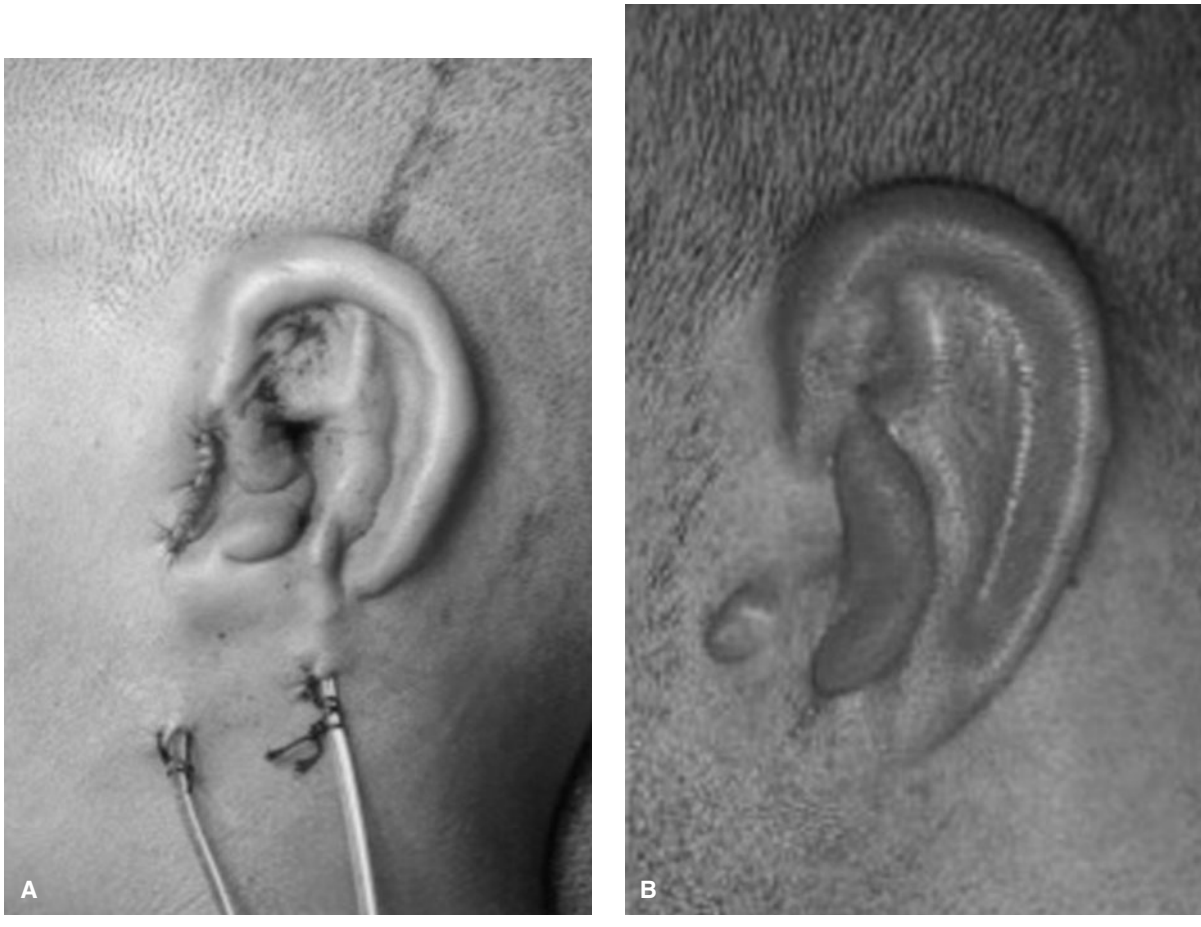
A. Stage I

In this first and most critical of the four stages, rib cartilage is harvested, carved and placed under a cutaneous pocket. The normal ear is used to trace out a template on x-ray paper and appropriate measurements made on the microtia side. Next, the contralateral sixth to eight rib cartilages are harvested in continuity (see Figure 79–10). This curvature mimics that of the contralateral ear. The cartilage is then carved and sculpted to match the template (see Figure 79–11). At the end of the rib harvest, the wound should be irrigated while positive pressure ventilation is provided in order to evaluate for an air leak and therefore a pneumothorax.

