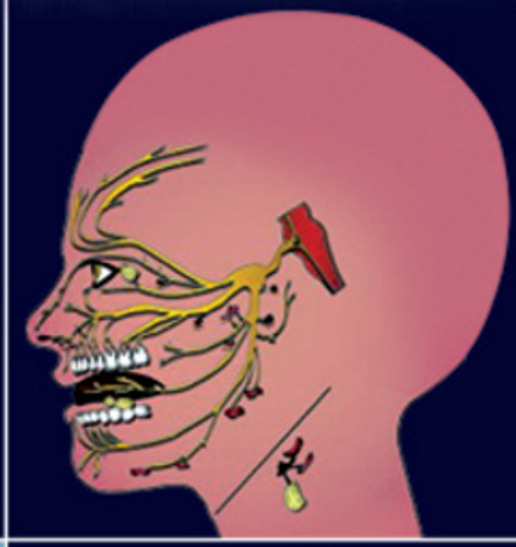
The Clinical Anatomy of the Cranial Nerves

The Nerves of "On Old Olympus Towering Top"



Joel A. Vilensky
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The Nerves of "*On Old Olympus Towering Top*"

Joel A. Vilensky, Ph.D.
Professor of Anatomy and Cell Biology
Indiana University School of Medicine
Fort Wayne, IN

Wendy M. Robertson, P.A., M.D.
Senior Staff Neurologist
Department of Neurology
Henry Ford Hospital
Detroit, MI

Carlos A. Suárez-Quian, Ph.D.
Professor
Department of Biochemistry and Molecular & Cellular Biology
Georgetown University Medical Center
Washington, DC

WILEY Blackwell

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Editorial Offices
1606 Golden Aspen Drive, Suites 103 and 104, Ames, Iowa 50010, USA
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
9600 Garsington Road, Oxford, OX4 2DQ, UK

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Dedication

This book is dedicated to teacher, mentor, and friend, Dr. Sid Gilman. We thank him most sincerely for being all three and for revealing to us, through his knowledge and actions, the amazing neurological talents of his own mentor, Dr. Derek Denny-Brown.

Contents

Preface

This book is about the most interesting nerves in the body. So interesting and also sometimes so frustrating that we repeatedly in this book refer to the cranial nerves as being "magical." The traditional twelve cranial nerves defy logic by the amazing senses they convey, the convoluted intracranial paths they take and the problems they can cause when they do not function correctly.

The title of our book, *The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top"*, is derived from a mnemonic that virtually all clinicians learn to remember the numbers associated with each of the cranial nerves (see Introduction chapter).

In *The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top"* we have done our best to describe the anatomy and physiology of these nerves from a clinical perspective, but in a such a way that the reader does not need to be a clinician to understand our text. This is facilitated by general sections in our Introduction on the nervous system and on the osteology (bones) of the skull.

We liberally sprinkle our chapters with case studies so that the reader can "feel" what patients experience when one or more of their cranial nerves don't function correctly, as well as understand better intellectually what these nerves do compared to texts without such clinical cases.

As with all anatomy books, this one has many illustrations. We searched many sources or drew our own (or commissioned an artist to draw them) to obtain images that we felt illuminate and simplify the complexity of these nerves in terms of anatomy and function. Further, and we think unique to this book, we present many images from actual anatomical dissections of the cranial nerves. The latter show the reader the real anatomy of these nerves rather than the sometimes simplified version that drawings may present.

We believe this book is suitable for an undergraduate course on the cranial nerves, and is certainly a useful supplement to health professionals learning about these nerves for the first time, including first year medical students, or those wanting to review the anatomy of the cranial nerves for their clinical practice. We also believe interested lay persons and patients with cranial nerve disorders will find this book understandable, informative, and useful.

Joel A. Vilensky
Carlos A. Suárez-Quian
Wendy M. Robertson

Contributors

Howard P. Cupples, M.D.
Professor and Chair, Emeritus
Department of Ophthalmology
Georgetown University School of Medicine
Washington, DC

Andrew Frederickson, M.S.
Researcher
Center for Cranial Nerve and Brainstem Disorders
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania

Lucille Hess, Ph.D., CCC-SLP
Professor Emeritus
Communication Sciences and Disorders
Indiana-Purdue University-FW
Fort Wayne, Indiana

Peter J. Koehler, M.D., Ph.D., FAAN
Staff Neurologist
Department of Neurology
Atrium Medical Centre
Heerlen, The Netherlands

Mortimer Lorber, D.M.D., M.D.
Professor Emeritus
Department of Pharmacology and Physiology
Georgetown University School of Medicine
Washington, D.C.

M. Anthony Pogrel, D.D.S., M.D.
William Ware Endowed Professor and Chairman
Associate Dean for Hospital Affairs
Department of Oral and Maxillofacial Surgery
University of California
San Francisco, California

Mohan K. Rao, M.D.
Staff Otolaryngologist
Ear, Nose, & Throat Associates PC
Dupont Medical Park
Fort Wayne, Indiana

Carol E.H. Scott-Conner, M.D., Ph.D.
Professor of Surgery
Department of Surgery
University of Iowa Carver College of Medicine
Iowa City, Iowa

Raymond Sekula, M.D.
Professor of Neurosurgery
Department of Neurosurgery
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania

Alex Senchenkov, M.D.
Staff Surgeon
Mayo Clinic
Rochester, Minnesota

Ujjowala D. Shrestha, M.D.
Consultant Pediatric Ophthalmologist
Tilganga Institute of Ophthalmology
Kathmandu, Nepal

Laurie Swan, P.T., Ph.D., DPT
Instructor, Pierce College
Owner and CEO, Synaptic Seminars
Puyallup, Washington

Jonathan Trobe, M.D.
Professor of Neurology and Ophthalmology
Department of Ophthalmology
University of Michigan School
of Medicine
Ann Arbor, Michigan

John E. Woods, M.D.
Emeritus Professor of Surgery
Mayo Clinic
Rochester, Minnesota

Acknowledgments

This book has many illustrations based on cadaver dissections. We will never know the names of the many people who donated the bodies that we (or others) photographed to convey the anatomy of the cranial nerves, but we are most grateful to these individuals for their generous donation.

Haley Moon was a research/technical assistant for this book and helped in all ways including obtaining permissions to use illustrations and doing some of the artwork. We thank her very much. Lowene Stipp and Joanne Summers are thanked for the secretarial assistance they provided to develop this book.

Steven Fraser drew all of the illustrations that appear as the second figure in all of the chapters and we are grateful to him for his beautiful work and for his patience with our many revisions.

We thank Dr. Edward Weber for graciously providing radiologic images for us.

At Wiley we thank our editor and editorial assistant, Justin Jeffryes and Stephanie Dollan, for assisting us with development and producing this book.

The concluding chapter of this book contains essays from clinicians (Contributors) about their experience with the cranial nerves and we are grateful to them for the time they spent writing these amazing stories for us.

Our families are much thanked for allowing us the two years we spent writing and editing this book.

We are grateful to Dr. Fen-Li Chang and the Indiana University School of Medicine – Fort Wayne for hosting our meeting in Fort Wayne.

We would like to thank the students we have taught and the teachers we have had for all they have done for our careers and for making us cherish learning and teaching human anatomy and its clinical relevance.

Donald Black is thanked for his review of some of the initial chapters of this book. We would also like to thank Drs. Mark Hofmeyer, Blair Marshall, and David Pearle, MedStar Washington Hospital Center, who helped us appreciate the changes that the heart and esophagus undergo following transplantation in Chapter 10. Dr. Susan Stoddard provided some initial guidance in the development of this book and we appreciate her assistance.

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Finally, we thank our very capable and immensely helpful typesetter Revathy Kaliyamoorthy, SPi Global.

Introduction

THE CRANIAL NERVES AND THIS BOOK

The cranial nerves (CNs) are *magical*. These nerves play an essential role in the processes that allow you to experience the wonder of the world around you – that is, to experience smell, taste, sight, and hearing, to maintain your balance and also to feel the wind on your face, a kiss on your lips, and to express feelings using the muscles of your face without even being consciously aware that you are doing so. Similarly, speaking, singing (good or bad), and eating are all directly controlled by the CNs. In fact, one CN, the tenth nerve or vagus, is responsible for controlling digestion from your lips to almost the end of your digestive tract and this same nerve regulates heart rate, breathing, and speech. In contrast, the nerves of the rest of your body (spinal nerves) primarily control voluntary muscle movement and convey simple sensations, for example, touch, but do not have the finesse of the CNs. In other words, we think spinal nerves are rather mundane and cranial nerves are, well, as we said at the beginning, magical.

Despite being able to conduct unique sensations, cranial nerves are constructed similarly to spinal nerves. They are in essence cables composed of many individual wires (fibers). However, whereas all spinal nerves contain both afferent and efferent fibers, that is, fibers entering and leaving the central nervous system (CNS), this is not necessarily the case for a CN.

CNs are part of the peripheral nervous system (PNS) and are typically defined as arising from the brain, and passing through holes (foramina) in the bones of the skull to exit it. To some extent, this definition of the CNs is somewhat loose because two of them, the first (olfactory) and second (optic), are really not nerves at all, but rather extensions of the brain. So what we refer to as the 12 CNs is somewhat more historical than anatomical. We will come back to this. A schematic view of the CNs exiting from the CNS is shown in Figure I.1 using small unlabeled versions of the figures that we will use within the individual CN chapters.

From Figure I.1, you can see that the CNs are numbered by the order in which they emerge from the brain, front to back: Olfactory, Optic, Oculomotor, Trochlear, Trigeminal, Abducent, Facial, Acoustic (vestibulocochlear), Glossopharyngeal, Vagus, Spinal Accessory (accessory), and Hypoglossal. Medical students have used numerous mnemonics to learn these nerves with this one being by far the most common: *On Old Olympus Towering Top A Finn And German Viewed Some Hops.* The numbering of the CNs uses Roman, not Arabic, numerals (I to XII), so CN II refers to the second CN, that is, the optic nerve.

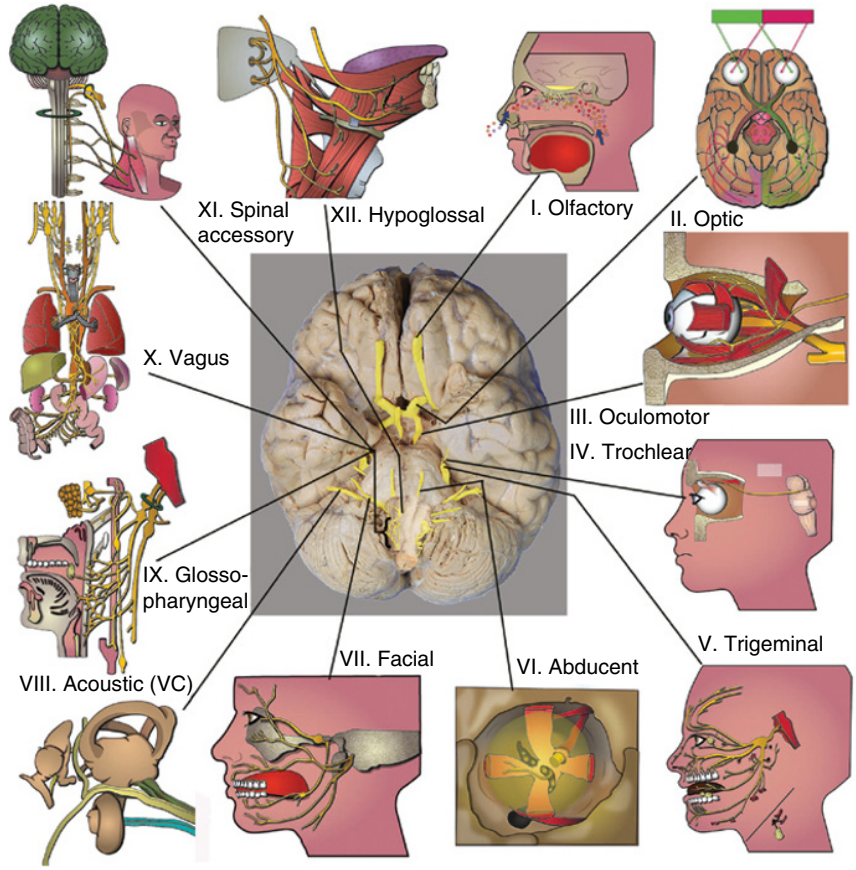

Figure I.1 Schematic illustration depicting the origin and functional aspects of the 12 CNs. The central image is a human brain as viewed from its base with the origins of the CNs highlighted in yellow. The small surrounding images are shown in larger versions with labels in the individual chapters of this book.

The Roman anatomist, Galen, first identified the CNs in the second century AD, although he did not identify all of them. He considered the CNs to be hollow and to distribute "animal spirits."

Although Figure I.1 suggests that anyone looking at the base of the brain as shown here would count 12 CNs, this is not true. Whereas the anatomy of the second CN (optic) leaves no doubt that this is a unitary structure, many of the other CNs emerge from the brain as more than a single element (roots or rootlets) and how these elements are grouped together is somewhat arbitrary and based on historical precedence. As we will discuss in subsequent chapters, there is still a debate as to the constituent elements of some of the CNs and in this book we will also briefly describe a thirteenth cranial nerve (CN *N*) that has been known to exist for more than a hundred years, although it is not clear whether it is functional in humans.

In order to unambiguously refer to the relative position of structures within the human body, including the nervous system, anatomists have developed

a lexicon of terms to use (Table I.1). Some of these positional terms are also identified in Figure I.2.

The PNS is comprised of the spinal and CNs. *So cranial nerves are part of the peripheral and not the central nervous system.* In order to understand the PNS, it helps to begin with the spinal nerves because, as we said earlier, they are structurally similar to CNs. Spinal nerves for each level of the body below the head emerge segmentally (on both sides) from the vertebral column after being formed by the fusion of rootlets arising from the dorsal (back; posterior) aspect and ventral (front; anterior) aspects of the spinal cord (Figure I.3).

Conveniently, the ventral root at each level contains virtually only motor (efferent) fibers that regulate the activity of muscles and glands, and the dorsal root contains only sensory (afferent) fibers, which allow you to feel sensations. The cell bodies of the neurons in the dorsal and ventral roots are located

Table I.1 Commonly used terms of relationship and comparison

Term	Meaning
Superior (cranial)	Nearer to head
Inferior (caudal)	Nearer to feet
Anterior (ventral, rostral)	Nearer to front
Posterior (dorsal)	Nearer to back
Medial	Nearer to median plane
Lateral	Farther from median plane
Proximal	Nearer to trunk or point of origin (e.g., of a limb)
Distal	Farther from trunk or point of origin (e.g., of a limb)
Superficial	Nearer to or on surface
Deep	Farther from surface
Dorsum	Surface of hand, foot, nose, or penis toward back in quadrupedal position

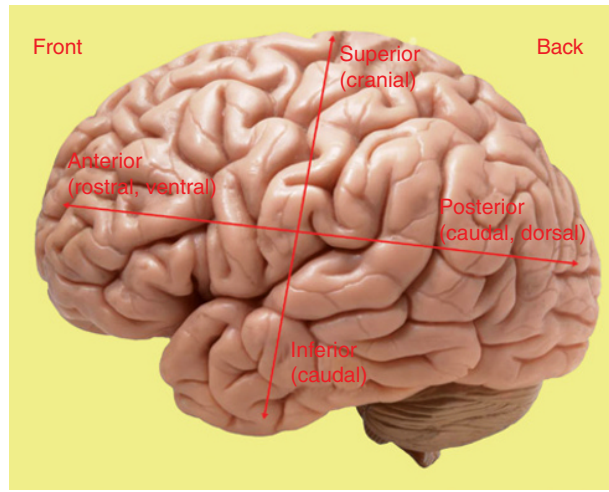

Figure I.2 Terms of orientation for the brain and spinal cord displayed on a side view of a human brain.

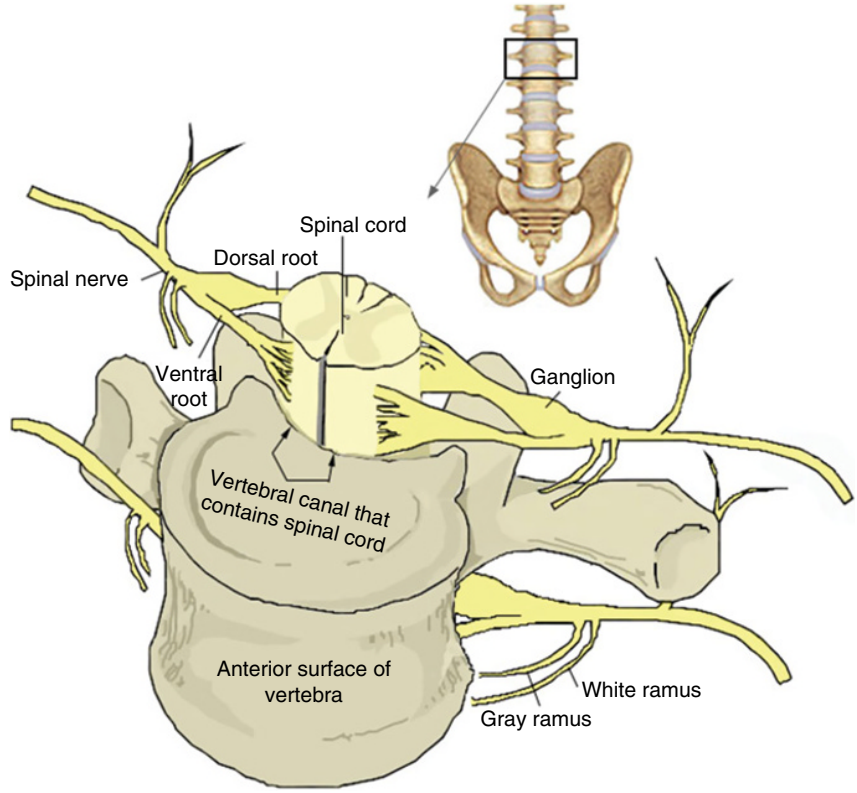

Figure I.3 This three-dimensional image shows the components of a spinal nerve, with the spinal cord shown within a vertebra of the vertebral column. The small upper inset shows how the vertebra fits into the vertebral column.

differently. The cell bodies of the motor fibers are in the nuclei (collections of cell bodies within the CNS, not to be confused with the nucleus of a cell) in the spinal cord, brainstem, or even in the gray matter of the brain. In contrast, the cell bodies of the afferent fibers are located in a ganglion (collection of cell bodies outside the CNS) near the point of fusion of the dorsal and ventral roots (Figure I.3). There are 31 pairs of these ganglia, one for every vertebral segment level. Sensory impulses (transmissions) entering the CNS do not really pass through or stop at these ganglia, they simply go straight into the CNS (dendrite to axon), but the attachment of the axons and dendrites of sensory neurons to their cell bodies in these ganglia provides for cell metabolic functions. Note in Figure I.3 that as the dorsal and ventral roots emerge from the vertebral canal they fuse to form a spinal nerve.

Within the two groups of nerves, efferent and afferent fibers, we can make a further subdivision based on the type of structure that they supply. Fibers that innervate (provide stimulation to) skeletal muscles, skin, tendons, joints, and ligaments are called somatic fibers. Visceral motor fibers are those that innervate internal organs, smooth muscle within vessels, and glands. Because both somatic and visceral fibers may receive and send impulses to the CNS, there are four categories of fibers within spinal nerves: somatic afferent,

somatic efferent, visceral afferent, and visceral efferent (the white and gray rami [group of fibers] shown in Figure I.3 are important relative to the visceral afferent and efferent impulses but are not important for CNs). CNs do not emerge from the brain in dorsal and ventral roots but, nevertheless, still have these four types of fibers, although the four types are not present in every CN; that is, CNs tend to be more specialized than spinal nerves. Some of the cranial afferent neurons are further classified as special somatic afferent fibers, which are concerned with sight, hearing, and balance, and special visceral afferent fibers, which are concerned with smell and taste. These "special" fibers are the components of the CNs that we would most consider *magical.* (Some of the muscles innervated by the CNs are developmentally derived differently than most of the muscles of the body (from the branchial arches rather than from somites), and thus, classically, the fibers of the CNs that innervate muscles have also been divided into general and special (branchial) motor fibers. There is really nothing *special* about these motor fibers or the muscles they innervate except derivation and we will not make this distinction in this book.)

In both the cranial and spinal nerves, the visceral efferent fibers are part of the autonomic nervous system (ANS). The ANS is a motor system that can be divided both anatomically and physiologically into two components, sympathetic and parasympathetic (Figure I.4).

The term "sympathetic" owes its name to Jacobus (Jacques) Winslow (1699–1760) who thought that this nervous system component both controlled

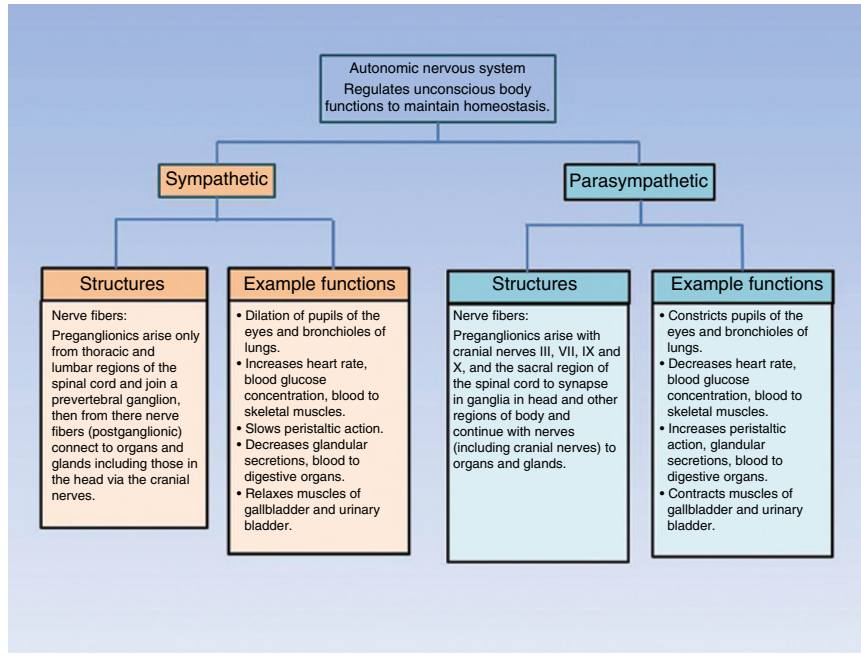

Figure I.4 A flowchart showing the features and characteristics of the ANS, with examples of function.

the viscera and the feeling of *sympathy* – by sympathy, Winslow meant that the nerves control the reactions of distant parts of the body in response to emotions, as in blushing in reaction to embarrassment and stomach aches in response to stress.