The microtia harvest incision should be placed in a location that avoids compromising blood flow and can be incorporated into a future incision site. The microtia remnant is carefully dissected free from the overlying skin. A pocket for the framework is dissected such that it is 1–2 cm larger than



▲ **Figure 79–11.** **(A)** Template with rib components to be carved. **(B)** Completed cartilage framework.

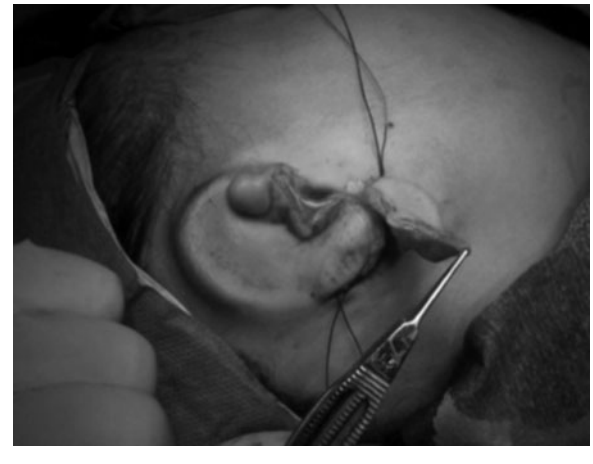


▲ **Figure 79–12.** **(A)** Stage I, immediately postoperatively. **(B)** Stage 1, two months postoperatively.

the framework. The placement of the framework is based on the location of the normal ear and not on the position of the hairline or the desired location for the external auditory meatus. The framework is placed into the pocket and held in place with the use of the suction effect of two small drains. The convolutions of the ear are packed gently with Xeroform in order to maintain their shape (see Figure 79–12).

B. Stage II

The second stage, referred to as the lobule transposition, can be performed within 6–8 weeks of the first stage. The surgery is performed by transposing the vestigial lobule along an inferiorly based pedicle. The helical rim of the framework created during the first stage needs to be incised and tailored to allow attachment of the lobule equally on either side of the framework (see Figure 79–13). This stage can be performed under local anesthesia in cooperative patients.



▲ **Figure 79–13.** Stage II, lobule transfer.