The parasympathetic system was defined by Walter Gaskell (1847–1914) and John Newcomb Langley (1852–1925) about 100 years after the sympathetic system, and it was Langley who actually described the ANS as a two-part motor system with the names, parasympathetic and *orthosympathetic*. Gaskell and Langley demonstrated that the two systems were complementary and often antagonistic. Classically, the sympathetic system is associated with a *fight or flight* reaction whereas the parasympathetic system is associated with a somewhat relaxed state, *rest and repose*. So the widening of your pupils is a sympathetic response whereas the narrowing of the pupils is a parasympathetic response.

A distinguishing feature between the autonomic and somatic nervous systems is that, in the autonomic system, the emergent motor nerves must synapse prior to reaching their target structure, so visceral efferent axons synapse after they leave the CNS, whereas somatic efferent axons do not. The autonomic synapses occur in ganglia, which contain the synapses between the *preganglionic* and *postganglionic* neurons and also the cell bodies of the postganglionic neurons (Figure I.5). These ganglia may be visible to the naked eye and are often named. Whereas the parasympathetic ganglia for the head are within the head, the sympathetic fibers that supply the head actually originate in the spinal cord (inferior to the head) and synapse in ganglia as they ascend to reach the head.

As we said earlier, a CN may be considered to be like a telephone cable with up to millions of individual wires (fibers) within the cable (Figure I.6). Groups of fibers are arranged into fascicles (Latin: bundles) and covered with a connective tissue sheath called the perineurium. Individual fibers are covered by a similar sheath, the endoneurium, and the whole nerve is covered by the epineurium.

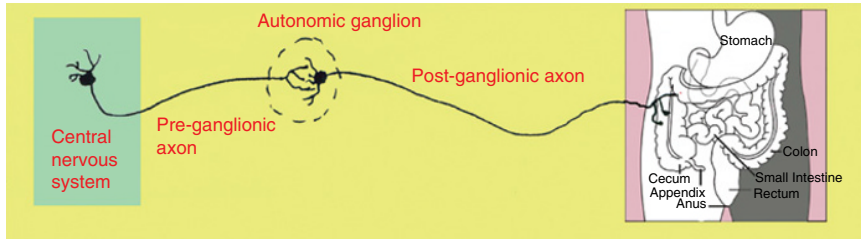

Figure I.5 Generalized autonomic pre- and postganglionic neurons with a ganglion (note that the pre- and postganglionic neuron synapse in the ganglion). In general, the ganglia of sympathetic fibers are visible to the naked eye and are located close to the spinal cord, whereas the ganglia of parasympathetic fibers in the head are located near their target structures. In contrast, parasympathetic ganglia in the rest of the body are microscopic and tend to be located in the walls of the target organs. For this figure, we show a sympathetic fiber providing innervation to a part of the colon.

Nerves, whether spinal or cranial, can be injured. Specifically, they can be cut (totally or partially), compressed, demyelinated (see the following text), develop tumors, or become atrophied. Any of these actions will compromise function and cause the patient to experience symptoms (often pain). The arrangement of nerves into fascicles comprised of individual fibers helps explain why sometimes an injury to a nerve may cause only a motor function deficit, only a sensory deficit, or both. The individual fibers within a nerve conduct only one specific modality, sensory or motor. If the injury only destroys sensory fibers, then the patient will only experience loss of sensation to the particular region of the body served by the nerve. If only motor fibers are injured, the patient may still feel sensation, but lose his or her ability to willfully move an arm or leg. In general, the closer to the CNS that a peripheral nerve is injured, the greater likelihood that both motor and sensory deficits will ensue.

Moreover, because nerves are living tissue, they receive a blood supply as shown by the artery and vein within the nerve in Figure I.6. The expanded single axon shown in the figure is covered by a myelin sheath (deep to the endoneurium). This sheath is formed by accessory PNS cells called Schwann cells and speeds up the transmission of impulses along the nerve. However, CNs, similar to spinal nerves, also contain many unmyelinated fibers in which

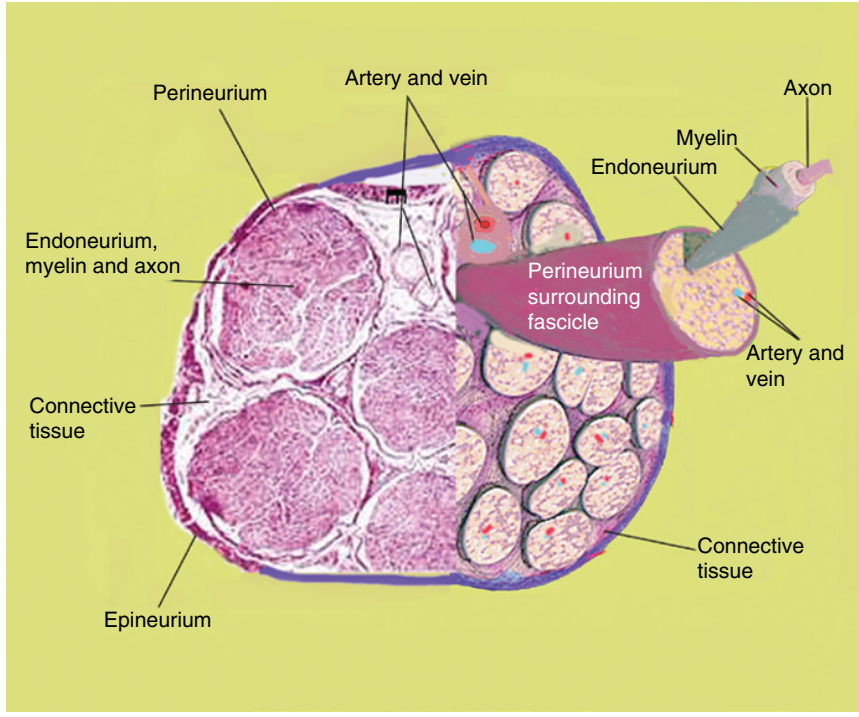

Figure I.6 Components of a nerve. The right side of the illustration shows a drawing of the cross-section of a nerve containing numerous fascicles. The drawing is paired on the left to a histological microphotograph of a nerve. Note the blood vessels within the nerve, the connective tissue sheaths surrounding the nerve, the fascicle and the single nerve fiber, and the myelin sheath.

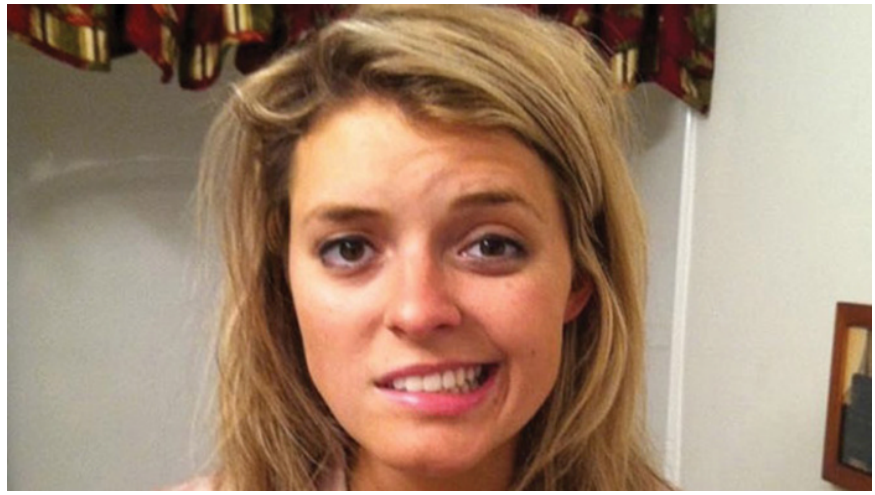

Figure I.7 Mary King with Bell palsy. Courtesy of Mary King.

the impulses move a bit slower than in the myelinated fibers (the Schwann cells associated with unmyelinated fibers do not make myelin).

To the authors of this book, CNs are incredibly interesting because they convey much of the world to us and, despite hundreds of years of study, we still do not fully understand them. Therefore, we wrote this book not only to teach you about the nerves, but also to convey how amazing these nerves are and how unfortunately, when they are affected by disease, people can be devastated. We want you to know and understand what can and does go wrong with these nerves and then what happens to the patient. We did our best to write this book assuming no more than a basic understanding of biology.

Figure I.7 shows an example of what can go wrong with a CN. Look at the woman shown in the photograph. The woman, Mary King, is a reporter for a Columbia, South Carolina, TV station. She is trying to smile. Which side of her face is working and which is not? Mary had an episode of facial nerve (seventh CN) paralysis commonly known as Bell palsy. As you might imagine, this was very debilitating for someone in front of a TV camera (see Chapter 7 for more about this condition and Mary).

Part of the role of the clinician in diagnosing a patient with symptoms consistent with CN dysfunction is to determine, using physical findings and laboratory and imaging studies, whether the patient's symptoms are indeed due to CN dysfunction or due to CNS dysfunction. This is often much easier said than done. Furthermore, for reasons unknown, patients with very similar laboratory and imaging findings can have very different symptoms. Further complicating diagnoses is the fact that despite hundreds of years of study there are still perplexing aspects of CN anatomy and physiology. They are still surprisingly very enigmatic.

Although there is no one treatment that is universally used to treat CN disorders, corticosteroids (steroids) are very commonly used as an initial treatment, alone or with additional therapeutic measures. In many chapters of this book we mention corticosteroid treatment. Corticosteroids are medications

that are similar to cortisol, a hormone produced naturally by the adrenal gland (a small gland that is located above the kidney). Pharmacologically, the common corticosteroids used clinically are prednisone and methylprednisolone. The primary value of corticosterioids is to reduce the normal inflammatory and immune responses of the body, which in some cases are believed to worsen the signs and symptoms associated with CN dysfunction.

Because CN dysfunctions have been known for centuries, there is a rich history of cases of patients suffering with these conditions. Furthermore, the symptomatology of patients with CN abnormalities in the 19th and 20th centuries would be immediately recognizable to a contemporary neurologist. The written reports from these prior time periods are much richer in description and sometimes more dramatic in text than modern case reports. Indeed, the "antiseptic" style of writing case reports in present day journals, while emphasizing precision and treatment rather than patient details, loses much of the early richness and drama described in historical cases. Because of this literary elegance, in this book we present many 19th and early 20th century case reports associated with CN dysfunction. We also provide modern cases from medical literature as well as some case material from health forums on the Internet. Of course, all personal identifiers have been removed from these cases, if they existed in the first place (except for Mary King because she gave us permission to use her case – and we thank her for this). The Internet cases often provide a sense of how frustrating or painful some CN conditions can be and how desperately these patients wait for cures. Unique to this book, these cases (all in highlighted boxes) are intertwined with the anatomy and function of the nerves, which we hope makes this book more interesting to read than other medical textbooks.

Additionally, unique to this book, all of our cases are real. No cases were formulated to show CN dysfunction. Rather, we searched the literature and the internet to find relevant and interesting cases.

Along with the textual case material, we also often include the illustrations that accompanied the case description in the literature. Again, these photos are of real patients. We are grateful for their willingness to be photographed and to the authors of the original publications for writing about such interesting cases. However, because some of these photos are old, they are usually in black and white and may not be of the quality that is typical in modern textbooks. Nevertheless, they clearly show the effects of the CN dysfunction.

As with any anatomy textbook, this book has many figures. Where possible, we used photographs of dissected cadavers so that the reader can obtain a real picture of the anatomy of the CNs.

Some of the illustrations that show CN anatomy or function were drawn specifically for this book whereas others were obtained from many different sources. We hope that by showing a variety of images we can appeal to the many different learning styles of our readers. However, each chapter begins with what we believe to be an interesting image pertaining to that CN and the second image in the chapter is always a summary image drawn in the same style. Along with that summary image, the text for each of the CN chapters begins with a summary of the anatomy and function of that nerve and also an interesting case report.

To provide you with enough background on the CNS and PNS to understand the cranial nerves, the next section on The Central Nervous System briefly reviews the anatomy of the CNS. Following that is a section on the Osteology of the Skull.

Why do we describe skull osteology in a book on the CNs? As we mentioned above, CNs by definition must exit the skull. You might think that this is done in a simple way so that the nerves exit at a location near where they need to go, but this is not always the case. Rather than being direct, some CNs tend to follow very circuitous routes, sometimes passing through multiple foramina in the skull before reaching their terminal structure. In addition, the individual elements within some of the CN branches follow different routes than the other fibers in the mother nerve. These complex routes relate to the embryology and phylogeny of the nerves. Thus, in order to have some understanding of these routes, you need to have some knowledge of the major bones of the skull and the foramina and canals within them.

Although the impulses within CNs enter and exit the CNS, for ease of understanding we will almost always refer to the CNs as exiting the CNS.

Each of the detailed CN chapters is numbered using the same number as the nerve it covers, although using an Arabic rather than a Roman numeral.

The last (concluding) chapter of this book is unique. It is partially comprised of short essays by modern clinicians who work with the CNs every day, expressing their amazement or frustrations or respect (these are not mutually exclusive) for these nerves. This chapter serves to reinforce the clinical importance and "magical" quality of these nerves in contemporary medical practice.

THE CENTRAL NERVOUS SYSTEM

The structural and functional unit of the nervous system is the neuron (nerve cell; Figure I.8). In the CNS, the neuron communicates with many other neurons at the synapse (Figure I.8). The neuron is made up of the cell body, which contains the nucleus of the cell and peripheral processes, the dendrites, and axons (Figure I.8). Most neurons have one axon and several dendrites. The dendrites serve as receivers of signals from other nerve cells. The axon conducts electrical impulses called action potentials to other neurons, glands, or muscles.

The neuron is supported by various types of *glial* cells, for example, oligodendrocytes in the CNS and Schwann cells in the PNS. There are up to 50 times more glial cells than neurons in the CNS. They have myriad functions, including structural support, removing debris, buffering the chemical environment, nourishment, contributing to the blood–brain barrier, and formation of myelin. As we mentioned above, myelin is an insulating sheath that enhances the speed of conduction of the action potential.

The CNS consists of the brain and spinal cord. The brain includes the cerebrum, the cerebellum, and the brainstem, and is composed of gray and white

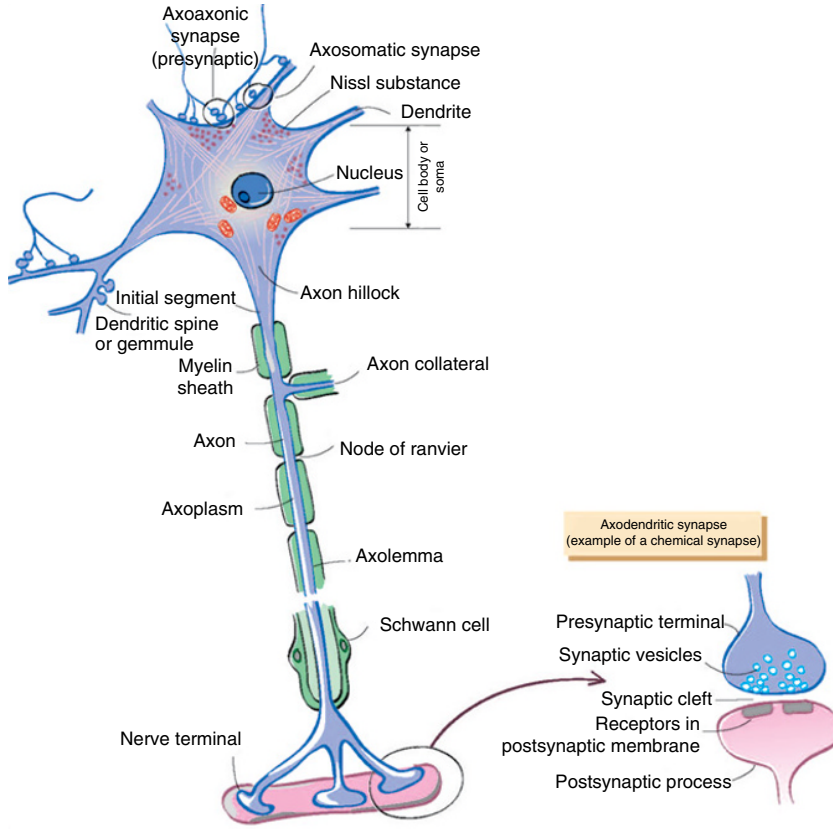

Figure I.8 Schematic illustration of a neuron and synapse. Modified from Barker and Cicchetti (2012).

matter (see the following text). A view of the brain, as seen from its side, shows the four lobes of the cerebrum and the primary motor and sensory areas (Figure I.9a). The frontal lobe is involved with attention, concentration, problem solving, and personality. It also contains the primary motor cortex, which is involved in the control of voluntary movement and the brain area involved in the production of speech. The parietal lobe is involved with the interpretation of sensory function and contains the somatosensory cortex (where sensory information from the body is perceived). The temporal lobe is primarily concerned with memory and language comprehension. The occipital lobe is the center for interpretation of visual information. Figure I.9b also shows the brainstem as if the surrounding lobes of the cortex were transparent.

In Figure I.10 on the left, the inferior views of the brain and brainstem are shown, as are the origins of the CNs. On the right, the image shows the CNs entering the bony canals of the skull into which they travel (see the next section on Osteology of the Skull). This image also shows how the brain and brainstem fit into the skull. We show this cadaver-based image of a dissected brain and

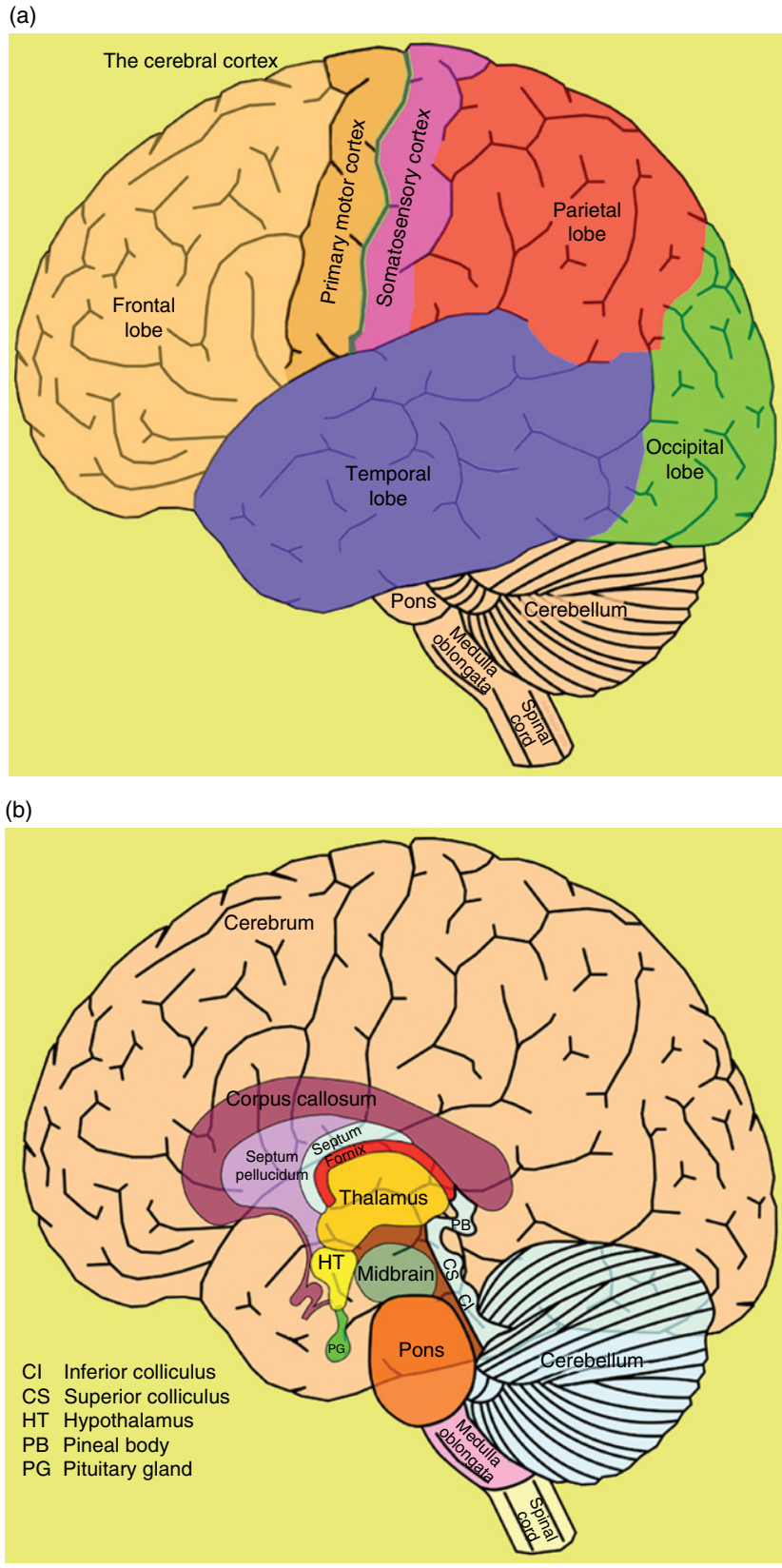

Figure I.9 (a) Lateral view of the brain and brainstem. (b) Lateral view of the brain and brainstem with the latter shown as if you were looking through the left half of the brain. Courtesy of and modified from: http://tayloredge.com/reference/Science/BiologySlides/CerebralCortex.gif.

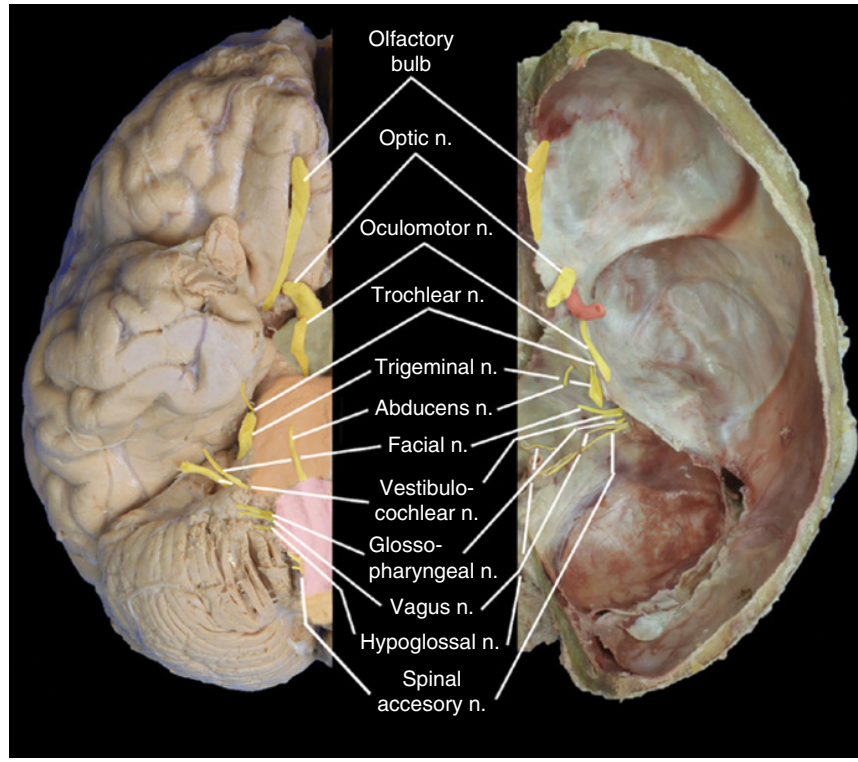

Figure I.10 Inferior view of the brain and brainstem showing the origin of the CNs on the left and the bony canals into which they travel on the right, which is a superior view of the cranial floor. The orange structure is the pons, the pink is the medulla, and the yellow is the spinal cord.

base of a skull to demonstrate how they truly appear. Often schematic images present a simplified image of the CNs emerging from the base of the brain and these images are far removed from how the nerves really look. Beginning students are thus sometimes presented with an unrealistic, simplistic view of the brain and its CNs and we wish to dispel any notion that the CNS is simplistic.