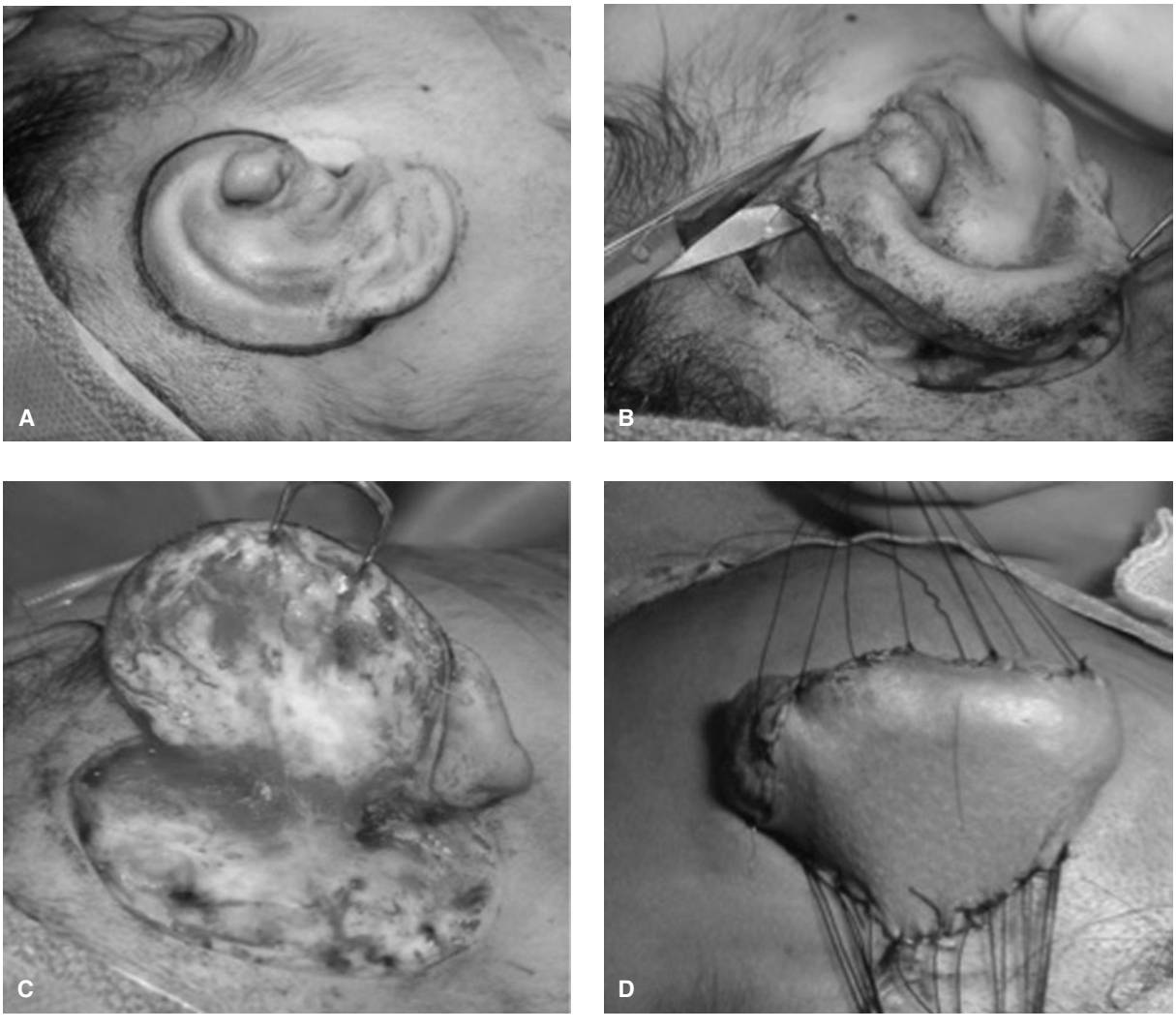
C. Stage III

The third stage involves creating the auriculocephalic angle. After the postauricular area is shaved and prepped, an incision is made extending from the anterior crus, anterosuperiorly, to the antitragus inferiorly. If the lobule requires repositioning, the incision is continued around the entire lobule. The framework is then dissected free from the underlying soft tissue of the mastoid region. A pocket is dissected in the lobule to allow placement of the inferior aspect of the framework.

The skin posterior to the incision is undermined widely in the superior, posterior, and inferior directions. This flap is then advanced to fill in the defect in the new postauricular region. A split thickness skin is harvested from the patient's hip and cut to the size of the defect along the posterior aspect of the elevated ear. The skin graft is sutured in place with a Xeroform bolster is sutured to the postauricular surface. Of note, greater projection of the ear can be obtained by placing a piece or rib cartilage behind the elevated ear and placed under the subcutaneous pocket (see Figure 79–14).

D. Stage IV

The fourth stage involves creation of the tragus. A composite graft is harvested from the contralateral ear conchal

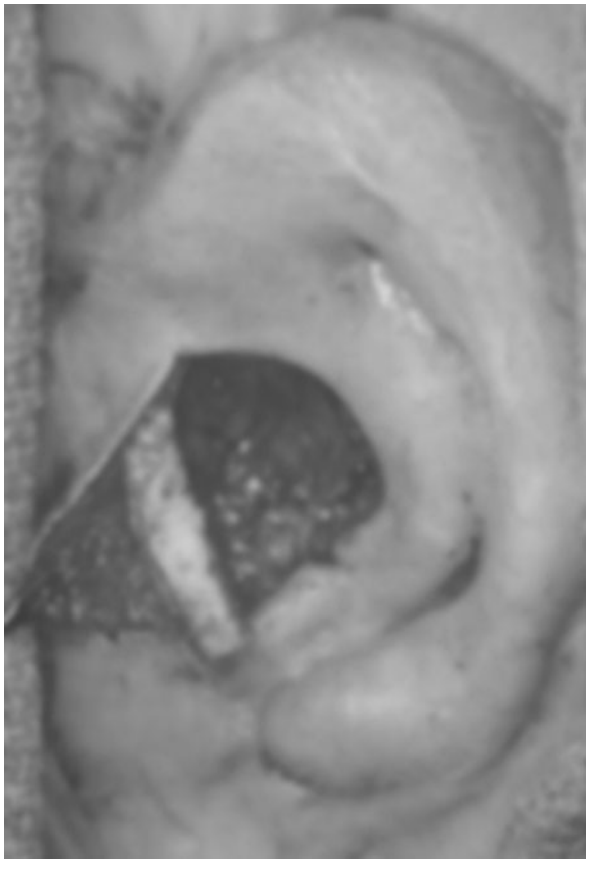


▲ **Figure 79–14.** Stage III, creation of auriculocephalic angle. **(A)** Marking of incision, **(B)** incision posterior to framework, **(C)** framework elevation, and **(D)** placement and suturing of split thickness skin graft along posterior auricle.

cartilage. In bilateral microtia, a piece of cartilage and skin from the microtia remnant can be used to create the tragus. A "J" incision is made in the location of the planned posterior border of the tragus. The primary limb of the "J" is placed in the posterior tragal margin, while the curve is placed in the intertragal notch (see Figure 79–15). Once an adequate flap is created anteriorly to receive the composite graft, it is then placed and sutured into place along the undersurface of the flap. Cotton bolsters are sutured onto both the anterior and posterior aspects of the newly created tragus, in order to secure the graft and create a pretragal sulcus.

Use of Synthetic Implants

An alternative to antilogous rib cartilage is the use of synthetic prefabricated auricular framework. The most popular of these is porous high-density polyethylene (PHDPE, Porex). It is an inert, noncompressible product that is pliable when heated and can be shaped further. It also has good tissue compatibility and ability to accept tissue ingrowth into its framework. Advantages of its use include the elimination of a chest incision and associated morbidity. Critics cite incidents of implant exposure and infection rates as reasons not to use implants. Some pitfalls of synthetic implants and prostheses include the fact that they are firmer than autogenous grafts, are relatively immobile, are less delicate and are more prone to traumatic injury.



▲ **Figure 79–15.** Stage IV, creation of conchal bowl and tragus.

COMPLICATIONS

In Brent's earlier series, he reported a complication rate of 1.6%, but in a more recent series of 1200 cases, he reported no complications. Complications after autologous reconstruction are uncommon, but range from risk of skin loss, cartilage exposure, infection, hematoma, malposition, graft resorption leading to poor contour, scar contracture, pneumothorax, and atelectasis. Skin loss and cartilage exposure can be prevented by careful examination of the repair at the conclusion of the case. If there is any evidence of skin blanching or undue tension, the cutaneous pocket should be made larger or the projection of the framework should be reduced. Preoperative antibiotics, thorough skin prep, sterile technique and postoperative hygiene are key components in preventing infection. Careful hemostasis and the use of suction have been shown to be useful in preventing hematoma.

Intraoperative pneumothorax is a complication, which can be easily treated. A red rubber catheter should be placed in the pleural opening and any residual air removed using a syringe. A chest x-ray should be obtained immediately after closure of the wound. If there is no pneumothorax, the red rubber catheter can be removed after closure. The patient should be followed with serial x-rays.

SUMMARY

Microtia is an uncommon congenital deformity, which is nonetheless psychologically and socially disturbing to the child affected by it. Careful patient selection and thorough patient education, combined with detailed surgical planning and technique, facilitate successful outcomes. Complications can be prevented with judicious preparation and some foresight. The use of autologous cartilage versus an implant is a decision that should be made not only based on surgeon experience with the procedure, but with consideration to patient candidacy as well.

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Quatela VC, Thompson SK, Goldman NG. Microtia reconstruction. *Facial Plast Surg Clin N Am* 2006;14:117–127 (This is paper reviews the basics of normal ear architecture, the anatomy of a microtic ear, and a review of the Quatela technique for microtia repair.)

Siegert R, Weerda H, Magritz R. Basic techniques in autogenous microtia repair. *Facial Plast Surg*. 2009;25(3):149–157 (This paper reviews the Weerda classification and thoughts on reconstruction.)

Zhang QG, Zhang J, Yu P et al. Environmental and genetic factors associated with congenital microtia: a case-control study in Jiangsu, China, 2004 to 2007. *Plast Reconstr Surg*. 2009;124 (4):1157–1164. (This paper outlines possible etiologies for microtia, including environmental causes, teratogens and genetic aspects.)

We would like to acknowledge Anil R. Shah, MD for his contribution to this chapter in the previous editions of CDT.

Facial Fillers & Implants

80

Anil R. Shah, MD, FACS, Jeffrey B. Wise, MD &
Minas Constantinides, MD, FACS

ESSENTIALS OF DIAGNOSIS

- Analysis of the type of rhytid, including anatomic location and depth and whether it is static or dynamic
- Knowledge of the longevity of each facial injectable
- Analysis of facial skeletal proportion, occlusion, and preoperative symmetry.