Figure I.11 shows a magnetic resonance image (MRI) of a brain (see the following text) in which the white and gray matter of the brain are clearly distinguishable (they are also easily distinguishable in an unembalmed, sliced brain; in the particular type of MRI technique used to produce the image in Figure I.11, the "white" matter actually appears almost black). White matter is composed of myelinated nerve fibers and their supporting cells. Gray matter is composed of neurons and their supporting glial cells, which lack myelin. Gray matter is present in the cortex and nuclei of the brain. The cortex consists of layers of neurons, whereas nuclei are clusters of neurons.

Motor signals (destined for muscles) in the head and neck originate primarily in the motor cortex (frontal lobe) and are transmitted through the subcortical white matter (the internal capsule) to the brainstem and upper spinal cord, where they synapse in the appropriate motor CN nuclei.

Sensory signals originate in the periphery, for example, a touch on the skin of the face. The information from that sensory stimulus is transmitted by the

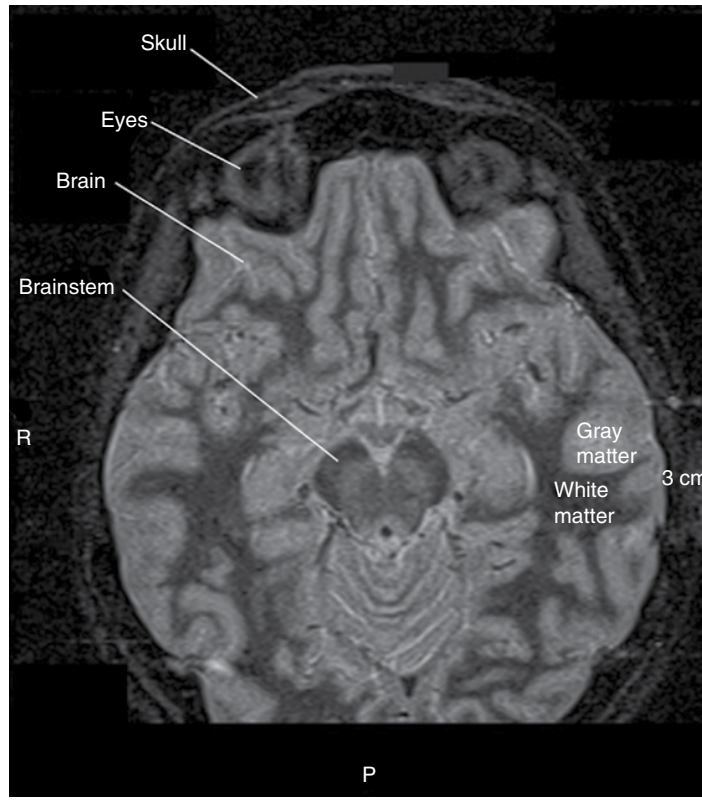

Figure I.11 Axial MRI scan of the brain. This specific type of MR scan intensifies the difference between the white and gray matter but has the white matter appearing as almost black whereas the gray matter does look gray. Courtesy of Dr. Edward Weber.

peripheral nerve to the sensory nerve cell, which sends another axon into the CNS. A synapse occurs in the sensory nucleus in the brainstem with a second sensory neuron which transmits the impulse to the thalamus. There, a third sensory neuron in this pathway transmits the information to the sensory cortex in the parietal lobe. There the sensation is consciously perceived (as a touch on the face in this example). Exceptions to this sensory pathway are the olfactory and optic CNs, whose special sensory impulses do not pass through the thalamus.

The brainstem (midbrain, pons, and medulla oblongata) is the connection between the brain and the spinal cord (Figures I.9, I.10, I.12, and I.13). Figure I.12 shows a midline sagittal illustration of the brainstem in which the CN nuclei have been drawn in. Figure I.13 shows the origin of CNs III to XII, both in a dissected brain (as also shown in Figure I.1) and in an illustration as they emerge from the brainstem. CNs I and II emerge directly from the brain (see Chapters 1 and 2). Note, as mentioned previously, that the clear and distinct images of the CNs depicted in artists' drawings are only an interpretation of the actual situation in which the rootlets forming the individual CNs are often poorly definable and variable. Hence, viewing only sketches of the brainstem to learn about the CNs will provide only an approximation of the real thing.

There are now several different imaging technologies that can give us remarkable pictures of the CNS. Computerized tomography (CT) scans

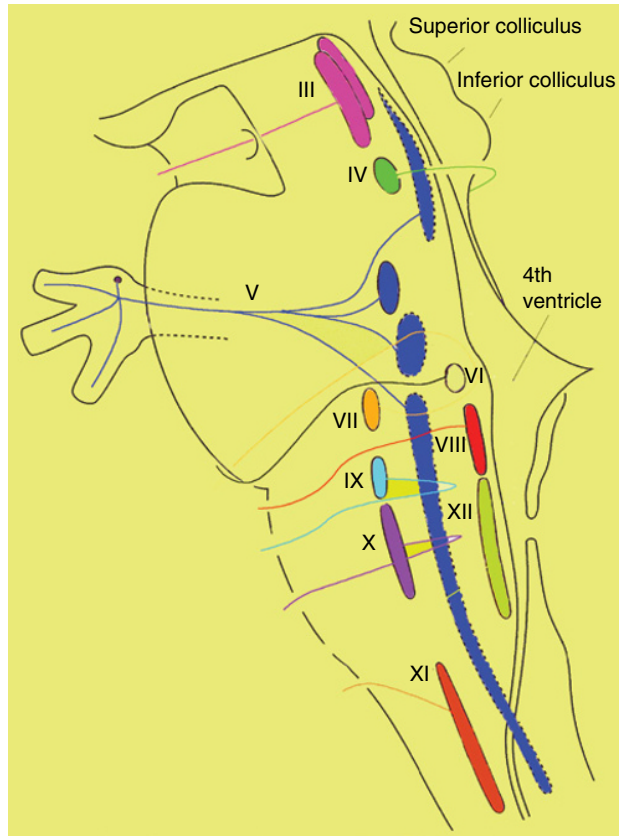

Figure I.12 Drawing of a lateral view of the brainstem showing the location of the CN nuclei.

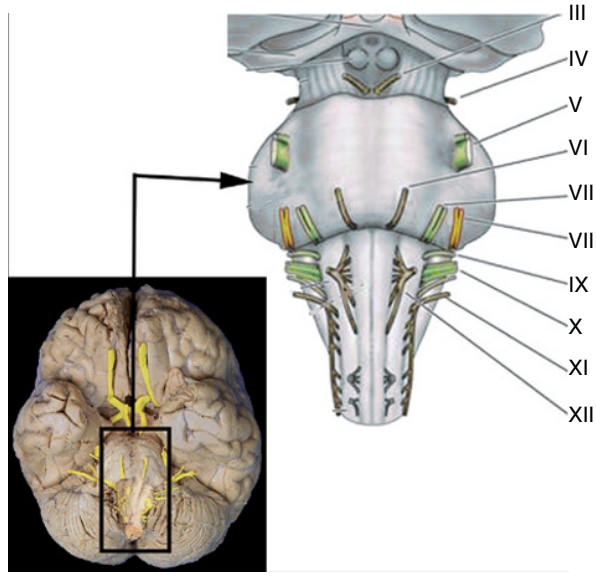

Figure I.13 The figure on the lower left shows an inferior view of the brain with the origins of CNs digitally enhanced in yellow (same image as in Figure I.1). The larger figure on the right shows a drawing of the brainstem and the origin of the CNs.

(Figure I.14) utilize X-rays to show the skull and soft tissue of the brain and spinal cord. Magnetic resonance imaging (MRI) scans use magnetic fields to produce high-resolution images of the CNS (much higher than those provided by CT). Both technologies can show lesions in the CNs, with CT being better at showing fractures in bone that may cause CN dysfunction and MRI being better at showing intrinsic lesions of the nerves, such as tumors.

The brain and spinal cord are covered by three layers of protective connective tissue membranes called the meninges (Figure I.15). The pia mater

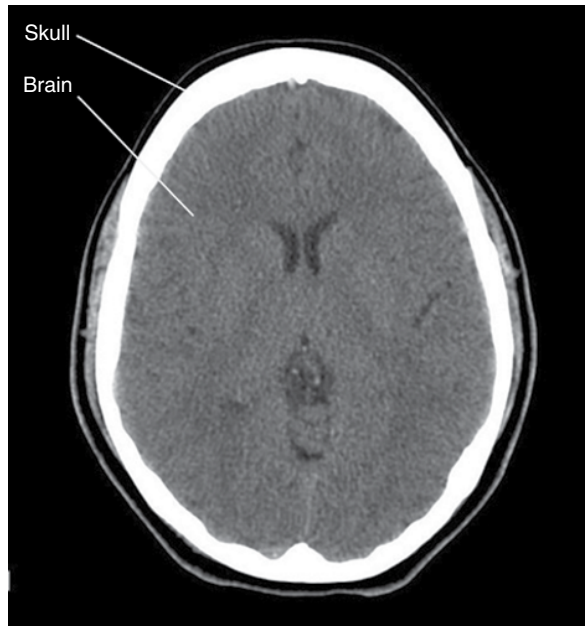

Figure I.14 Axial (transverse) CT of skull and brain (imagine looking down at the skull and brain from the top after it had been cut open but the image produced shows the right side of the brain on the left side of the image). Note that a CT shows much less brain tissue detail than the MRI shown in Figure I.11. CT scans take much less time to obtain than MRI scans and are also less expensive.

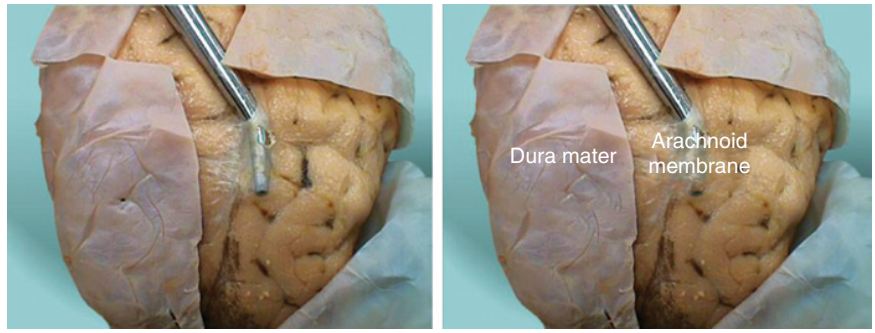

Figure I.15 Meninges of the brain. The dura is a heavy outer covering of the brain and spinal cord whereas the arachnoid is a delicate, translucent layer underneath the dura. The pia is a very thin membrane that is totally adherent to the surface of the brain (not labeled). Image courtesy of Dr. Pamela Gregory, Tyler Junior College, Tyler, Texas.

is very thin, delicate, and intimately associated with the brain and spinal cord. The arachnoid layer is translucent and spider-like – hence its name, Latin for spider. The arachnoid layer is separated from the pia mater by the subarachnoid space that is filled with cerebrospinal fluid (CSF). The subarachnoid space also accommodates the intracranial branches of arteries to the brain. A ruptured intracranial aneurysm (an aneurysm is the ballooning out of a weakened area of an artery – it resembles a snake's body after a large meal) will cause a subarchnoid hemorrhage, often a life-threatening event. The dura mater (Latin: hard mother) is the thick outer layer of the meninges that lines the skull and spinal canal. It is innervated by branches of CN V, the trigeminal nerve, so irritation of the dura mater can cause severe head pain, as occurs in meningitis, inflammation of the meninges.

Some of the common pathologic processes that can affect the CNs within the brainstem include stroke, hemorrhage, tumor, multiple sclerosis, and trauma. Lesions within the brainstem can cause symptoms and signs that can mimic peripheral CN lesions. Because of the small space within the brainstem, multiple symptoms related to involvement of nearby structures often provide a clue that the pathology is located within the CNS rather than the PNS.

Stroke, a sudden "vascular event" causing destruction of the part of the brain supplied by a particular blood vessel, can be either *ischemic* (an interruption of blood supply) or *hemorrhagic* (bleeding). Ischemic stroke is the most common type of stroke. Knowing the anatomy of the vascular supply to the brain can help to localize the blood vessel involved based on the patient's symptoms (conditions that are perceived by the patient, such as pain) and signs (conditions that can be seen or measured, such as the inability to close an eye and blood pressure). Most of the brainstem is supplied by the basilar artery and its branches (Figure I.16). Vascular abnormalities, such as an ischemic stroke, can cause CN problems from the death of the neurons in the nerve or in its nuclei (Figure I.17).

Any type of abnormal mass in the brainstem (e.g., tumor or blood clot) can exert pressure on the surrounding structures including the CNs themselves and/or their nuclei. For example, the location of the oculomotor nerve makes it susceptible to compression by the uncus, the medial part of the temporal lobe (Figure I.18). When there is swelling of the brain or pressure on the temporal lobe, this causes the uncus to push down or herniate through the tentorium cerebelli, part of the membranous covering of the brain (see the previous text) that separates the cerebellum from the occipital lobes. The uncus puts pressure on CN III and the patient will likely have dilation of the pupil, drooping of the eyelid (ptosis), and paralysis of the eye muscles consistent with a CN III lesion (see Chapter 3).

The individual CN chapters will shed further light on each of the nerves and the magic of their impact on our everyday interactions with the world around us.

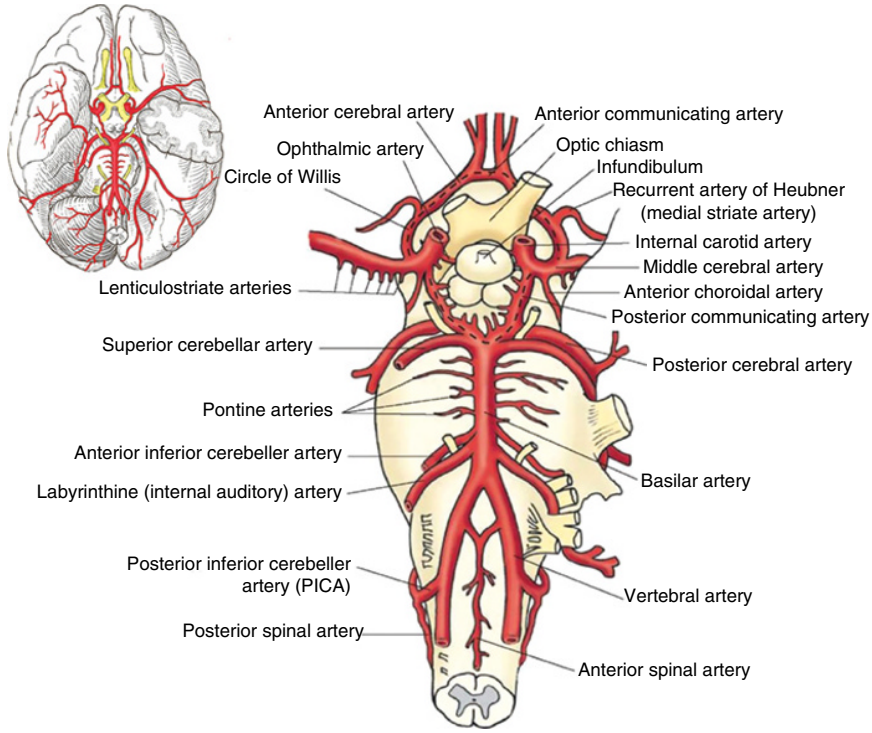

Figure I.16 Blood supply to the brain. The upper image shows the position of the major vessels supplying the brain. The lower image shows how the vessels lie relative to the brainstem. Lower image courtesy of http://what-when-how.com/neuroscience/blood-supply-of-the-central-nervous-system-gross-anatomy-of-the-brain-part-1/.

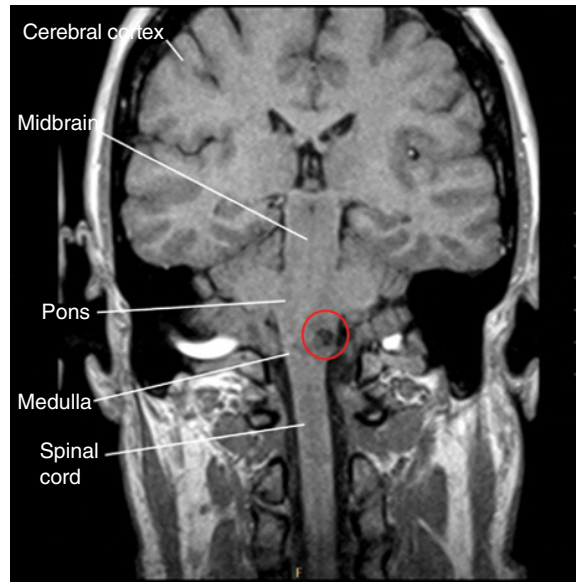

Figure I.17 Coronal MRI image (imagine the patient looking at you) of a patient with an ischemic stroke on the left at the border between the pons and medulla in the brainstem. The darkened area within the red circle indicates an area of brain tissue necrosis (tissue death).

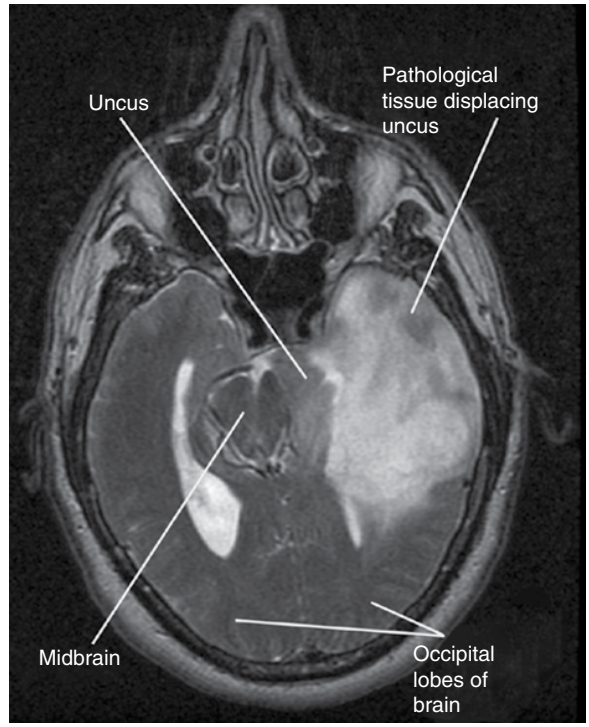

Figure I.18 Axial MRI showing left herniation of the part of the brain known as the uncus compressing the brainstem (it is on the left because you are looking at a slice of the brain as if you were standing at the patient's feet). This patient presented with double vision. The MRI examination confirmed the cause of the double vision as compression of CN III by the uncus of the temporal lobe of the brain (see Chapter 3).

OSTEOLOGY OF THE SKULL

"Alas, poor Yorick! I knew him, Horatio," Hamlet remarked while holding the court jester Yorick's skull recently exhumed in the cemetery (Figure I.19; in this photograph the great actor, Sir Laurence Olivier, plays Hamlet). Although Hamlet recalls his deceased friend fondly, nevertheless, he is sickened by the putrefying smell of the rotting flesh as he looks at the skull. Still, he remembers, "…Here hung those lips that I have kissed I know not how oft. Where be your gibes now?"

The skull is unique among human bones because even without its covering flesh it triggers memories and elicits emotions of the humanity that once formed part of it. In literature, the skull is often portrayed as a symbol of life's fragility, as in Hamlet. However, there is little that is fragile about the skull, and it provides a framework for passageways for the CNs to travel from the brainstem to their final destinations. The bones of the skull can and do break, however, and tumors can arise where the CNs pass through the cranial bones. Both of these scenarios can manifest with specific symptoms that are recognized by physicians and form the anatomical basis by which pathology associated with the CNS is often diagnosed. Hence, knowledge of the cranial bones and foramina (holes or canals within the bones) used by the CNs

Figure I.19 Sir Laurence Olivier playing Hamlet, contemplating Yorick's skull in Scene 1 of the Shakespearean play.

to transit within the skull becomes a prerequisite to become conversant in neuroscience. In this book we will discuss the cranial bones specifically as they relate to the CNs.

Understandably, beginning students often consider the skull to be a biological Rubik's cube. The skull does consist of 23 distinct bones that fit intricately together. Learning all of these bones and their foramina can become a daunting task. In this book, however, we break down skull nomenclature into its simplest components in order to make it relatively easy for beginning students to learn the vocabulary of the skull. When reading subsequent chapters of how the different CNs travel and exit the skull, we will refer to the figures in this chapter.

Views of the skull

Anterior (frontal) view

We will begin our exploration of the skull as Hamlet would have done, by confronting the front of the skull, the anterior view (Figure I.20). In this view, it is convenient to describe the bones as they are seen from top to bottom. Beginning with the forehead, the large bone colored blue-violet in Figure I.20 is aptly called the frontal bone. The frontal bone also contributes to the formation of the eye socket, or orbit (see the following text). Immediately below the frontal bone are the paired nasal (Latin: nose) bones (colored in tan) that form

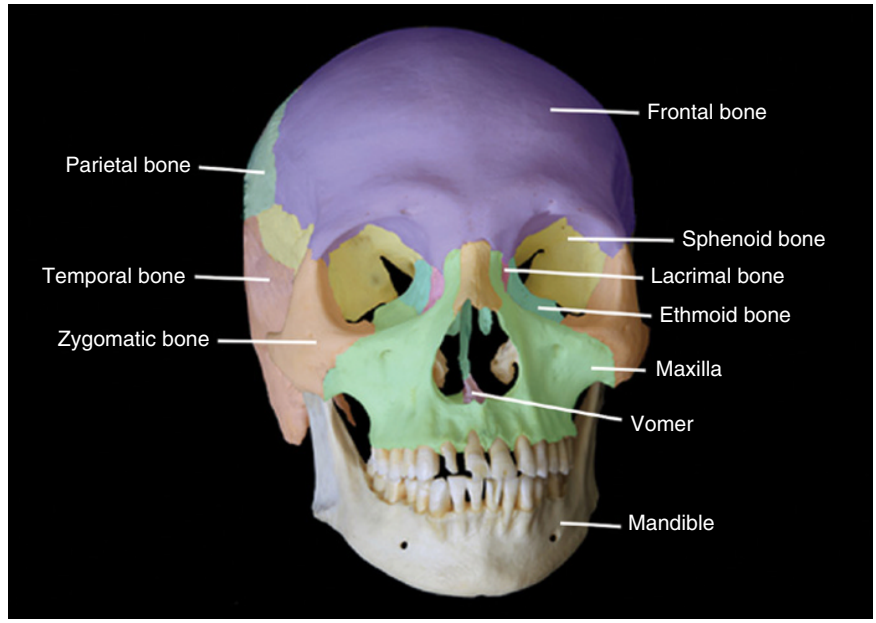

Figure I.20 Anterior view of the skull.

the bridge of the nose. The external nose consists principally of cartilage and these two nasal bones. Rhinoplasty ("a nose job"), the most common plastic surgery procedure, is performed on the cartilage portion of the external nose, not the bones. It is also the reason why rhinoplasty rarely affects the sense of smell. When reading about the olfactory epithelium (the actual area of the nasal cavity where we detect odors) in Chapter 1, you will learn that this area lies below the nasal bones, or even posterior to them. Hence, there is little chance of injuring the olfactory epithelium when trying to adjust the external nose. Extending to the frontal bone and just lateral to the nasal bones are processes of the maxilla (green). The maxilla helps form boundaries of the orbit and the openings of the nose, but is principally regarded as the upper jaw.

Two different bones can be observed within the nasal cavity. The upper, thin bone (colored light blue) is part of the ethmoid bone and is called the perpendicular plate of the ethmoid bone (ethmoid (Greek) means sieve-like). Below it can be seen a small part of the vomer, so called because it resembles a plow (Latin). Together, these two bones must come together in the midline and then join with the nasal cartilage to form the nasal septum (Figures I.20 and I.36).

The last major bone of the anterior view is the mandible, or lower jaw. Note that the teeth are present in both the maxilla and the mandible and together these two bones form a functional chewing device to begin the extraction of energy from the foods we eat. Indeed, one of the scourges of people as they age in developing countries is losing teeth due to poor oral hygiene. The pain associated with cavities and ultimately rotting teeth can be excruciating, sometimes remedied only by tooth extraction. With age and losing numerous teeth, it becomes difficult to chew high-protein foods (e.g., meats) to maintain good health.

The orbit

The orbit is somewhat pyramidal in shape and has superior, medial, inferior, and lateral walls (Figure I.21). The lateral walls are quite stout and protect the eye from blows received from the side. The medial wall is paper-thin and often the reason why real skulls appear damaged on this side. The simple act of grabbing the skull with the pincer-like action of the thumb and index finger through the orbits can destroy the medial walls.

Six bones make up most of the bony orbit (Figure I.21). The roof of the orbit consists mainly of the orbital plate of the frontal bone and a small portion of the sphenoid bone. The medial wall is made up mostly by the paper-thin ethmoid plate, anterior to which are the lacrimal bone and the maxilla, forming the exterior margin of the orbit. Two parts of bones make up the floor, the zygomatic bone and the maxilla. The lateral wall consists of the greater wing of the sphenoid and the zygomatic bones. This latter component forms the stout lateral boundary that we can feel when touching our own bony orbits. The lacrimal (Latin: tear) bone is so called because the tear sac resides in a small depression formed by the bone. The actual lacrimal gland resides just below the frontal bone. Thus, our tears travel from lateral to medial to collect in the lacrimal sac and then course down to our nasal cavity.

At the posterior (back) end of the orbit, or apex, there is a large and somewhat triangular aperture, the superior orbital fissure, which opens into the

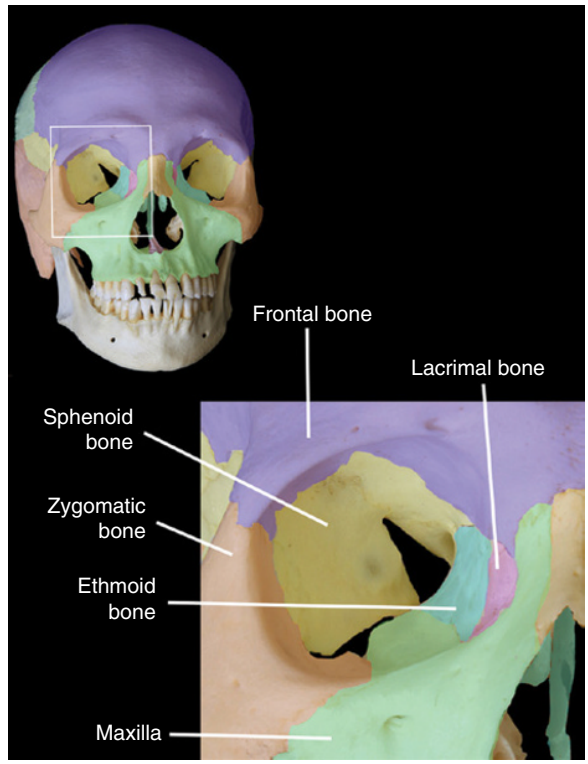

Figure I.21 The bones of the orbit.

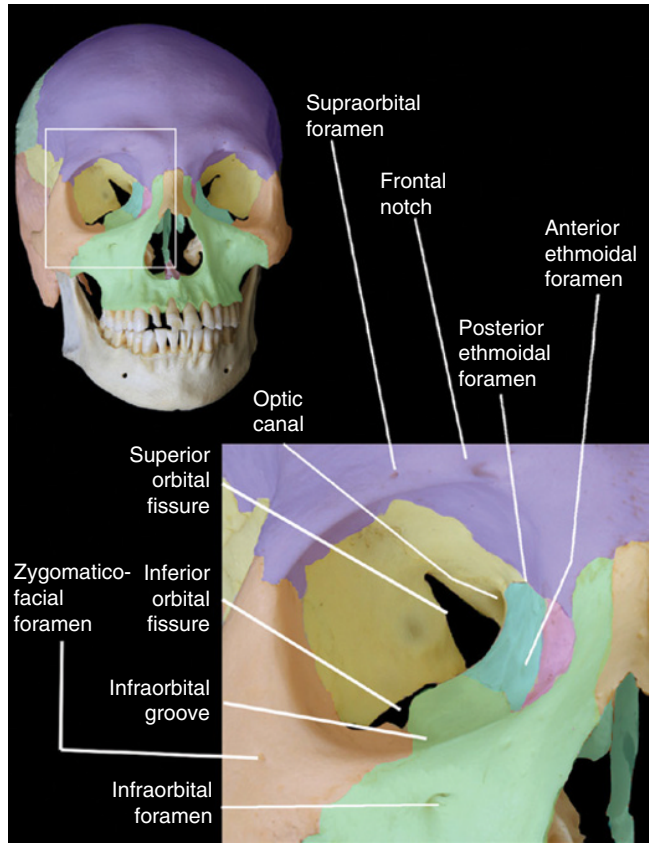

Figure I.22 The foramina and openings associated with the bony orbit.

middle cranial fossa of the cranial vault, and just medial to this is the optic canal, which also opens into the middle cranial fossa (Figure I.22). Many vessels and CN branches to the muscles of the eye enter the orbit via the superior orbital fissure and the large optic nerve enters via the optic canal. In the lateral part of the floor (inferior wall) is a long fissure, the inferior orbital fissure, which opens into the pterygopalatine fossa posteriorly. The infraorbital nerve glides into the infraorbital groove and then exits the face via the infraorbital foramen. Thus, it should be clear how a fracture of the floor of the orbit could rupture this nerve and eliminate some sensation from the face.

The anatomy of the orbit helps to explain symptoms associated with the condition known as a blowout fracture (Figure I.23), often the result of a blow to the orbital margin:

About 15 minutes after his bout, the boxer came to the athletic training room complaining that he felt a pop and his left eye then inflated after blowing his nose. The injury had actually occurred during the first round of a three round amateur fight at the Naval Academy. The examining

medical personnel noted numbness to the boxer's lower eyelid and under his eye, but no blurred vision (the boxer admitted to double vision immediately after receiving the blow, but it had resolved by the time he was examined). A CT scan was immediately performed to confirm the diagnosis of a blowout fracture to the medial wall and floor of the orbit (Karsteter and Yunker, 2006).

Figure I.23 shows three hypothesized mechanisms possibly underlying how a blow to the orbital margin causes a blowout fracture, which typically involves a fracture of the thin medial or inferior walls of the orbit: (1) the buckling mechanism, (2) the retropulsion model, and (3) the globe-to-wall model. In the first mechanism, the force from the blow on the robust, orbital margin is directed to the thinner, medial orbital wall and orbital floor, causing a direct buckling of these surfaces. In the second mechanism, the force compresses the orbital content that then fractures the more fragile walls (indirect trauma). In the last model, the globe itself fractures the orbital walls (again, indirect trauma). Regardless of how the forces are transmitted to the thin medial

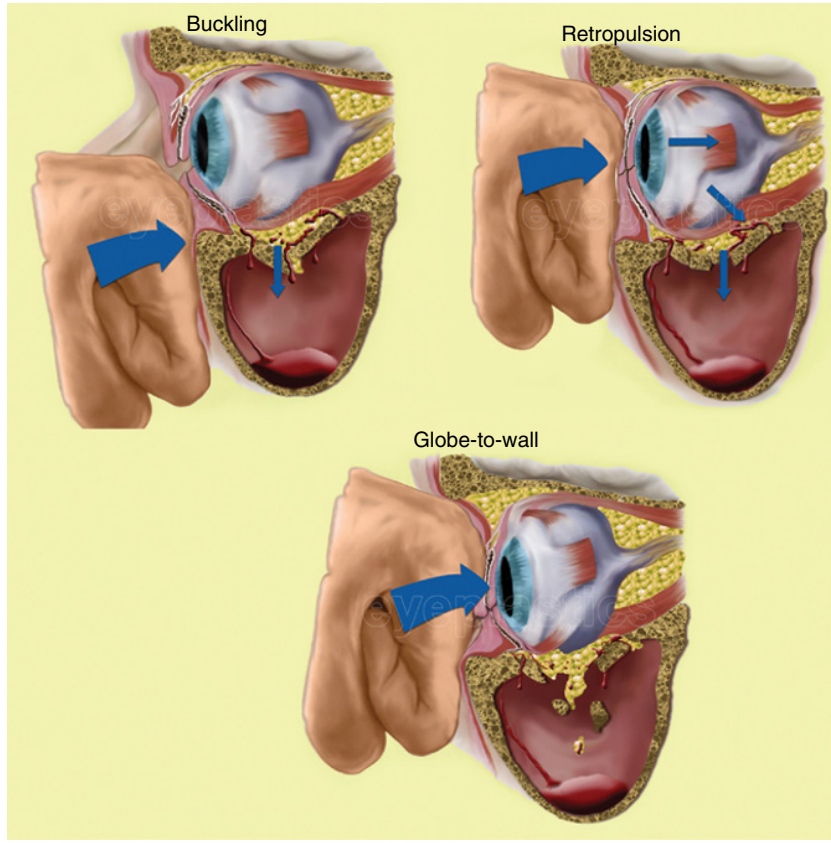

Figure I.23 Proposed mechanisms for inducing a blowout fracture of the inferior orbital wall. Reprinted courtesy of Eyeplastics, Inc.

and inferior orbital walls, the effects of a blowout fracture may temporarily or permanently damage the CNs of the eye (in the case of the boxer, at least initially, the blow to his orbit had injured one of these nerves or one of the extraocular muscles; see later chapters).

The floor of the orbit is also the roof of the large maxillary sinus, a large, mucosa-lined space located within the maxilla. This sinus and the other skull sinuses lighten the weight of the skull. Decay of the teeth of the maxilla, if left untreated, can involve the large maxillary sinus and ultimately lead to infection of the sinus. As the infection progresses, patients will complain of excruciating pain resulting from aggravation of the infraorbital nerve (a branch of CN V), which traverses the roof of the sinus.

On the supraorbital margin is the prominent supraorbital foramen or notch for the transmission of nerves and vessels of the same name, which are also branches of CN V (Figure I.22). Often, as in the example shown in Figure I.22, there is a foramen or notch (frontal notch) located just medial to the supraorbital foramen. In such cases, the medial foramen is likely to convey the supratrochlear nerve and the lateral foramen, the supraorbital nerve.

On the medial wall of the orbit are located two small ethmoidal foramina, the orbital ends of the anterior and posterior ethmoidal canals, which conduct vessels and nerves of the same name out of the orbit (all of these nerves are branches of CN V, the trigeminal nerve).

If you took a ruler and put its edge vertically next to the supraorbital and infraorbital foramina, and followed the edge inferiorly, you would see that there is an additional, large foramen in the same line, the mental foramen of the mandible (Figure I.24). This foramen is for another branch of CN V, one that conducts sensory fibers from the chin. In people who have lost all their lower teeth, the portion of the mandible that normally holds the lower teeth (alveolar process) degenerates so that the mental foramen becomes subject to pressure during chewing; this is quite painful.

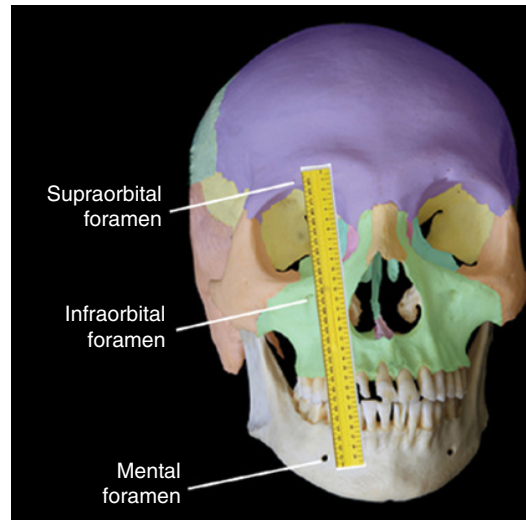

Figure I.24 Alignment of the supraorbital, infraorbital, and mental foramina.

Lateral view

From the side, the lateral view of the skull (Figure I.25), it is also possible to describe the visible bones from top to bottom. Again, we see part of the frontal bone, now abutting the jagged parietal bone. Below are the sphenoid and temporal bones, and posteriorly is the occipital bone. Finally, we again see the zygomatic bone, the maxilla, and the mandible. Generally, at this time, beginning students develop that "deer-in-the-headlights" look at the names of the skull bones. Why must they be so complicated? The simple answer is that the Romans and Greeks named the bones before English became the *lingua franca* of science, as it is today. If we were starting all over again, these bones would be named *the bone that forms the side wall of the skull* (parietal), *the bone that resembles the yoke of an ox* (at least to the ancient Greeks: zygomatic), and so on. Therefore, the best way to learn the names of the bones of the skull is to learn their meaning and/or direct translations into English. Thus, for completion, here are the English definitions of the remaining bones: the temporal bone refers to the bone located where grey hairs tend to appear first and hence reminds us of the passing of time as we age; maxilla is Latin for jaw, in this case, the upper jaw; mandible is Latin for lower jaw, derived from the verb to chew, mandere; sphenoid means wedge (and how appropriate is that for the bone that is wedged between the other skull bones); and, finally, there is the occipital, literally translated as the posterior part of the head. Now that we have identified the bones of this region, you will be able to relate them to the CNs.

The infratemporal fossa

Removal of the mandible exposes the important area known as the infratemporal fossa (the space *infra* (Latin: below) the temporal bone). Dissection of this space is arguably the most challenging dissection of all anatomy because

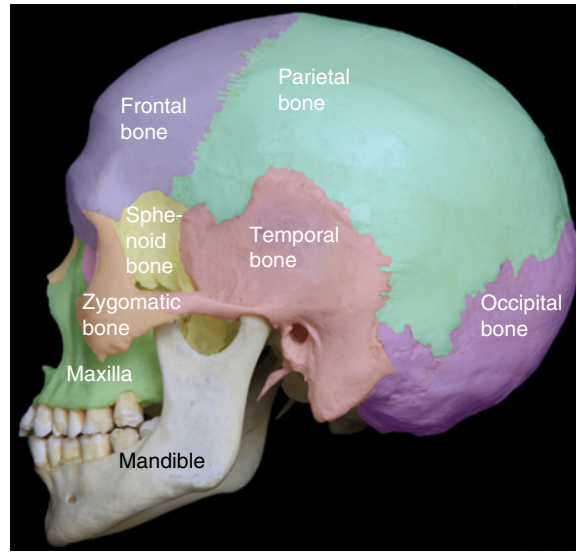

Figure I.25 Bones of the lateral view.

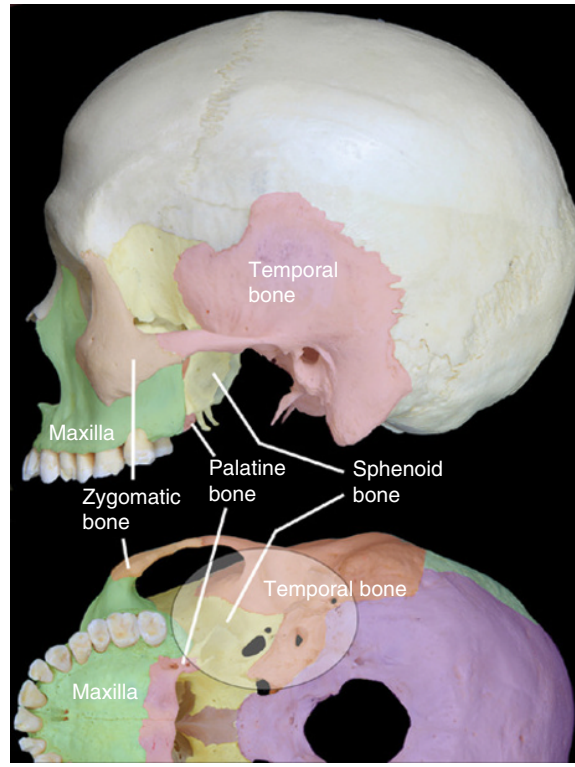

Figure I.26 Lateral and inferior views of the infratemporal fossa.

of the numerous CN branches, vessels, and muscles that are found here. In Figure I.26, the area known as the infratemporal fossa is demarcated by the shaded oval in the lower image. To reach it, the ramus of the mandible was removed (upper image). The ramus of the mandible makes up the lateral wall of the fossa. The medial wall is made up of the sphenoid bone, in particular the lateral pterygoid plate (the labeled part of the bone).

Now why would anything be called pterygoid? It is because pterygoid is ancient Greek for wing, and this part of the sphenoid bone does have a wing-like structure. If you are into dinosaurs, think pterodactyl, the large winged dinosaur of "Jurassic Park." Several bones make up the floor of the fossa; from anterior to posterior these include the sphenoid, temporal, and occipital bones. The anterior border of the fossa is made up of the maxilla and palatine bones.

Several holes (foramina) are clearly present in the infratemporal fossa. These are important and convey terminal branches of CNs and/or vessels. The names of the foramina will be discussed later in this chapter. However, we should not forget to look at the lateral wall of the infratemporal fossa, the ramus of the mandible (Figure I.27). There is one foramen on the inside of the ramus that serves as a portal for the inferior alveolar nerve and vessels (the nerve and vessels travel in the infratemporal fossa and will be discussed in detail in Chapter 5). The inferior alveolar nerve sends an individual branch to each tooth after entering the mandibular foramen. It is called the inferior

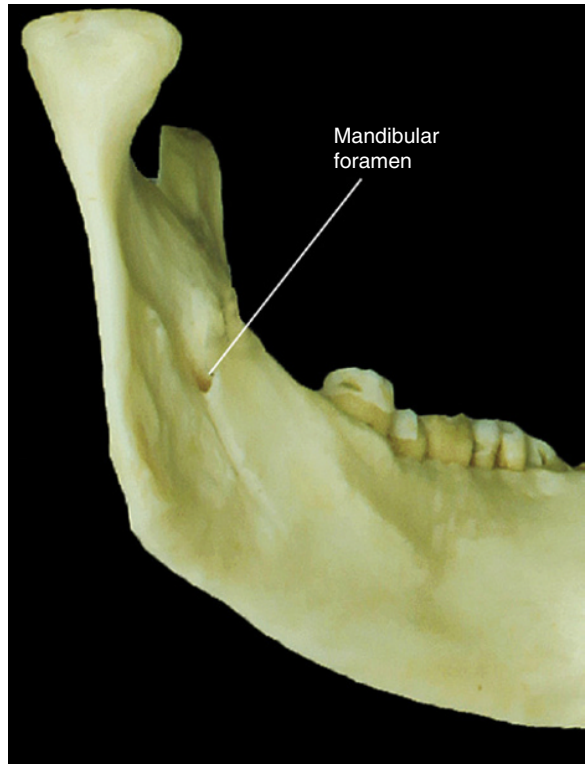

Figure I.27 Medial view of the side of the mandible showing the mandibular foramen.

alveolar nerve because the small branches of the nerve travel to the small cavities (alveoli) in the bone into which the teeth fit. (Think of the teeth as telephone poles that have been driven into holes (alveoli) in the mandible.)

Foramina of the lateral view

The large opening labeled in Figure I.28 is the external acoustic (auditory) meatus; below and posterior to this foramen is a bony process known as the mastoid process. Your auricle (external ear) is located around this meatus, which conducts sound waves to the tympanic membrane. The mastoid process is part of the very hard (petrous) portion of the temporal bone. You should be able to palpate this bump on yourself just behind your ear.