General Considerations

Facial contouring is a recent trend in facial aesthetic surgery. Facial implants serve to add volume, providing a more appealing shape to a person's face. Facial injectables have reached tremendous popularity due to their safety, "no-down-time" appeal, and economics. Both are discussed to provide background on an exhaustive topic.

FACIAL FILLERS AND INJECTABLES

There are a large variety of facial injectables, each serving a different purpose. A brief summary of the most commonly used facial injectables with a delineation of their advantages and disadvantages will be highlighted.

Botulinum Toxin

Botulinum toxin A (BOTOX® [Allergan, Irvine, CA] and Dysport [Medicis, Scottsdale, AZ]) decreases facial lines and wrinkles at sites of skin pleating caused by hyperfunctioning mimetic muscles. Botulinum toxin A is FDA approved for treatment of the glabella. Off-label uses have included periorbital lines (crow's feet) platysmal bands, the forehead, and nasolabial and melolabial lines. Botulinum toxin A is also used for hyperhydrosis of the palms and armpits.

Botulinum toxin A causes paralysis by inhibiting acetylcholine release at the neuromuscular junction. This is accomplished in three steps. First, the toxin binds the nerve. Second, the toxin is internalized into the nerve. Third, the toxin is cleaved by internal proteolytic enzymes, and the degradation by-products interfere with the normal process of vesicle fusion to the plasma membrane. This results in the inhibition of the exocytosis of acetylcholine.

The toxin requires 24–72 hours to take effect, reflecting the time necessary to disrupt the synaptosomal process. In very rare circumstances, some individuals require as many as 5 days for the full effect to be observed. The effects of botulinum toxin last from 2 to 6 months.

The dose of the toxin is measured as one standard unit, which is equal to the amount necessary to kill 50% of Swiss–Webster mice injected with that dose. Extrapolating the data from mouse experimentation, Meyer and Eddie estimated that a 104 kg adult male would sustain a lethal dose of botulinum toxin type A at amounts exceeding 3500 units, a dose that far surpasses any dosing regimen in the cosmetic treatment of the aging face.

Botulinum toxin is contraindicated in patients with peripheral motor neuropathic diseases or neuromuscular functional disorders such as Eaton–Lambert syndrome and myasthenia gravis. Similarly, botulinum toxin type A is contraindicated in pregnant patients and those who are lactating, although unintentional administration has not resulted in birth defects or pregnancy issues. Finally, caution should be taken when injecting botulinum toxin type A to those taking aminoglycoside antibiotics or other agents that interfere with neuromuscular transmission, since these agents may potentiate the effects of botulinum toxin both locally and regionally.

Hyaluronic Acid Derivatives

Hyaluronic acid derivatives (Restylane [Medicis Aesthetics, Scottsdale, AZ], Captique [Allergan, Irvine, CA] Juvederm [Allergan, Irvine, CA]) are glycosaminoglycan biopolymers,

similar to the substance found in the intercellular layers of the dermis of the skin, and are very biocompatible. They are used primarily for lip and nasolabial fold augmentation and for fine wrinkles. Some recent uses of hyaluronic acid derivatives include nonsurgical rhinoplasty and volumetric filling in senile earlobe repair. Rare cases of hypersensitivity have been reported, but preinjection skin testing is generally not advocated. Volume enhancement with hyaluronic acid derivatives lasts 4–6 months, with some reports of material lasting for up to 16 months. Newer formulations of hyaluronic acid containing preincorporated 3% lidocaine have been shown to have equivalent product longevity.

Complications are relatively uncommon with hyaluronic acid derivatives. In cases of overaugmentation, hyaluronidase can be used to decrease the amount of dermal filling. Caution should be taken when injecting superior to the Frankfort horizontal line. Peter describes a case of retinal artery occlusion through retrograde flow through a peripheral branch of the ophthalmic artery. Skin necrosis is rare (a report of two cases of 400,000).

Poly-L-lactic Acid

Poly-L-lactic acid (Sculptra) is a volumetric filler currently FDA approved for the treatment of lipoatrophy in HIV patients. Lipoatrophy in HIV is due to a number of factors including reverse transcriptase inhibitors and the disease process itself. Recently, poly-L-lactic acid has been used in an off-label capacity as a non-HIV facial filler. The main complication is nodule formation. This can be avoided by injecting deep to subcutaneous tissues and not in areas of significant muscle motion such as the lips. The duration of augmentation with poly-L-lactic acid is up to 3 years.