The mastoid process is not present in the newborn, but develops as the child begins to raise his or her head from the crib. The sternocleidomastoid muscle attaches to this process (see Chapter 11). The mastoid process provides another important function for CN VII (Chapter 7); the mastoid process protects CN VII as it exits the stylomastoid foramen (the foramen is located just deep to the mastoid process and is illustrated later in Figure I.32). This nerve is responsible for innervating all the muscles of facial expression, that is, muscles that we use to express joy, anger, etc., but also close our lips and eyelids. Now think back to the first sentence describing the formation of the mastoid process – it is not present in the newborn. Herein lies the problem: as children begin to learn the process of walking, they are known

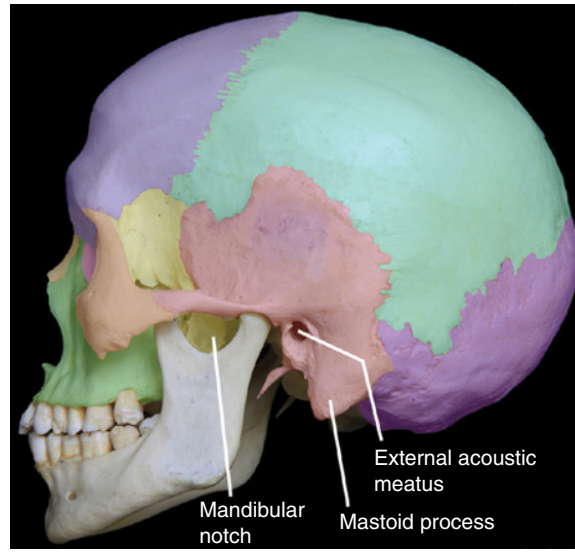

Figure I.28 Foramina of the lateral view of the skull.

as toddlers, that is, they toddle (a process not unlike walking drunk), are much less stable on their feet, and are prone to numerous falls. Indeed, the incidence of facial nerve trauma is greater in toddlers than in adults, mainly because the former lack the adult-type mastoid process that protects the exit of CN VII from the stylomastoid foramen. CN VII is also subject to injury during delivery by obstetrical forceps due to the absence of the mastoid process (see Chapter 7).

Posterior view

The bones observed in the posterior view (Figure I.29) include the parietal, occipital, and temporal bones. The occipital bone is rather interesting because it serves as an important attachment point for a muscle that helps steady the head, but is more appropriately considered as a muscle of the upper limb, the trapezius muscle. This muscle is called trapezius because it resembles a trapezoid and extends from the occipital bone and the spines of the cervical and thoracic vertebrae, and then attaches to the scapula and the clavicle (Figure I.30). The trapezius is innervated by the spinal accessory nerve, or CN XI, the same nerve that innervates the sternocleidomastoid muscle (Chapter 11).

Basal view

We now turn to the bottom view of the skull, the basal view (Figure I.31), and again observe some of the bones we have seen before and notice how they meet their contralateral partner to complete the skull. From the front to the back we see, in order, the maxilla, the palatine bone, the sphenoid, the vomer, the temporal bone, and the occipital bone. Note that there are two maxillae

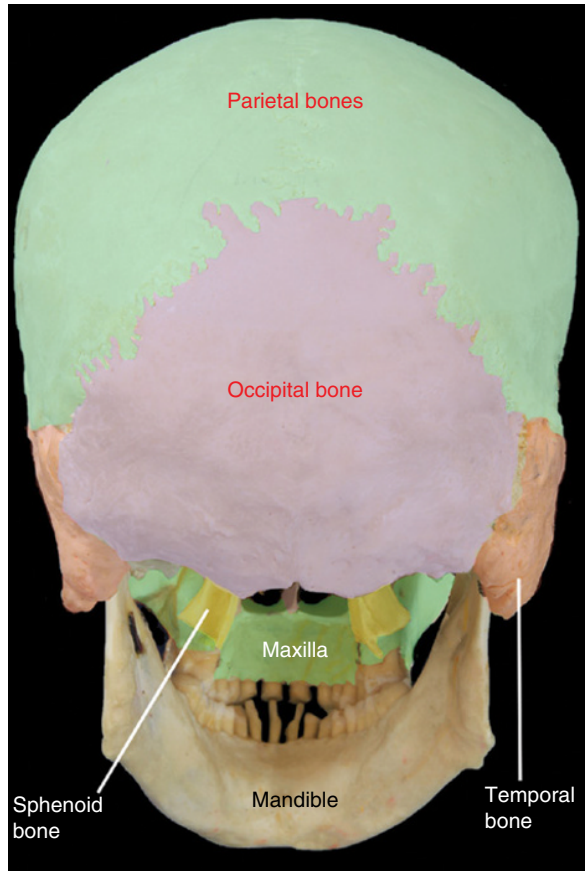

Figure I.29 Posterior view of the skull.

that meet at the midline and two palatine bones. Together, these two bones make up the hard palate of the roof of the mouth. When you run your tongue over the roof of the mouth, it is the maxilla that you feel. The uvula, or soft palate, hangs posterior to the palatine bone. Anatomically speaking, the vomer is above the palatine bone and the two maxillae. Compare this figure with the frontal view (Figure I.20) and the sagittally cut skull (Figure I.36, later). It is now possible to infer that the vomer extends the length of the hard palate. Again, note the wedge bone, the sphenoid, and realize why its name is so apropos; the bone is literally wedged between the maxillae, palatine, vomer, and temporal bones. The temporal bone, as discussed previously, prominently forms the roof of the infratemporal fossa. Finally, the last bone to consider in this view is the occipital bone, characterized by the foramen magnum (Latin: large hole).

The base of the skull can also be divided into functional regions. Anteriorly, the base of the skull serves as the roof of the oral cavity, the initial part of the digestive tract. Behind the palatine bone is the continuation of the digestive tract and also the upper part of the respiratory system (the oropharynx). Finally, the posterior part of the skull is the roof for the part of the spinal cord that exits the foramen magnum.

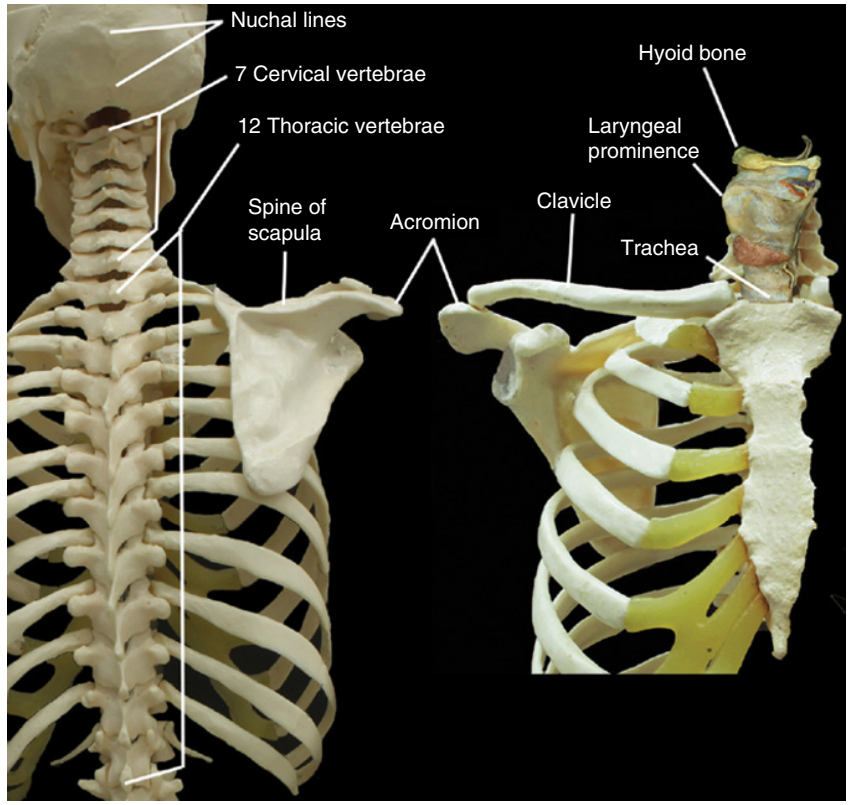

Figure I.30 Posterior (left) and anterior (right) views showing the attachment points of the trapezius muscle. Also, on right, the thyroid cartilage containing the laryngeal prominence and the hyoid bone of the neck are shown.

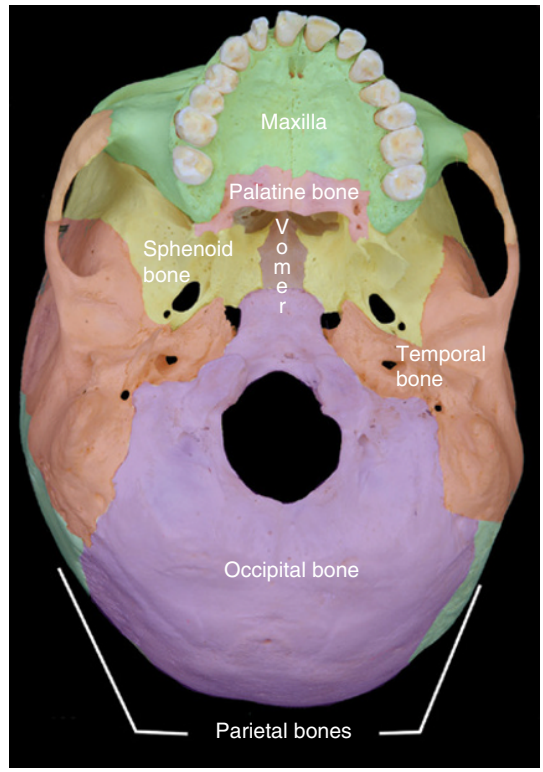

Figure I.31 Basal view of the skull – The external surface.

Foramina of the base of the skull

The foramina that are observed when looking at the external surface of the base of the skull are presented in Figure I.32. The two most anterior foramina, found in the maxilla, are called the incisive foramina, and are named for their closeness to (just behind) the incisor teeth. In the palatine bone we can see two foramina, one larger than the other. Hence, their names are based relative to each other: the larger (greater) and smaller (lesser) palatine foramina. At the junction of the maxilla and sphenoid bones two openings or regions can be observed. One is the inferior orbital fissure and the other is the pterygopalatine fossa. This space contains the pterygopalatine ganglion, one of the four autonomic ganglia of the head. Details of which nerves reach this ganglion are provided in Chapter 7.

Between the sphenoid and the temporal bone is the foramen lacerum. If you look closely at this foramen, you will see that the edges of the foramen appear somewhat jagged, or in Latin *lacer*, which implies mangled and/or lacerated. Moving a bit laterally to the temporal bone, two foramina are observed. The oval one is named foramen ovale (hint!). The smaller foramen is called foramen spinosum, a term that derives from the Latin for thorn. The rationale for this terminology is that the foramen spinosum is closely related to the spine of the sphenoid bone, a minor process, but nevertheless one that is used for the name.

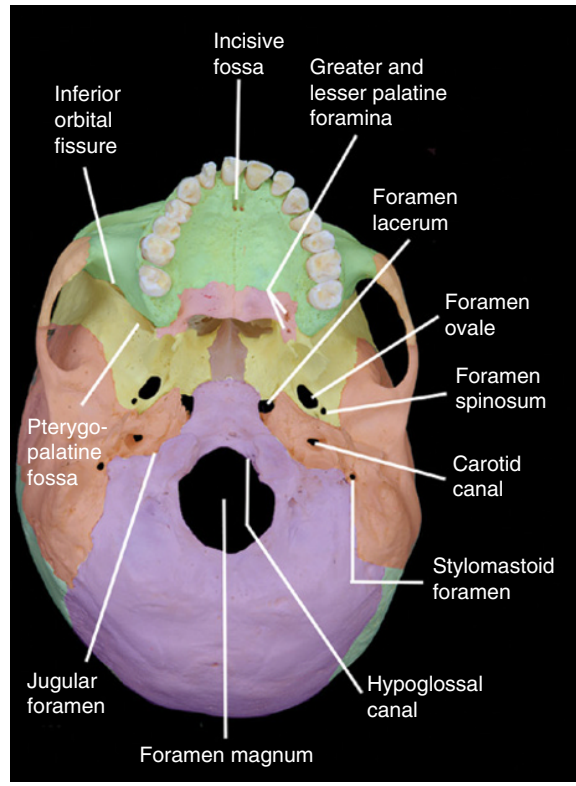

Figure I.32 Foramina that can be seen from the basal view.

The temporal bone has two foramina. The large one is called the carotid canal and is the port of entry of the internal carotid artery into the skull. Postganglionic sympathetic fibers from the thoracic part of the spinal cord also enter the skull at this point. The more posteriorly located foramen is called the stylomastoid foramen because it is located between the styloid and mastoid processes of the temporal bone (we mentioned this foramen earlier relative to the facial nerve). The styloid process (Latin: needle) is a needle-like structure that projects from the temporal bone (see it in Figure I.28, the pointy structure in front of the mastoid process). The term mastoid is a combination of Greek and Latin. From the Latin we get mastos (breast) and from the Greek we add the suffix *eidos* (form). Therefore, in essence, everyone has a couple of breasts hanging behind their ears.

The area between the temporal and occipital bones contains the jugular foramen. This is an irregularly shaped region for the exit of the venous blood from the skull in the internal jugular vein. CNs IX, X, and XI also exit the skull from this foramen. Clearly, a growth or tumor at this location will have a significant impact on the health of an individual because it can affect all three nerves. If we look further at the bottom-back (inferior-posterior) part of the skull, there are foramina associated with the bony occipital condyles, the hypoglossal canals, for exit of CN XII, the hypoglossal nerves, which control the muscles of the tongue. The condyles themselves rest on the first vertebrae, the atlas. Finally, the occipital bone can be observed to demonstrate one large foramen in the middle, the foramen magnum, which is where the spinal cord exits the skull.

The cranial fossae (superior view of the cranial floor)

The next view of the skull that needs to be examined is that of the skull once the calvaria or skull cap is removed. This view, shown in Figure I.33, represents the cranial fossae view, or the superior view of the cranial floor that we examined from the bottom in the previous section. There are three levels to the cranial fossae. The anterior part (anterior cranial fossa) is the highest and forms the roof of the orbit. It consists principally of the frontal bone. The middle part, the middle cranial fossa, is inferior to the anterior cranial fossa. The middle cranial fossa extends from the boundary of the sphenoid bone (yellow) to the temporal bone (pink). Finally, the most posterior part of the floor is called the posterior cranial fossa, made up mostly by the occipital bone. The bones observed in this view have been described before, albeit from different angles. From anterior to posterior they are the frontal, ethmoid, sphenoid, temporal, parietal, and occipital bones.

Foramina of the cranial fossae (superior view of the cranial floor)

Figure I.34 consists of two images of the skull taken at different angles to illustrate the respective foramina observed in different regions of the skull. The upper image was made from the perspective of viewing the anterior fossa as if you were standing directly behind it. The middle and posterior cranial fossae are presented as if you are looking straight down on the fossae.

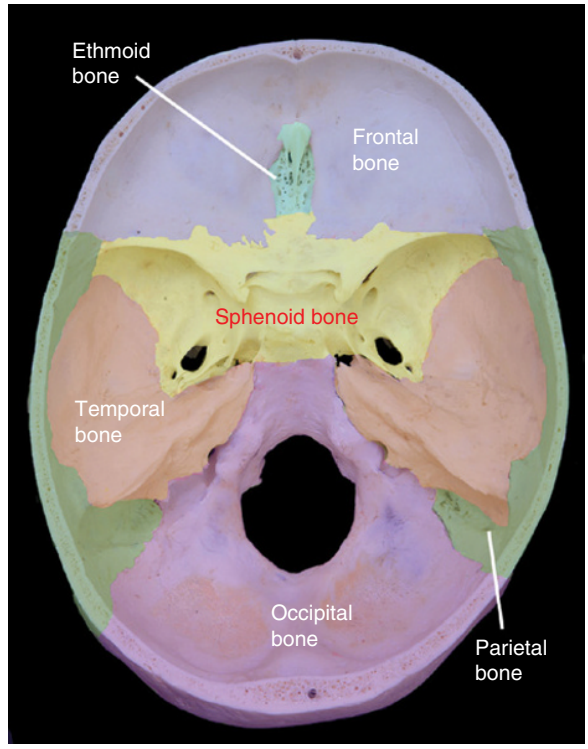

Figure I.33 The cranial fossae – the Internal surface of the skull.

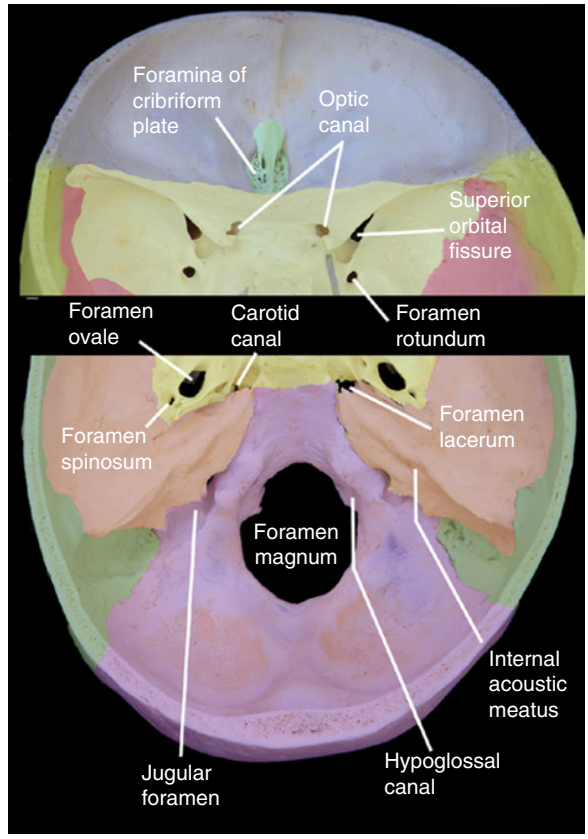

Figure I.34 The foramina (openings) of the cranial fossae.

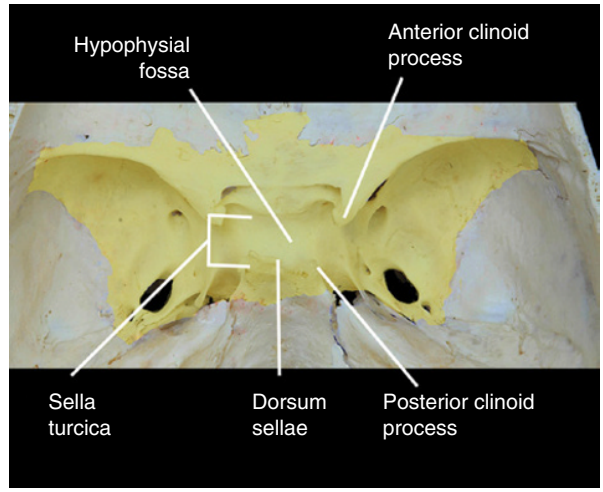

Figure I.35 The sella turcica, which is part of the sphenoid bone.

The first sets of foramina we encounter are those of the cribriform (Latin: sieve) plate. In life, immediately on top of these foramina rests the olfactory bulb, which is the terminus of numerous small olfactory nerves that traverse the cribriform plate from the olfactory epithelium in the nasal cavity (Chapter 1).

At the anterior central aspect of the middle cranial fossa is the cranial opening of the optic canal that conducts the optic nerve into the orbit. Posterior to this point is where the optic nerves join and cross to form the optic chiasm (Greek for the point where two lines cross, as in the letter X).

The general area shown in the middle of Figure I.35 is known as the sella turcica, or Turkish saddle, because it resembles these old types of saddles. The front of the saddle, which faces the back of the skull, is called the dorsum sellae. Anterior to the dorsum sellae is the hypophyseal (pituitary) fossa, or bed for the pituitary gland, surrounded by four processes, the two anterior clinoid and two posterior clinoid processes. The pituitary gland, a major gland responsible for hormonal control of many systems, sits in the hypophyseal fossa and can be a source of tumors. As the tumor grows the path of least resistance is upward, where it can impinge on the crossing optic nerves leading to visual abnormalities (Chapter 2).

The term clinoid is of particular relevance to the study of medicine. Indeed, it gave the profession the name of its practitioners, or clinicians. Clinoid is ancient Greek for bed and refers to bedposts, as in a four-poster bed. Early anatomists envisioned the pituitary as a central control center of the body and envisioned the pituitary resting on its bed.

From the view shown in Figure I.34, we also see in the middle fossa the internal opening called the superior orbital fissure. CNs III, IV, VI and the ophthalmic division of CN V traverse this fissure to enter the orbit. Prior to entering the fissure, these nerves travel through a dural space (cavernous sinus) filled with venous blood. The cavernous sinus communicates with the surface of the face via the ophthalmic vein in the infratemporal region. Infections of the face may thus reach the cavernous sinus and lead to serious infection of the sinus. Because CNs III, IV, VI and the ophthalmic division of

CN V travel through the cavernous sinus, any infection here could impact the actions associated with these nerves.

Just inferior to the superior orbital fissure is the foramen rotundum (the round foramen) through which the maxillary division of CN V exits the skull to reach the floor of the orbit. Next, we encounter the carotid canal for the internal carotid artery, the foramen lacerum, the foramen ovale, and the foramen spinosum. We discussed the naming of these foramina previously, when we presented the inferior view of the skull. Nerves that traverse these foramina will be discussed in the appropriate chapters, but it should be mentioned at this time that the foramen spinosum is for transit of the middle meningeal artery, not a CN.

We also see in Figure I.34 the prominent petrous portion of the temporal bone, which ends laterally and externally as the mastoid process. This part of the temporal bone is the hardest part of the skull, as hard as a rock. Hence, it was given the name petrous, Latin for Peter, the rock of the Church. The posterior aspect of the petrous portion of the temporal bone is in the posterior cranial fossa and the internal acoustic meatus passes laterally into this bone. Both CNs VII and VIII enter this foramen, which leads to the auditory or (Fallopian) canal (inside the bone and not shown in this image). Medial to, behind, and below the meatus is the internal opening of the jugular foramen, for passage of CNs IX, X, and XI, and the beginning of the internal jugular vein as previously described. Finally, we can also see the intracranial openings of the hypoglossal canals and the large foramen magnum.

Previously, we discussed how the facial nerve can be damaged as it exits the stylomastoid foramen. The facial nerve can also be damaged if the petrous portion of the temporal bone is fractured, as in the following case:

> A 60-year-old man was brought into the Emergency Department after an accident at work, resulting in his head being slowly crushed between a forklift truck and metal shelving. He distinctly remembered hearing a "popping" noise from his "head" before losing consciousness. A CT scan of his head showed longitudinal fractures of both petrous temporal bones extending cranially as linear undisplaced fractures of the flat parts of his temporal bones. The fracture lines passed through the region of the geniculate ganglia of the seventh cranial nerve [see Chapter 7]. Two days after admission, upon regaining consciousness, physical examination revealed bilateral abducent (VI) nerve palsies and facial nerve palsies. Upon further questioning, the patient revealed that he felt that the loss of control of his facial muscles started immediately after the accident (Rahman *et al*., 2012).

There are two interesting points to make about this case. First, the petrous part of the temporal bone can be fractured, even though its name implies that it is like a rock. Damage to the bone can affect CN VII and result in full or partial paralysis of the muscles of facial expression. The second interesting point about this injury is that the crushing injury also resulted in a lesion of the abducent nerve, CN VI, which is closely associated with CNs V

and VII. The mechanism by which this nerve is injured is not clear, perhaps stretching or contusion alone is sufficient to damage the nerve. Interestingly, the authors of the case reported that surgical intervention seemed to facilitate partial healing and the patient continued to improve at 18 months, suggesting that the fracture of the petrous bone did not fully sever either of the involved CNs.

Lateral and medial walls of the nasal cavity: median section through the skull

The final view we present (Figure I.36) is that seen as if the skull were sawed approximately in half front to back (if the skull was sawed perfectly in half it would split the thin nasal septum). Above the hard palate are medial and lateral walls of the nasal cavity, as shown in the left and right sides, respectively, in Figure I.36. The medial wall is formed by the nasal septum. As described previously, the nasal septum consists of the vomer, the perpendicular plate of the ethmoid bone, and the medial nasal cartilage. The latter is not shown in a bony skull, because it is not bone and generally not preserved. The lateral wall of the nasal cavity consists of the ethmoid bone and the maxilla. The olfactory area, where the olfactory mucosa is located, is high up in the cavity and is shown as a yellowish set of nerves in the figure (also see Chapter 1). Understand that the olfactory epithelium resides on both the medial and lateral walls of the nasal cavity, but the size of the cavity in this area is, at most, 3–5 mm.

This view also shows the air spaces in the skull, the frontal, maxillary, ethmoidal, and sphenoid sinuses. The hypophyseal fossa is clearly apparent. Unfortunately, one canal that cannot be demonstrated in this view is the pterygoid canal, which leads to the pterygopalatine fossa. The canal carries important nerves to the ganglia that is sitting in this fossa and will be discussed later in Chapters 5 and 7. However, the foramen that leads from this fossa into the nasal cavity, the sphenopalatine foramen, is visible. Branches of the maxillary nerve pass through this foramen to provide sensory innervation to the nasal cavity.

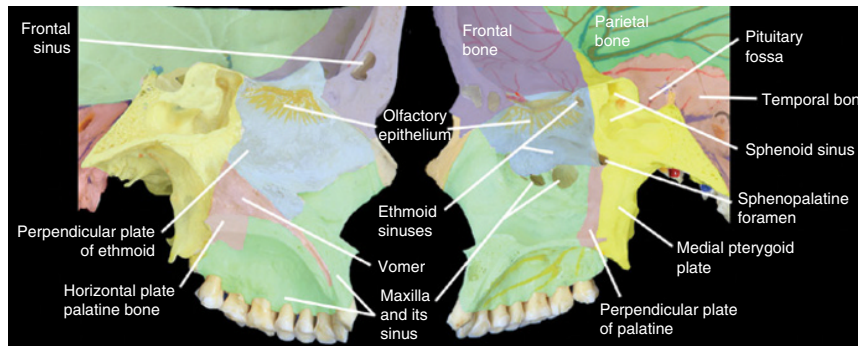

Figure I.36 Bisected skull. The medial and lateral walls of the nasal cavity and associated structures are illustrated. Compare this image with Figures I.31 and I.33, which exhibit the external and internal views of the skull base, respectively.

So yes, your skull is comprised of many bones and most of these bones contain *foramina* that allow CNs (and, to a lesser extent, blood vessels) to travel within the skull so that they can get where they need to go. An understanding of the CNs and especially of the effects of the conditions that affect them is impossible without an understanding of the foramina and canals that penetrate the skull.

Now we have done the tedious part; let us begin our exploration of the CNs by looking at CN I, the nerve of smell. As you will see, smell may seem like a rather trivial sense to you at the moment, but read on and you will come to understand how devastating its loss can be.

REFERENCES

Barker RA, Cicchetti F (2012) *Neuroanatomy and Neuroscience at a Glance*, John Wiley & Sons, Ltd., Chichester, West Sussex.

Karsteter PA, Yunker C (2006) Recognition and management of an orbital blowout fracture in an amateur boxer. *Journal of Orthopaedic and Sports Physical Therapy* **36**: 611–18.

Rahman S, Hayes S, Sunkareni V, Thomas S (2012) A case report of bilateral temporal bone fractures associated with bilateral sixth and seventh nerve palsies. *The Internet Journal of Otorhinolaryngology* **14**. doi: 10.5580/2b88.

1 The Olfactory Nerve

Figure 1.1 Helen Adams Keller (1880–1968) was an American author, political activist, and lecturer. She was the first deaf–blind person to earn a Bachelor of Arts degree. The story of how Keller's teacher, Anne Sullivan, penetrated the isolation imposed by Keller's absence of language ability has become widely known through the dramatic depictions of the play and film, *The Miracle Worker*. Here, Keller is shown using one of her remaining senses, olfaction, to smell roses.

ANATOMY/FUNCTION SUMMARY

Figure 1.1 shows Helen Keller enjoying the fragrance of roses. In her 1908 book, *The World I Live In*, Chapter VI is titled, "Smell, The Fallen Angel", and begins, "For some inexplicable reason the sense of smell does not hold the high position it deserves among its sisters. There is

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
First Edition. Joel A. Vilensky, Wendy M. Robertson and Carlos A. Suárez-Quian.
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something of the fallen angel about it." Keller then proceeds to describe the importance of smell to her and her own very acute sense of smell (hyperosmia). "The sense of smell has told me of a coming storm hours before there was any signs of it visible…. From inhalations I learn much about people. I often know the work they are engaged in. The odors of wood, iron, paint, and drugs cling to the garments of those who work in them.… When a person passes quickly from one place to another I get a scent of impression of where he has been – in the kitchen, the garden, or the sick-room."

The olfactory nerve (really a collection of many filaments that are collectively referred to as the olfactory nerve; Figure 1.2) is a purely sensory nerve (special sensory) that conveys the neural impulses that the brain is able to interpret as odors. Our sense of taste is intimately blended with our sense of smell. The olfactory nerve has the simplest anatomy of any of the cranial nerves. There are neurons sensitive to odorous molecules in the upper recesses of the nasal cavity, which send impulses that are interpreted as smells to the brain (Figure 1.2).

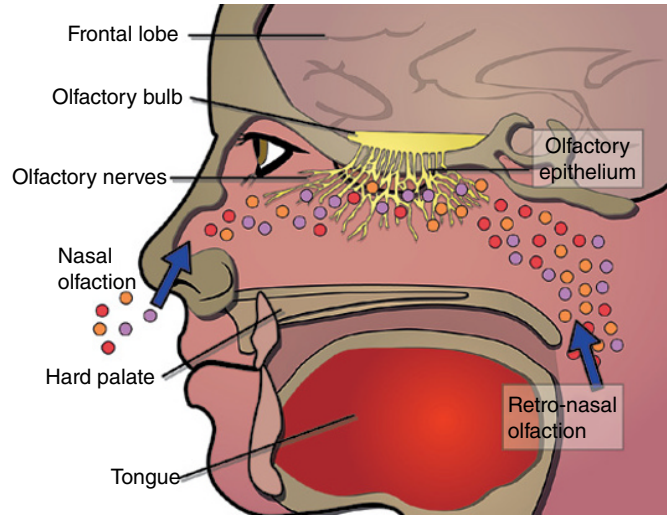

Figure 1.2 Schematic illustration of the olfactory nerve.

Below is an Internet case of anosmia (loss of smell) written by Joan, a 45-year-old woman, who implies that life without a sense of smell is similar to living in a two-dimensional world:

> I suffered from allergic symptoms and chronic sinusitis all of my life – plus nasal polyps and a deviated septum. I had three surgeries to repair the septum and remove diseased tissue and polyps that were obstructing

my sinuses and nasal passages. My anosmia developed gradually sometime after the second surgery. It was especially devastating for me because a large part of my life and livelihood relied on my sense of smell – I sold fragrance and aromatherapy products, and had even created several very successful fragrance blends myself. I had very brief periods of partial or total restoration of my sense of smell and taste after an intensive course of oral steroids. The recovery was a week of "glorious 3-D" living – with my smell and taste completely restored. But it disappeared just as quickly as it came. Because the side effects of oral steroids prevent me from being able to take them more than once or twice a year, oral steroids are not a permanent solution – "but I haven't given up hope for finding one."

ANATOMY/FUNCTION

Olfaction begins when molecules from an aromatic substance (e.g., Chanel No. 5 as opposed to gold bullion) enter the nasal cavity and ascend with an inhalation (Figure 1.2). These aromatic molecules then interact with a layer of about six million specialized sensory receptor cells that are nestled among the supporting mucosal cells in the roof of the nasal cavity on protuberances called concha.

This specialized mucosal area (often referred to as the olfactory epithelium) can be distinguished by a faint yellowish color from the adjacent more reddish respiratory mucosa (Figure 1.3). With every breath, air is forced over 10–50 very fine hairs called cilia (0.3 μm in diameter) arising from each of the olfactory receptor cells that are sensitive to aromatic compounds in the air. The incredibly thin unmyelinated axons from the olfactory receptor cells (about 0.2 μm in diameter) coalescence into about 20 bundles, collectively referred to as the olfactory nerve, and ascend about 30 mm from the nasal cavity through the cribriform plate and enter the cranial cavity. As discussed in the introductory chapter, the cribriform (sieve-like) plate is characterized by foramina that allow the passage of the axons from the sensory cells to the brain. The actual space in the nasal cavity in which the olfactory epithelium is located, the olfactory cleft, is only about 1–2 mm wide and thus can be easily blocked by disease.

Once through the cribriform plate, the olfactory nerve axons synapse in an ovoid extrusion of the cerebral cortex that rests on the cribriform plate called the olfactory bulb, which is about 8 mm^2 in size (Figure 1.4).

The olfactory sensory cells are unique among human sensory receptors because they can regenerate if damaged, but only if their supporting layer of cells is preserved. This is possibly an evolutionary adaptation to their

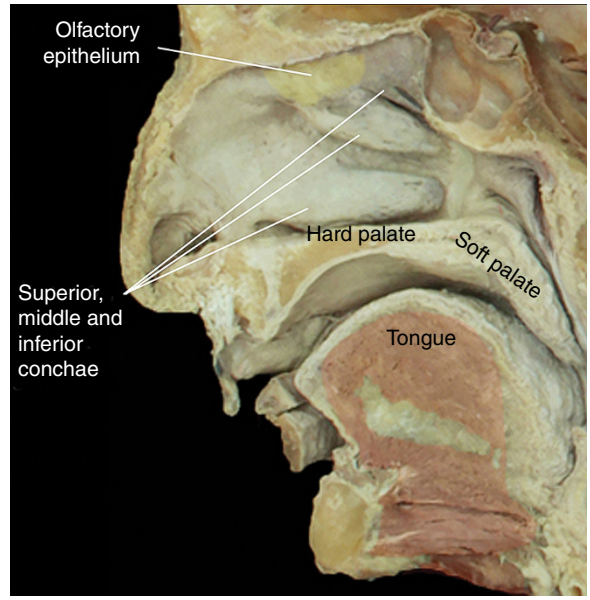

Figure 1.3 Bisected view of the head of a cadaver showing the interior of the nasal cavity and the location of the olfactory epithelium (yellow shading).

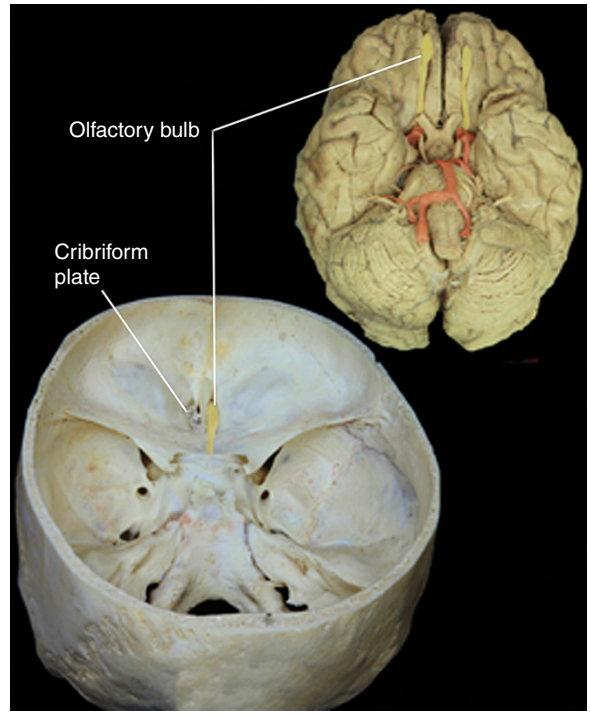

Figure 1.4 Paired images showing the location of the olfactory bulb in the skull and on the brain. The inside surface of the base of the skull is shown on the lower left of the image. The surface of the brain that rests on the skull is shown on the upper right side of the image. An olfactory bulb was digitally inserted into the skull to demonstrate how it rests on the cribriform plate.

relatively high susceptibility to damage. These cells are even capable of repenetrating the cribriform plate and forming new connections with the olfactory bulb when damaged. Furthermore, they uniquely project directly to the brain (olfactory bulb) without an intervening synapse. Although this allows a very precise relationship to exist between odorants and cognition of them, it also unfortunately forms a primary route for exposure of the brain to viruses, bacteria, prions, and airborne toxins. Both Alzheimer and Parkinson diseases have been hypothesized to be caused by organisms and toxins that enter the brain via the olfactory route, although proof of this hypothesis has been elusive.

Humans have approximately 350 functional types of olfactory receptors, that is, receptors that will respond to a few specific odorants. This allows great specificity to olfactory sensations. Furthermore, not all sensations that we associate with smell are in fact truly conveyed by the olfactory nerve. The trigeminal nerve (Chapter 5) has sensory branches in the mouth and nose that respond to sensations such as warmth, coolness, pungency, and irritation. For example, ammonia not only smells awful but also results in a pungent, burning feeling in the nose resulting from trigeminal stimulation. Thus, our cognition of smell is complex, based not only on odors but also taste and these trigeminal sensations. Because of this interaction, it is sometimes not possible to truly say that a patient has complete anosmia because in high concentrations some substances may be perceived via trigeminal stimulation.

The olfactory bulb has cells arranged in six concentric layers. Each particular olfactory neuron only synapses with one or two olfactory bulb cells so that the receptor-specific odorant response is preserved. The primary output neurons of the olfactory bulb project via the olfactory tract to brain structures that are referred to as the primary olfactory cortex.

CLINICAL ASPECTS

Loss of smell

Although the consequences of the total absence of a sense of smell, anosmia, would intuitively seem small compared to loss of one of the more prominent senses such as vision, the effect on quality of life and on one's safety is substantial. If asked about how anosmia has affected their lives, patients often begin by narrating humorous anecdotes about how they no longer react to offensive or nauseating odors. However, when these patients get more serious they talk about how sad they feel when they look closely at a strawberry before eating it and smell nothing. Some patients describe how they have lost their libido because smell is so important to sex. One mother related how she had a very difficult time bonding with her newborn child because she could not smell the child.

People with anosmia can be self-conscious about personal hygiene, often taking several showers a day because they do not know whether or not their body odors are offensive. Cooking becomes difficult and eating becomes monotonous with little associated pleasure. Because eating is typically social,

people with anosmia can lose interest in being with friends and can become depressed and socially isolated.

The French author, Marcel Proust, described in *Remembrance of Things Past* (also known as *In Search of Lost Time*) how the sense of (smell and) taste of a small cake (a madeleine) caused an intensely pleasurable memory to take hold of his body related to complex feelings from childhood.

Importantly, the loss of smell also results in danger to the patient who cannot smell smoke or gas leaks. Such patients cannot tell whether fish has been out of water for 3 hours or 3 days, or whether milk is sour. Because people with anosmia cannot taste well, they may tend to eat excessively in an attempt to get some satisfaction from food.

In 2004, Drs. Richard Axel and Linda Buck were awarded the Nobel Prize in Medicine for the discovery of odorant receptor mechanisms and the organization of the olfactory system. Dr. Axel said in his Nobel acceptance speech:

In humans, smell is often viewed as an aesthetic sense, as a sense capable of eliciting enduring thoughts and memories. Smell however is the primal sense. It is the sense that affords most organisms the ability to detect food, predators, and mates. Smell is the central sensory modality by which most organisms communicate with their environment.

Accordingly, humans who lose their sense of smell are often seriously disabled and depressed. Part of the explanation for the unexpected seriousness associated with anosmia is that along with the loss in smell is a similar loss in taste. Much of what we think of as taste actually results from a complex interaction of taste, smell, and touch. When we eat, aromatic compounds in the food enter the nose from the mouth during swallowing (Figure 1.2). This is why taste is also often distorted during an upper respiratory infection when inflammation of the nasal passages interferes with this process.

Olfactory testing

Prior to the mid-1980s, only rudimentary methods of testing the ability of patients to smell were available. Typically, the clinician would have an assortment of commercially available odors (e.g., menthol oil, lavender oil, coffee, ammonia, clove, vinegar, pepper, and turpentine) and observe if and how the patient responded to each. However, the strengths of the odorants varied and it was not possible to quantify patient response or whether there was much clinical interest in doing so.

The Smell Identification Test™, which was developed in the mid-1980s, consists of four booklets, each containing 10 "scratch & sniff" odorants. The odorants are embedded on brown strips at the bottom of each of the test booklets (Figure 1.5). The stimuli are released by scratching the strips. Written above each odorant strip is a multiple-choice question with four possible responses. A percentile score for the patient is determined relative to normal individuals.

Figure 1.5 The four booklets of the Smell Identification Test™.

More sophisticated testing is possible using electrophysiological apparatus, which are only available in specialized centers. The electrophysiological tests evaluate either electrical activity at the surface of the olfactory epithelium (electro-olfactogram) or integrated electrical activity on the scalp in response to odors (i.e., odor-event recorded potentials).

Olfactory disorders

There are several types of olfactory dysfunction. Anosmia is the complete loss of the ability to detect odors. Partial anosmia is the loss of the ability to detect some, but not all, odors. Hyposmia or microsmia refers to decreased sensitivity to olfactory stimuli. Increased sensitivity to olfactory stimuli is referred to as hyperosmia. Dysosmia or parosmia is distortion of olfactory perception, referred to as cacosmia when the odor is perceived as fetid. Phantosmia is the perception of an odor when no true olfactory stimulus is present, such as olfactory hallucinations. The inability to recognize an odor that can be perceived is olfactory agnosia.

The causes of olfactory disorders may also be divided into three classes: (1) conductive or transport impairments, which result from mechanical obstruction of the nasal passage as in chronic nasal inflammation; (2) sensorineural impairments, which result from damage to the olfactory epithelium as might occur after a viral infection; and (3) central olfactory neural impairment, which results from central nervous system damage as when tumors compress the olfactory tract, and neurodegenerative disorders. These causes are not mutually exclusive. It is possible, for example, for a virus to damage the olfactory epithelium and cause an upper respiratory infection that might also cause conductive impairment.

Growths in the nasal and cranial cavities

Hyposmia (anosmia) may be caused by nasal polyps, which are soft, painless, benign growths on the lining of the nasal passages or sinuses. They can result from chronic inflammation, recurrent infections, or allergies. Larger polyps can obstruct nasal passages, leading to anosmia. Nasal polyps affect up to 4% of the general population.

A wide variety of cancers can arise in the nasal cavity. By obstructing airflow and/or cellular destruction these tumors can cause olfactory dysfunction. Some of these tumors arise from accessory salivary glands that are scattered around the throat and nasal cavity.

A rare aggressive tumor, called an olfactory neuroblastoma (esthesioneuroblastoma), actually originates directly from the olfactory nerves. An olfactory neuroblastoma can occur at any age, although it tends to peak in young adults and in the elderly. There are no known risk factors. Olfactory neuroblastomas tend to be large tumors that invade the cribriform plate and virtually always affect olfaction, both neurologically and mechanically. These tumors can become very large and disfiguring (Figure 1.6). They may cause complete anosmia.

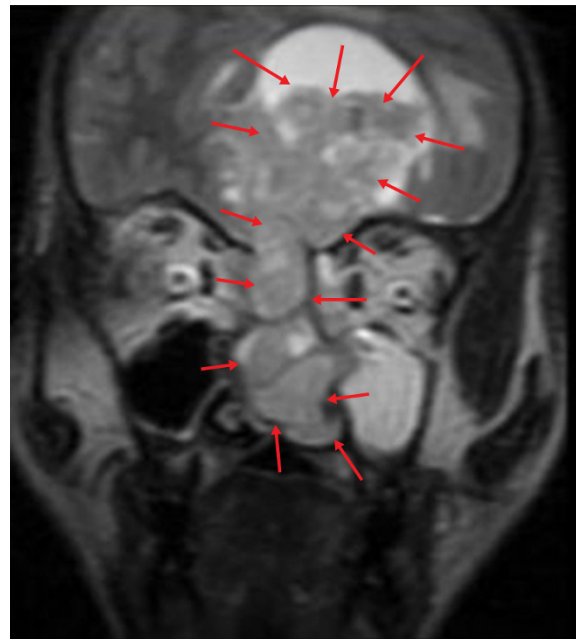

Figure 1.6 Coronal view of a CT scan of a patient with a massive neuroesthesioblastoma. The arrows outline the tumor, which has greatly distorted the normal nasal anatomy in this patient.

A cranial cavity tumor that can affect olfaction is an olfactory groove meningioma (Figure 1.7). These tumors arise in the midline from the arachnoid layer of the brain covering (meninges) that lies over the cribriform plate. These benign slow-growing tumors cause olfactory impairment in a majority

of patients, presumably because of mechanical impingement on the olfactory nerves, bulbs, and tracts, as exemplified in the Internet case below:

> Dave said this about his meningioma. "The tumor stretched and then snapped my olfactory nerve. The tumor was benign and it is gone, but the anosmia will be with me the rest of my life. It has been about nine years since I woke up and smelled the coffee."

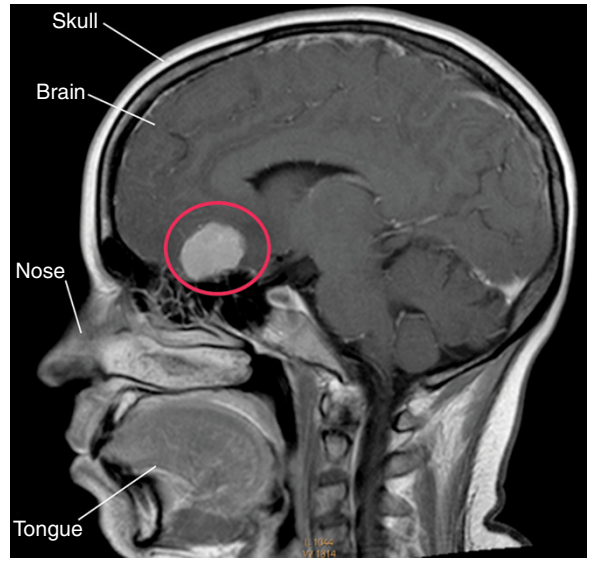

Figure 1.7 MRI of the brain of a patient with a meningioma (tumor of meninges). Note how the tumor (circled in red) is located immediately above the cribriform plate and is therefore in a perfect location to compress the olfactory bulb and thereby interfere with olfaction. Reproduced with permission and courtesy of Health@SarahRamsden.com.