Calcium Hydroxylapatite

Calcium hydroxylapatite (Radiance FN, Bioform, Inc, Franksville, WI) is a major mineral constituent of bone. It has an off-label use for soft tissue augmentation in the face, primarily for reduction of nasolabial folds. Calcium hydroxylapatite should be injected subdermally to avoid nodule formation. In addition, the injection of radiesse should be avoided in the lips. The true longevity of calcium hydroxylapatite is not known.

Bovine Collagen

Bovine collagen (Zyderm and Zyplast; McGhan Medical Corporation, Fremont, CA) is composed of 95% type I collagen and is most commonly used to augment lips and nasolabial folds. Zyplast is cross-linked with glutaraldehyde (creates a longer lasting effect) but must be injected into the deep dermis. Zyderm is injected into the superficial dermis. Hypersensitivity reactions occur in about 3% of patients; therefore, skin testing and even secondary skin testing are advocated. Bovine collagen augmentation lasts 2–4 months.

Human-Derived Collagen

Human-derived collagen (Cosmoderm and Cosmoplast, Inamed Corporation, Santa Barbara, CA) is used for the treatment of facial rhytids and lip augmentation. In contrast to bovine-derived collagen, human-derived collagen carries essentially no risk of hypersensitivity reactions, obviating the necessity for pretreatment skin testing. Typically, injections maintain augmentation similar to that of bovine collagen. Adverse reactions may occur in patients with known allergy to bovine collagen.

Autologous Fat

Fat transplantation has the advantage of being an autologous substance. Fat transplantation is used as a volumetric filler. The concept of loss of facial volume is recent, and surgeons recontour the face, the nasolabial folds, temporal fossa, prejowl sulcus, and perioral and periorbital areas.

Most commonly, fat is harvested from the lateral thigh or abdominal region. Fat is then either strained or centrifuged, and injected into areas requiring volume. Technique in handling fat is crucial in maintaining adipocyte viability. Fat transplantation often requires multiple treatment sessions and has variable degrees of resorption. Fat can be frozen with minimal loss in fat viability and reinjected at a future date.

Disadvantages of fat harvest include donor site morbidity, potential for prolonged facial swelling, and unpredictable resorption. In addition, fat can lead to granulomas that can be treated with triamcinolone injections or direct excision. Advantages of fat transplantation include a potentially permanent natural facial filler that can serve as an adjunctive or stand-alone procedure.

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Raspaldo H, De Boulle K, Levy PM. Longevity of effects of hyaluronic acid plus lidocaine facial filler. *J Cosmet Dermatol.* 2010;9(1):11–15. [PMID: 20367667] (Comparison of hyaluronic acid fillers versus those with lidocaine to determine longevity of effects)

Sattler G. Long-lasting results with polylactic acid. *J Drugs Dermatol.* 2003;9:422. [PMID: 15303782] (Review article demonstrating benefits of polylactic acid as a facial filler.)

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Vartanian AJ, Frankel AS, Rubin MG. Injected hyaluronidase reduces Restylane-mediated cutaneous augmentation. *Arch Facial Plast Surg.* 2005;7(4):231. [PMID: 16027343] (Intradermal hyaluronidase injections can be used to reduce dermal augmentation from previously injected Restylane. A small dose of hyaluronidase equivalent to 5–10 U may be injected initially.)

FACIAL IMPLANTS

Preoperative Assessment

The hypoplastic chin is the most common indication for chin augmentation. On frontal view, the face can be divided into thirds, with the lower third spanning from the subnasale to the mentum. Aging results in loss of vertical height of the mandible. On lateral view, a vertical line can be dropped from the lower lip. In females, the chin should be 1–2 mm posterior to this line. In males, the chin should lie at the same level as this line. There are a number of techniques to analyze chin size and projection (Table 80–1).

Patients' occlusion should be assessed preoperatively to ensure that orthognathic treatment is not necessary. Type I occlusion is when the mesial–buccal cusp of the maxillary first molar contacts with the mandibular first molar's buccal groove. Type II occlusion is when the maxillary first molar is anterior to the buccal groove (an overbite), and Type III is when the maxillary molar is posterior (an underbite).

Analysis of the malar and submalar region is much more complex and requires three-dimensional planning. The

Table 80–1. Chin Analysis.