Upper respiratory infections

Upper respiratory infections (colds), usually viral, are the most common cause of chronic hyposmia or anosmia. Even the common cold may cause permanent damage to olfaction, as Judy indicated in her Internet forum posting.

> I've had a cold that started last Friday. Last night I noticed I couldn't smell anything – perfumes, coffee, etc. On Monday I was still unable to smell so I went to the doctor, who said that I am "completely blocked up", nose-wise. I used nasal decongestant spray for a few days, but have stopped. I still can't smell much. How long do you think these symptoms will last? Usually I can smell more than this when I'm sick. It's been a bad year cold-wise!

Colds cause inflammation and swelling of the mucosal lining of the nasal cavity. This swelling and mucous secretion can physically block odorants

from reaching the cilia on the receptor cells and thus prevent the cells from responding to odorants. Olfactory function has been found to be decreased in patients during a cold, even when the patient does not have signs of nasal congestion. However, strangely enough, mild or moderate nasal congestion in the absence of disease does not necessarily cause impairment of smell function and may actually enhance it, perhaps forcing more air into the olfactory cleft. Olfactory disorders associated with colds are typically not serious and regress as the cold regresses and/or can be successfully treated with medications. Sometimes, however, the cold virus can have lasting effects.

The British columnist and author Diana Appleyard wrote a column in the *Daily Mail* on January 28, 2012: *A cold left me unable to smell or taste for two years… Would I ever enjoy the aroma of roast chicken or flowers again?*

"Two years ago, I suffered from a very heavy cold. With a runny nose, itchy eyes, persistent cough and sore chest, my symptoms were nothing out of the ordinary. Yet when they disappeared, I was left with one that has had a profound and dispiriting effect on my life. I seemed to have permanently lost my sense of taste and smell.

After my cold, I kept thinking these senses would return, but as weeks turned into months, I was in despair. Would they ever come back?

Until you lose them, you have no idea how much pleasure they bring to everyday life. A stressful day is soon forgotten by the aroma of a dinner of roast chicken and a glass of rioja. A walk in the woods is heightened by pine and wild garlic."

Diana saw her physician who examined her nasal passages with a nasal endoscope and found swelling and inflammation. He told her that her condition was treatable using a salt-water nasal wash, a steroid spray to reduce the inflammation in the lining of her nose and anti-histamines.

A month after she began treatment her sense of smell and taste begin to return. "It's as if the world is gradually being restored to color around me. I am still taken by surprise occasionally." Diana's sense of smell fully recovered.

Unfortunately, there is no direct diagnostic test to demonstrate viral anosmia. If no other cause of anosmia can be found and the patient has had a recent upper respiratory infection, then a diagnosis of viral anosmia is made.

Mick O'Hare described his presumptive viral anosmia in the September 24, 2005 issue of *New Scientist*. He noted that although he had a cold he knew immediately that this was different. He had a total loss of any sense of taste or smell. He said it was initially terrifying and his doctors generally told him that "he had to live with it."

Chronic bacterial infection is also believed to be associated with destruction of the nasal receptor cells, but because hundreds of species of bacteria normally inhabit the nasal cavity, it is almost impossible to determine which of these can cause such destruction.

Drug-induced hyposmia (anosmia)

Many drugs interfere with the ability to smell, although taste is affected more frequently. Unfortunately, most of the data supporting this relationship are case reports that lack quantitative olfactory testing. Drugs known to affect smell and/or taste based on olfactory measurement rather than anecdotal reporting include calcium channel blockers, antibiotics, antithyroid drugs, opiates, antidepressants, and sympathomimetics (drugs that mimic the action of the sympathetic nervous system). Recreational drugs that are snorted, for example, cocaine, are sometimes associated with anosmia because of destruction of the olfactory epithelium. This happened to Jim:

> I lost my sense of smell due to cocaine use over 30 years ago. I only used it recreationally for about five years in the early 80's but it did enough damage that I lost a lot of my sense of smell and some of my sense of taste. Over the years I have regained some of that, but certain flavors are just outside the range that I can taste…in the same way that some smells are outside the range that I can smell. It seems similar to being color blind but pertaining to sense of smell instead.

Nonbiologic airborne toxins

Airborne toxins, including herbicides, pesticides, solvents, and heavy metals can damage the olfactory primary cells, especially with chronic exposure. One of the heavy metals that can do this is zinc, as described in Bonnie Blodgett's book, *Remembering Smell: A Memoir of Losing and Discovering – The Primal Sense*. In the fall of 2005, she developed anosmia. Based on the recommendation of her husband, she had used a zinc-based "homeopathic" gel called Zicam™ to relieve her cold symptoms. She had thought, "What did I have to lose?"

Zicam is actually the name for a series of products marketed for cold and allergy relief. The only active ingredient is zinc. On June 16, 2009, the Food and Drug Administration (FDA) advised consumers to stop using three of Zicam's products including the nasal gel because of the risk of anosmia. The FDA advisory panel indicated that the FDA had received reports of anosmia from approximately 130 Zicam users since 1999. The FDA also issued a Warning Letter to Matrixx Initiatives, Inc., which owns Zicam LLC, that eventually led to the recall of all affected products. In 2006, Matrixx settled 340 lawsuits for $12 million from patients who said the product eliminated their sense of smell. By 2009, hundreds more suits had been filed. Blodgett noted that from the original lawsuit each of the plaintiffs received about $12,000, which was a paltry sum to many of them. Blodgett associated this small sum to the perception that smell is a relatively unimportant sense.

After using Zicam Blodgett's cold was unfazed and she spent a week congested and miserable. A week later she noticed very vile odors. She didn't realize it but she had cacosmia (phantosmia).

Rather, she questioned her sanity. An ear, nose and throat specialist (ENT) prescribed an antidepressant that he hoped would relieve her from the "odiferous onslaught of burning flesh, rotting fish, feces, and the like."

The antidepressant was effective but upon losing the olfactory hallucinations, Blodgett also lost all sense of smell. The specialist had actually told her that this was likely to happen because such hallucinations often precede anosmia.

When the specialist had asked her how much Zicam she had used, Blodgett told him that she had figured "the more the better." She stated that immediately after using the product her "sinuses were suddenly on fire, and so were the tissues far in my throat where the gel had apparently started to drip. *So this is how cattle feel under a branding iron*, I thought as tears filled my eyes."

The ENT specialist told Blodgett that he suspected that the active ingredient in the Zicam, zinc gluconate, is toxic to the smell receptors. He explained that all of her olfactory receptors were likely destroyed. When Blodgett asked why he thought it was the gel rather than the cold virus that destroyed her nasal cells, he said that the immediate acute pain suggested to him that it was the Zicam.

For much of her 240 page book, Blodgett describes her ordeal with anosmia. Her profession as a gardener made her malady even more devastating. She of course also lost taste. She stated that physical intimacy with her husband become "oddly arid" because she couldn't smell her husband. Depression followed.

After about six months of anosmia, on a walk with her dog, Blodgett passed a popcorn shop and all of a sudden smelled popcorn. She thought she was hallucinating. Next she sniffed her dog's poop and her upper lip curled. A few weeks later she started smelling the flowers in her garden. She finishes her book with: "My journey was done. I was home again, and whole. The world was more intoxicating than ever before. I could really smell it."

Despite the lawsuits and FDA action, in the book, *The Neurology of Olfaction*, the authors suggest that the putative relationship between Zicam and hyposmia is dubious because it is unclear whether the underlying infection or the medication is the cause of the disorder.

A study in *Occupational Medicine* in 2005 described a more classic case of a patient losing his sense of smell due to chemical exposure.

A 31-year-old worker in Finland did not use any personal respiratory protection while applying a waterproofing compound in bathrooms. The patient had noted that the chemical's odor was very strong. After four weeks of using the chemical the patient felt irritation in his eyes and

mucous membranes. The patient was unable to smell any tested odor. The chemical waterproofing compound was found to emit a variety of toxic chemicals including butanol, acetone, acrylates, and carbon disulfide, all of which have been reported to induce hyposmia or anosmia. The patient remained anosmic after one year (Hannu *et al*., 2005).

Trauma

In 1870, Dr. William Ogle said in a presentation to the London Medical Society, "I wish to bring to the Society some cases in which the sense of smell was either entirely lost, or greatly impaired. … I will begin with three cases which have fallen under my notice in which smell, and smell alone, was completely lost."

CASE 1.- Mr. A. fell from a horse twenty-seven years ago, and struck his head heavily against the ground, on the left side and in the posterior part. Ever since the accident he has been liable to headache, and his "nerves are not so strong as they were." He has also ever since completely lost the sense of smell. The very strongest odors brought under his nose produce no sensation whatsoever. The tactile sensibility of his nostrils is with this quite unaffected. The slightest touch of the mucous membrane is felt perfectly, and snuff produces tickling and sneezing. He states that he has lost not only the sense of smell, but also that of taste: for he cannot in the least distinguish one meat from another. Boiled onions, boiled apples, boiled turnips, all appear the same to his palate. He cannot at all recognize the aroma or flavor of wines; though he can distinguish wines from each other to a certain extent by their different degrees of roughness and of sweetness. Port, for instance, he can tell from claret by its being sweeter and less rough. Besides sweetness he can distinctly recognize saltiness, bitterness, and acidity. Excluding these qualities, one substance is exactly like another to his palate, excepting so far as they are more or less hard and rough.

Notwithstanding all this he is not absolutely indifferent as to his food. He has preferences, derived apparently from memory; and he especially dislikes any new article of diet. There is no muscular palsy, no loss of sensibility, nor other symptom than those mentioned.

CASE 2.- Mr. B. was knocked down by a cab some two years ago, and fell backwards, striking his occiput heavily against the road. For a minute he was stunned, but recovered, and managed to get home, where he was laid up for a time suffering from the local injuries, and from severe headache. All this, however, passed off, and he was left with no other permanent symptom than total loss of smell. This has remained without change ever since the accident. He cannot perceive the very strongest odors, that for instance of asafetida [a herb with a pungent odor]. The tactile sensibility of the nostrils is perfectly normal. Ammonia salts and snuff tickle his nostrils, and cause lachrymation or sneezing as in other men.

He states that he has lost not only smell but taste. Cinnamon appears to his palate utterly without flavor. He cannot tell one meat from another when his eyes are shut, though he can in some degree distinguish various articles of diet by their tactile qualities. He cannot recognize the aroma of wine. Port, he says, tastes like sugar, claret like weak vinegar. The former also seems thicker than the latter. He cannot only recognize sweetness and acidity, but also bitterness and saltiness. This, however, is the limit of his gustatory perceptions.

He is not quite indifferent as to his food, but still has fancies and preferences, dependent perhaps on habit; so also he still smokes.

CASE 3.- Mr. C. was admitted into hospital in February, 1869. He had been knocked about the head in a drunken row the preceding Christmas, and ever since had suffered from strange sensations in the head, and from occasional attacks of nose-bleeding. He was somewhat deaf since the injury to his head, and had completely lost his sense of smell. He could neither smell asafetida nor buchu [a fragrant herb]. He stated that he had also lost his taste; but he could perfectly distinguish quinine, table salt, and sugar, from each other, and pronounced each correctly to be bitter, salt, or sweet. After a short stay in the hospital, serious head symptoms declared themselves, and the man became so noisy and violent that he had to be removed; and eventually he became, I was informed, insane.

There can, I think, be little doubt that the loss was due to rupture of the olfactory nerves as they pass from the bulb through the holes in the ethmoid bone [cribriform plate].

It is easy to understand how a blow, which is not sufficiently violent to do serious mischief to the anterior brain generally, may still suffice to tear the olfactory nerves, owing to their very small size, and, still more, owing to their excessive softness. In only one recorded case of loss of smell from a blow on the head, have I found mention of the exact part struck. There also, as in these cases, the blow was on the occiput (Ogle, 1870).

Because the olfactory receptors are located very high in the nasal cavity, blows to the nose, even those that cause a "broken nose," typically have only transient effects on olfaction. The major association of trauma with olfactory dysfunction results, as exemplified by Dr. Ogle's cases, from head trauma, injuries that are colloquially referred to as "head-bangers." In head trauma, anosmia or hyposmia, as surmised by Ogle, is usually attributed to a shearing of the olfactory nerve fibers as they exit from the cribriform plate to enter the olfactory bulb (Fig. 1.2). There does not need to be a skull fracture for anosmia to be present, which is important from a medicolegal standpoint. Back and side impact injuries cause smell damage more frequently than front impact injuries. The incidence of olfactory dysfunction related to head trauma is thought to lie between 4 and 15%. The probability of loss of the sense of smell

from head injury correlates to the severity of the injury and the degree of rapid acceleration and deceleration of the head.

The recovery of smell in patients with head trauma is a function of many factors including age, severity, and elapsed time. Initially, there is often a relatively rapid recovery because the anosmia may simply be due to nasal swelling.

Previously, we mentioned that the olfactory receptor cells can regenerate. So why don't they in typical head trauma cases? Although the olfactory neurons probably do regrow, it is likely that trauma-induced scar tissue overlying the cribriform plate prevents the axons from penetrating the plate and reaching the olfactory bulb.

Ogle did not mention whether any of his three patients suffered from olfactory hallucinations, which are common in head trauma cases, as shown by Becky's case from the Internet.

Becky fell and suffered a concussion in 2006. She lost her senses of taste and smell that day. Her doctors told her that 1/3 of head injury patients suffer with anosmia and 1/3 of them never recover. Her primary physician said that if she didn't recover her smell within a year then she probably never would. "Well it is after a year and so far I'm still anosmic! The first year was the worst, I had horrible phantom smells (odors that were horrible and wouldn't go away!). I lost weight and was depressed." Becky's "phantom odors" lessened after the first year.

Treatment

A patient with an olfactory deficit needs to be evaluated to determine whether the cause is conductive, sensorineural, or both, or if it is due to CNS dysfunction. Growths causing conductive loss can typically be evaluated by nasal endoscopy. Further analysis may involve a CT scan of the nose and paranasal sinuses or an MRI scan, which is better than CT for delineating soft tissue abnormalities (e.g., inflammation). CT, however, is better than MRI for discerning bony abnormalities such as a fracture of the cribriform plate from a traumatic event. If the patient has a mechanical obstruction that reduces the exposure of the olfactory cells to inhaled air, then surgery, steroids, or anti-inflammatory sprays may be helpful.

Steroids are also often prescribed in high doses after a suspected traumatic injury to the olfactory nerves with the aim of reducing scar-tissue formation, but the value of this treatment is questionable.

Aging and olfaction

Reduction in smell ability is a normal consequence of aging in humans. Generally, the age-related decline in the sense of smell is more severe in men than in women. In contrast to reductions in hearing and vision, age-related decline in smell often is unappreciated by the patient or their clinician. Above the age of 65, between 50 and 75% of the population shows significant

decreases in the ability to smell. The causes of this decline in the sense of smell relate both to neurodegenerative changes within the CNS and also to factors that directly affect the olfactory nerves. The olfactory receptors undergo damage because of repeated infections, viral and others, that occur throughout life. Surprisingly, smell likely declines with age because some of the foramina of the cribriform plate close with age. This presumably reduces the number of olfactory nerve filaments that can reach the olfactory bulb. Why this occurs is not known.

At least 90% of patients with Alzheimer disease demonstrate an abnormal sense of smell if tested, often unrecognized by the patient. Similar findings have been found in patients with Parkinson disease. In fact, the American Academy of Neurology's guidelines for the diagnosis of Parkinson disease conclude that, if a patient with suspected Parkinson disease has normal results on a smell test, the clinician should suspect a Parkinsonian-type disorder other than idiopathic Parkinson disease. The ramifications of the loss of sense of smell with these neurodegenerative diseases are significant. Patients often have a loss of appetite and weight loss related to their decreased sense of smell and taste. Safety is a concern because of the inability to smell smoke or recognize spoiled food.

This chapter discussed the cranial nerve of the most primitive "special sense," smell. The next chapter discusses the cranial nerve of the most advanced special sense, vision.

REFERENCES

Hannu T, Toskala E, Tuomi T, Sainio M (2005) Anosmia in association with occupational use of a waterproof coating chemical. *Occupational Medicine (London)* **55**: 142–4.

Ogle W (1870) Anosmia, or cases illustrating the physiology and pathology of the sense of smell. *Medico-Chirurgical Transactions* **53**: 263–90.

2 The Optic Nerve

Figure 2.1 This painting is by Jacques Blanchard (or Blanchart) (1600–1638), who was a French Baroque painter. It is titled, *Tobias Healing the Blindness of his Father*. The painting depicts the Catholic Bible story of Tobias using fish gallbladder to cure the blindness of his father, which was caused by bird droppings entering his eyes.

ANATOMY/FUNCTION SUMMARY

The ability to see is the most "magical" of our magical senses that are conveyed by the cranial nerves. How photons of light are converted to the stunning visual images of our world is still far from understood. Cranial nerve II, the optic nerve, plays one of the initial critical roles in this process. Figure 2.1 shows the biblical (Catholic) story of Tobias' use of fish gall bladder to cure the blindness of his desperate father. In order for you to see, light rays must reach the retinal cells in your eye. These neurons convert the visual information

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
First Edition. Joel A. Vilensky, Wendy M. Robertson and Carlos A. Suárez-Quian.
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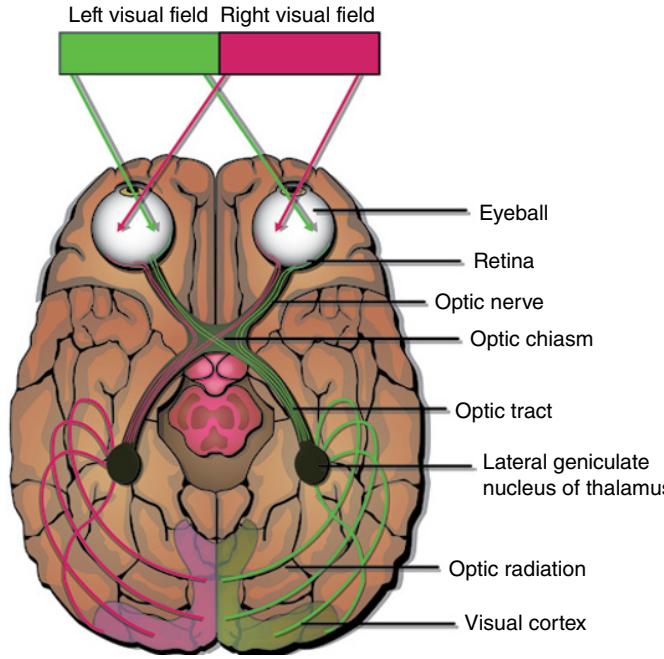

Figure 2.2 Schematic illustration of the optic nerve and visual pathway in the brain. Note that some information from both eyes normally crosses over to the opposite side of the brain. Each eye thus transmits the information it receives to both sides of the brain.

into impulses that pass into cranial nerve II, the optic nerve (Figure. 2.2). This nerve passes out of the orbit of the skull into the cranial cavity, where the two optic nerves cross at the optic chiasm. As shown in Figure 2.2, the crossing of the optic nerve is actually a partial crossing because only fibers carrying visual information from the nasal parts of the retina (the parts closest to the nose) actually cross, so that all of the information from one complete visual field (right or left) goes to the opposite side of the brain. The visual information is then partially processed in the lateral geniculate body of the thalamus before being passed on to the visual cortex in the occipital lobe, where conscious vision resides.

US Army Captain Eugene Blake described a case of blindness due to traumatic evulsion (extraction by force) of the optic nerve in 1918:

> The case occurred in a Russian Jew, aged twenty-nine years, on May 14, 1917. Early in the morning on that date, while driving a baker's wagon, he collided with a milk team. His own wagon was overturned, throwing him to the ground in such a manner that his head struck upon a trolley track, his wagon falling on top of him. He was brought into the New Haven Hospital at 7:30 a.m. the day of the accident.
>
> The patient was thrown from his wagon, falling upon his head in such a way that the force of the blow was directed upward and to the left. This

explains the fracture and separation of the superior maxillary and nasal bones and the extrusion of the left eye from the orbit, as evidenced by the location of the wounds. Evidently the direct line of force was upward and to the left, but enough pressure was disseminated to the right to produce just sufficient protrusion of the right eye to separate the optic nerve from the globe without rupturing the sclera and causing collapse of the eye as occurred on the left side. It is as though one pulled an apple from its stem.

In the course of a few weeks the excavation at the site of the optic nerve-head was filled in with newly-formed connective tissue, the hemorrhages were absorbed, and the circulation restored in several of the vessels in the lower portion of the retina. The patient made a good recovery in all respects, except, of course, his vision, which was nil. His temperature ranged from 97° upon admission to 101°, reaching normal on the twenty-eighth day. He was later transferred to the State Asylum for the Blind. (Blake, 1918)

The author's analogy of the optic nerve as a stem and the eyeball (globe) as an apple is perfect to explain the loss of vision in that eye. In this chapter, the pertinent anatomy of cranial nerve II will be presented along with examples of cases demonstrating how lesions of the respective components of the nerve impact vision.

ANATOMY/FUNCTION

Optical properties of the eye: a diversion

In order for you to see, light must strike the retina and be properly focused, which is dependent on the curvature of the cornea, the turgidity (degree of swelling) of the lens, and the axial length of the eye (Figure 2.3). The light reaching the retina is converted into electrical impulses by the photoreceptors situated at the deepest layer of the retina (Figure 2.4). These receptors are rods and cones. Rods are sensitive to low levels of light whereas cones are responsible for fine detail and color vision. Rods are found throughout the retina except at a region called the fovea (Latin: pit) where only cones are found. The fovea is within the macula or macula lutea (from Latin *macula*, "spot", and *lutea*, yellow) a 5-mm diameter, oval-shaped, highly pigmented yellow area on the retina. From the retina the optic nerve conducts the electrical impulses to the brain, which interprets these impulses so that you can see the world around you.

Light first passes through the cornea of the eye, a clear specialized layer of cells that functions in part by refracting (bending) the light towards the lens. The cornea forms approximately the front 20% of the eyeball and is continuous with the sclera, a white layer that forms the boundary of the eyeball. (Indeed, the expression "don't shoot until you see the whites of their eyes" refers to the fact that guns of the 18th century were only accurate to about

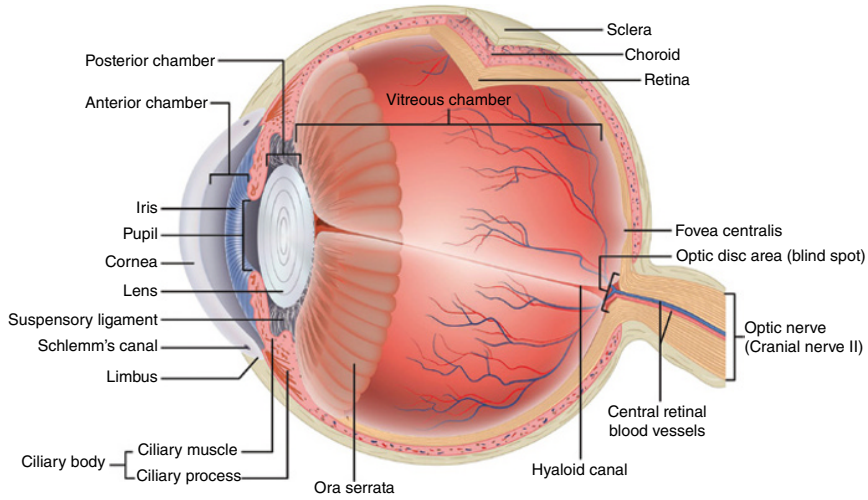

Figure 2.3 Anatomy of the eye. The macula lutea is a yellow depression surrounding the fovea centralis. Modified from an image copyrighted by Dreamstime Images (Used with permission).