Rish technique	A line perpendicular to the Frankfort horizontal line is projected tangential to the most anterior edge of the lower lip vermilion border. This perpendicular line is the meridian that marks the desired chin projection.
Legan's angle	One line is projected through the glabella and the subnasale, and a second line is projected through the subnasale and the pogonion. The ideal angle created between these two lines is 12° ± 4°.
Merrifield Z-angle	A line is projected through the pogonion and the most anterior point of the upper lip vermilion border. The angle this creates with the Frankfort horizontal line should be 80° ± 5°.
Zero meridian of Gonzales-Ulloa	A line perpendicular to the Frankfort horizontal line projected through the nasion. The pogonion is supposed to be within 5 mm of this line. Retraction of the chin ≥1 cm is deemed first-degree retraction, 1–2 cm is second-degree retraction, and >2 cm is classified as third-degree retraction. Significant is that first- and second-degree retractions are treatable with implants, but third-degree retraction is best treated with maxillofacial surgery.

Table 80–2. Midface Analysis.

Hinderer	In a frontal view, draw a line from the lateral commissure of the lip to the lateral canthus of the ipsilateral eye. Another line projects from the tragus to the inferior edge of the nasal ala. The area posterior and superior to the junction of these two projections should be the most prominent area of the malar eminence.
Powell	A vertical line is drawn through the middle of the face; then the segment between the nasion and the nasal tip is bisected by a line that curves gently upward to the tragus on both sides. A line is drawn from the inferior ala to the lateral canthus and another one, parallel with this one, is drawn from the lateral intersection of the curvilinear horizontal line and the line from the oral commissure marks the point where the malar area should be most prominent.

submalar triangle is the area below the malar eminence and the location of many facial deficiencies. Binder classified patterns of midfacial deformity and the resultant augmentation required. There are a variety of methods of analyzing the midface and its projection (Table 80–2).

Procedure

Chin implantation can take place by an external or intraoral route. The extraoral approach has the advantage of not contaminating the implant through the oral cavity. The intraoral approach prevents an external scar. Implants placed intraorally tend to "ride" high postoperatively, partly because of the difficulty in fixating the implant. The surgeon should be aware of the position of the mental nerve, which emanates from the bone approximately 1 cm above the edge of the mandible and approximately 2.5–3.5 cm from the midline, lying in the vertical plane between the first and second premolar.

Typically, malar and submalar implants are placed by an intraoral route. An incision is made along the upper gingivobuccal sulcus, and an elevator is used to lift the periosteum off the face of the maxilla. The masseteric fibers are released off the face of the maxilla.

The infraorbital nerve is avoided as it exits the infraorbital foramen 4–7 mm below the inferior orbital rim on a vertical line that descends from the medial limbus of the iris. A tight periosteal pocket is created that is small enough to fit the implant tightly. The implant can be further fixated with a titanium screw, a resorbable suture, or a temporary external suture and bolster.

Complications

Complications of facial implants are rare and include hematoma, infection, nerve paresthesia (transient or permanent), and motor nerve injury. No study has shown a change in infection rates in extraoral versus intraoral approaches.

ePTFE (W.L. Gore & Associates, Flagstaff, AZ) is an expanded, strongly hydrophobic, fibrillated polymer that can be produced in sheets, three-dimensional strands, and suture material. ePTFE has been associated with infection, extrusion, and scarring. It has been used with success in a recent study with only 0.62% of implants requiring removal for infection. ePTFE has the advantage of being soft, with minimal encapsulation and bony resorption. ePTFE is unavailable at this time as a preformed facial implant.

Silicone is a relatively inert substance, which has more encapsulation than ePTFE. Bony resorption increases with overlying muscle action translating to implant mobility. Therefore, the implant should be secured in a tight pocket with either sutures or titanium screws. In addition, subperiosteal placement increases bony resorption. Well-positioned implants with osseous erosion should not be replaced. Silicone implants are easier to place than ePTFE owing to less flexibility at the peripheral portion of the implant and higher resistance to crushing.

Malar and submalar implants can result in injury to sensory nerve (V2) or motor nerve (buccal or temporal branch), albeit a rare event. More commonly, midface implants may result in asymmetry due to preexisting facial skeleton imbalances.

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Note: Page numbers followed by *t* indicate tables; those followed by *f* indicate figures.

H