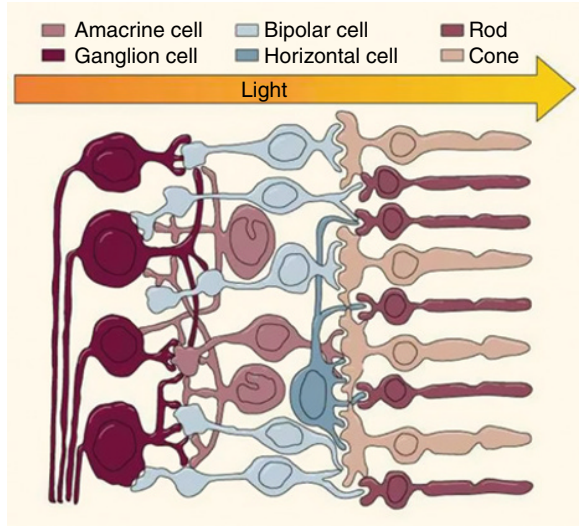

Figure 2.4 The layers of the retina and the formation of the optic nerve. Courtesy of www.EUSEM.com.

50 yards, the distance at which one can just begin to see the sclera.) Just deep to the sclera is the choroid layer where the vessels of the eye run. The walls of these vessels are so thin that physicians can see right through them with an ophthalmoscope and often it is the ophthalmologist who first discerns cholesterol plaque build-up in patients. Light does not need to travel through the choroid layer, but this dark layer does serve to dampen the reflection of incident light within the eye. Also, if this layer is damaged, the apposed retina could detach and impair vision.

If you look closely at Figure 2.3, you will notice that the outer part of the choroid layer is thickened. This part of the choroid layer is called the ciliary process and serves as an attachment point for smooth muscle cells, the ciliary muscles. Together, the ciliary process and muscles make up the ciliary body. From the ciliary body, thin fibers, suspensory ligaments, extend to reach the lens. The ciliary body is under the parasympathetic control of CN III (see Chapter 3) and we use this apparatus to change the shape of the lens when conditions permit us to be relaxed. When we want to read, for example, presumably under conditions in which we are relaxed, that is, not needing to fight or flee, our ciliary body contracts, the suspensory ligaments become loose, and the lens becomes rounder (more turgid), gaining the ability to bend light more acutely to focus on our retina. In contrast, when the ciliary body relaxes, the suspensory fibers tighten and the lens becomes more stretched. Under these conditions, we see distant objects in focus (see Figure 2.14 for the lens accommodation reflex).

The serrated looking transitional zone located between the ciliary body and the true, complex retina is known as the ora serrata. Even if light finds its way to the ora serrata, we lack the appropriate receptors to respond to light in this region.

The ciliary body also continuously secretes aqueous humor (fluid) that is found in the anterior and posterior chambers of the eye. This fluid helps to nourish the cells of the eye. Because the aqueous humor is continuously being produced, it needs to be drained away at a constant rate to maintain normal intraocular pressure. The drainage of the aqueous humor occurs via Schlemm's canal. If the fluid is not drained at the same rate that it is produced, pressure builds up within the eye, which can severely impact the retina. This condition is called glaucoma.

The iris is the colored part of the eye – hence its name. Iris is derived from the name of the Greek goddess of the rainbow. The iris is continuous with the ciliary body and controls the opening of the pupil. The aqueous humor drains through the iris to reach Schlemm's canal. Thus, any disease of the iris could, as a consequence, lead to increased intraocular pressure leading to glaucoma. The iris consists of smooth muscle cells that are regulated by autonomic innervation. When we are startled or frightened, the smooth muscles of the iris will dilate the pupil, a sympathetic response. In contrast, when we are relaxed, the pupils constrict, a phenomena regulated by parasympathetic fibers of CN III. Drugs derived from the belladonna plant dilate the pupils by acting as inhibitors of the neurotransmitters of the parasympathetic fibers. It is also the reason why they were given their name – belladonna means beautiful lady in Latin and dilated pupils were believed to be a mark of beautiful women throughout history. Italian women, for example, were reputed to engage in the dangerous practice of ingesting the belladonna plants to dilate their eyes, a practice that can end in death.

The last region of the eyeball to be mentioned, besides the retina is the vitreous chamber. This chamber is filled with a clear gel known as vitreous humor, which helps maintain intraocular pressure. Unlike the fluid of the

anterior chamber, the vitreous humor is not generally replenished during life. If we bleed into the vitreous humor, for example, the blood will stay in the chamber unless surgically removed. Other obstructions in the chamber will be recognized visually as "floaters." As we age, the vitreous humor can partially liquefy and separate from the retina, impairing vision. If a tear in the retina occurs, the vitreous humor can leak under the retina and cause additional separation of the retina, exacerbating the partially detached retina.

At this point, we can go back and follow the path of light as it reaches the retina. The impulses from the rods and cones pass through intermediate layers of cells in the retina and then ganglion cells that are located adjacent to the vitreous chamber (Figures 2.3 and 2.4). The axons from the ganglion cells converge to form the optic nerve at the optic disc (Figure 2.3), which is actually a blind spot in the visual field because there are no light receptors there. Normally, this blind spot is not apparent to you because your brain "fills in" the missing information.

In addition to carrying fibers that enable you to see, the optic nerve mediates visual reflexes that are often tested as part of a typical neurological exam (see the following text).

General anatomy of the optic nerve

It is likely that a Greek anatomist, Alcmaeon, was the first to study and dissect the optic nerve in the 5th century BC. Subsequently, the Roman physician and father of anatomy, Galen, described the eye and its parts. He considered the optic nerves to be the first pair of cranial nerves and hypothesized that these were the only nerves with "a clear perceptible pore, whence some anatomists have called them canals, not nerves." He assumed that this canal allowed *pneuma* (visual spirits) to convey images from the eye to the brain.

The optic nerve is not really a cranial nerve in the strict sense, but rather a tract of about 1.2 million brain axons that develops from an embryologic structure known as the optic cup. As opposed to peripheral nerves (and most of the other cranial nerves) in which the myelin surrounding axons is produced by Schwann cells, optic nerve myelin is produced by oligodendrocytes, in common with other CNS tracts. This is clinically significant and impacts daily life because the optic nerve resembles other CNS axons in that it lacks the general ability to regenerate after damage, a general property of peripheral nerves.

As shown in Figure 2.5, the optic nerve may be divided into four sections: (a) optic head, (b) orbital part, (c) intracanalicular part (in the optic canal), and (d) cranial part. Importantly, the optic head, although a part of the eyeball, is also a true part of the optic nerve itself and will be discussed further with the three other parts of the nerve.

The central processes (axons) of the ganglion cells of the retina converge in the innermost layer of the retina toward the optic nerve head (Figure 2.4). This is located a little medial to the posterior pole of the eyeball near the fovea (Figure 2.3). At the optic nerve head, the nerve fibers acquire myelin sheaths and are collected into an approximately 4 mm thick cord forming the nerve. Approximately 1 cm behind the eyeball, the central retinal artery and vein enter

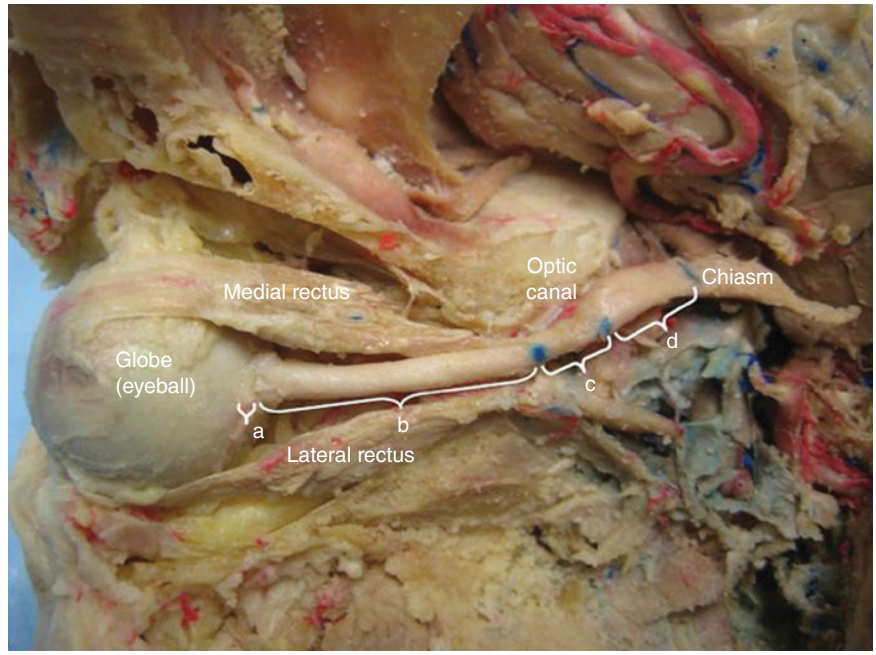

Figure 2.5 Detailed anatomy of the parts of the optic nerve as viewed from above (see text for explanation). Reprinted with permission from Selhorst and Chen (2009).

the nerve and continue to the retina in the central region of the nerve (Figure 2.3). The optic nerve is surrounded by the three meninges and accordingly by the subarachnoid and subdural spaces. The pia mater envelops the nerve.

The second part of the optic nerve (part b) runs from the optic head through the orbit to the optic canal (part c; see also Figure I.22). It exits the optic canal into the middle cranial fossa (part d) and takes a medial direction, fusing with the contralateral nerve to form the optic chiasm (Figure 2.2). From the chiasm, the axons of the optic nerve continue in a posterior (dorsal) direction as the optic tract (Figure 2.2). The optic tract can be traced to the lateral geniculate body of the thalamus. Most of the fibers of the optic nerve (and tract) synapse with cells of the lateral geniculate body. Others bend medially into the superior colliculus and the pretectal region and are responsible for optic reflexes (see the following text). The neurons of the lateral geniculate body send axons that run in the optic radiation to the visual cortex (Figure 2.2).

The following is an Internet case that shows the frustration of a patient born with a hypoplastic (underdeveloped) optic nerve:

> I was born with optic nerve hypoplasia, so I am legally blind and I am male and 22 years old. There is no surgery that has been developed to cure it, and if one did evolve, it would be extremely risky to go through with. In school, it was always difficult to make friends because I was "different" but I was able to focus on my studies and because of this my grades were excellent. I was able to graduate with high honors

and obtained a scholarship so I could go to college – something no one in my family had done. I have never been able to drive a car and never will be able to according to every doctor I have seen. This makes me very dependent on others, which is stressful and frustrating. I am attending a university and have my own apartment, but rely on friends and family to drive me places. I hate that. Because my vision is low, I also find it difficult to use public transportation or ride a bike because I am afraid of getting lost or even getting injured if I can't see something. Crossing the street alone is even a scary task for me and people find this hard to understand because I seem to go through daily life so normally. I am pursuing a bachelor's degree in Social Work and I would love to have a job in human services where I can help others like being a counselor and I know I'm capable of these types of jobs outside of the transportation. I am truly trying to live as normally as possible, but it becomes more and more difficult. My biggest fear now is that once I am finished with college and have thousands of dollars in student loans to pay back, I will not be able to get a job because I cannot drive. However, I will continue pursuing my education and try to accomplish all that I can, but I do feel discouraged at times and do not want these obstacles to jeopardize my future.

The patient's frustration with his vision is clearly apparent.

At the optic chiasm, all of the fibers that arise from the lateral (temporal) halves of the two retinae continue without crossing into the ipsilateral (same side) optic tract (Figure 2.2). Fibers from the medial (nasal) halves of the retinae, however, decussate in the chiasm to the optic tract of the contralateral (opposite) side (Figure 2.2). Thus, all the light that enters the eyes from the left visual field (and therefore impinges on the right halves of both retinae) gives rise to impulses that will be transmitted in the right optic tract and finally to the visual cortex of the right brain (Figure 2.2).

The fibers forming the optic nerve maintain a topographic relationship in the nerve and its projections in the brain as visual field quadrants. These quadrants are divided by an imaginary horizontal line and an imaginary vertical line that pass through the fovea, the region of highest visual acuity of the retina. Thus, any partial lesion of the optic nerve and its projections will affect vision in a particular area of the visual field (the alternative would be to have fibers from each part of the retina randomly distributed in the nerve).

Although the retina is split evenly in terms of giving off optic nerve fibers from its nasal and temporal halves, more fibers cross at the chiasm than do not cross. Although there is no real scientific explanation for this, William Gowers in his 1866 textbook, *A Manual of Diseases of the Nervous System*, explained that the nose "shuts off the rays from the peripheral part of the temporal half of the retina and the power of sight extends but little further than the area habitually stimulated. Hence, while the retinal halves are of equal size, the functional area is smaller on the temporal side and fewer nerve-fibers proceed from it."

CLINICAL ASPECTS

Optic nerve head

As previously mentioned, the optic nerve head is that part of the nerve within the eyeball (part a in Figure 2.5). The axons of more than a million retinal ganglion cells converge to form the optic nerve head and this "crowding" makes it susceptible to disease, especially ischemia (inadequate blood supply).

The anterior surface of the optic nerve head, when viewed with an ophthalmoscope, is called the optic disc (Figures 2.3 and 2.6). It represents the area of the retina where the ophthalmic artery and vein enter and exit, respectively, and is devoid of rods and cones. Thus, this specific area of the retina cannot respond to light and is described as the blind spot. Caucasians have a significantly smaller optic disc size than Blacks, Asians, and Latinos and this smaller disc size may be associated with an increased risk for some disease states (see the following text) probably because large optic discs have less nerve fiber crowding and more overall optic nerve fibers.

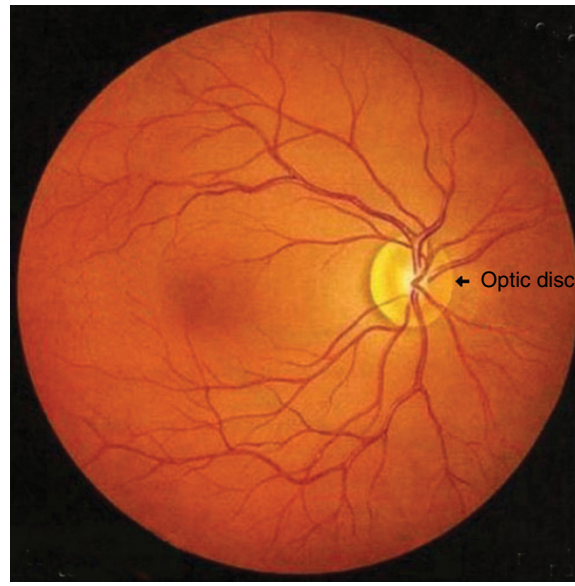

Figure 2.6 Normal optic disc as viewed from an ophthalmoscope. Reprinted with permission from Oliver and Cassidy (2005).

As the retinal cells converge into the nerve at the retina's posterior pole, the nerve thickens as the axons become myelinated. Because the nerve represents an extension of the CNS, it too will be surrounded by meningeal layers. The tough dura mater is continuous with the sclera of the eyeball, and deep to it will be the arachnoid mater, followed by the pia mater. Between the arachnoid and pia maters will be the cerebrospinal fluid (CSF). Delicate septae penetrate the nerve from the pia, separating it into 300–400 fascicles and allowing pial blood vessels to nourish the axons within the nerve. The presence of the

CSF in the nerve serves a protective and nutritional function for the nerve cells, as it does in other parts of the CNS. Unfortunately, when the normal balance of the CSF within the CNS goes amiss, it may cause disastrous effects to the retina.

Papilledema

Papilledema is a swelling of the optic disc (usually bilateral; Figures 2.7 and 2.8) resulting from increased intracranial pressure. Usually, the patient complains of a headache. Vision dysfunction can range from blurry vision to blindness. The increased CSF pressure within the space surrounding the optic nerve (orbital part) compresses the nerve and thereby prevents venous outflow from the central vein of the retina within the nerve (Figures 2.2 and 2.8) while the higher pressured arterial blood continues to flow through the central artery (so there is continuous inflow with little outflow from the eye). The pressure increase may be associated with an intracranial mass, arteriovenous malformation, large infarction (area of dead tissue) with brain swelling, venous thrombosis, cancer, and many other conditions that either obstruct CSF flow or block its absorption. Treatment is directed at reducing the cause of the increased pressure. If this can be done prior to severe visual loss, most of the visual defects are reversible.

In 1929, US Navy physician Dr. A.H. Cecha published a description of a fatal case of papilledema ("choked disc") in a Marine Corps sergeant.

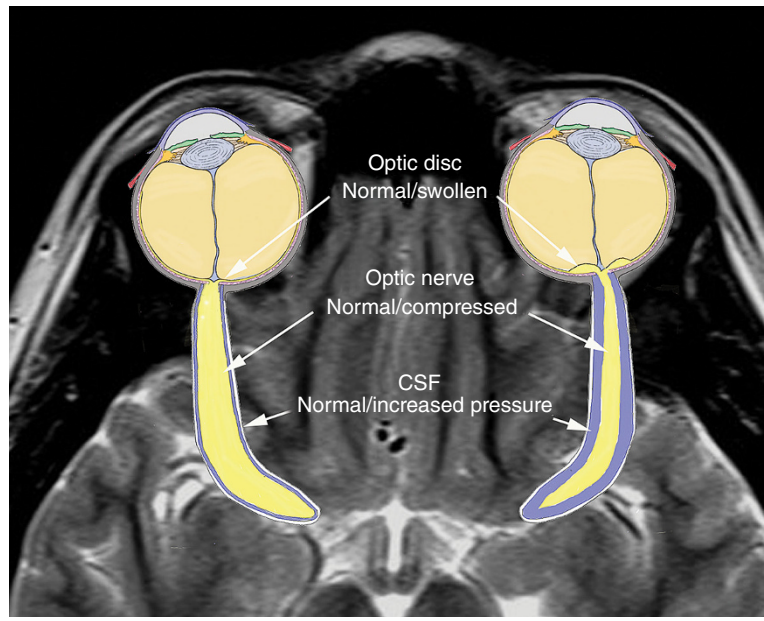

Figure 2.7 Illustration of the mechanism underlying papilledema. Increased CSF pressure compresses the optic nerve and caused a swollen optic disc, as seen on the right. The drawing is superimposed on an axial MRI of the anterior part of the brain and orbits. The optic nerve is purposely drawn excessively large to demonstrate the condition and is not therefore anatomically correct relative to the MRI. MRI courtesy of Dr. Edward Weber.

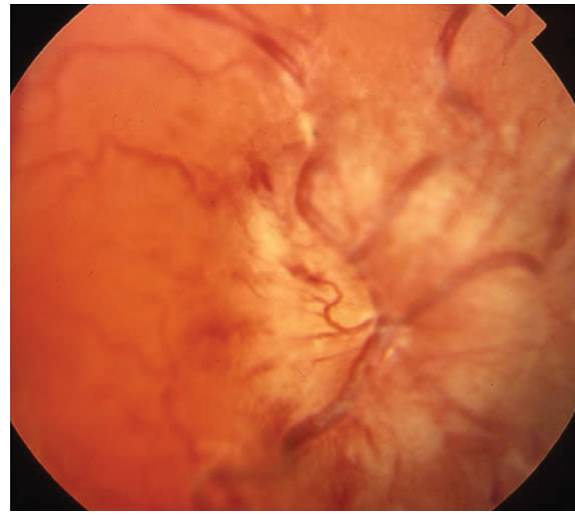

Figure 2.8 Swollen optic disc (papilledema) as seen through an ophthalmoscope. Compare with the normal disc shown in Figure 2.6.

Present history: Chief complaints on admission to hospital were general headache, vertigo, anorexia, malaise, and, in particular, a perverted sense of smell and taste. The patient stated that any odor, even of fresh flowers, was unpleasant to him so that at times he would stagger and almost faint. His food had no taste to it, sweet and sour foods seeming alike. He had no symptoms referable to the respiratory, genitourinary, or cardiovascular system. No evidence of intestinal fermentation.

Ophthalmoscopic examination: Advanced stage of papilledema in each fundus (optic disc), more pronounced in the right eye. The patient subsequently died.

Autopsy: The calvarium was removed and the dura exposed. Upon removal of the brain a soft tumor stained with blood, about the size of a walnut, was found in the right frontal lobe, laterally and 1 inch in front of the central fissure. The pathological specimen was sent to the Naval Medical School, Washington, D.C., where a diagnosis of glioma of the cerebrum was made (Cecha, 1929).

Judy is a more recent case of papilledema from the Internet. Judy was misdiagnosed with intracranial hypertension (pseudotumor cerebri) after months of undiagnosed symptoms and almost became blind due to papilledema. Her MRI showed a blood clot in the back of her brain. Judy noted that her diagnostic opening CSF pressure for her lumbar puncture overflowed the gauge (it was over 50). Judy was treated with a lumboperitoneal shunt to relieve the CSF pressure and was told to take a baby aspirin a day. Her vision recovered but she continues to have headaches.

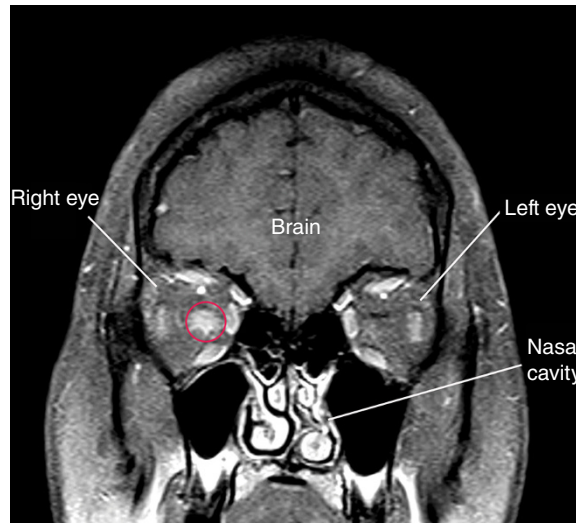

Figure 2.9 Coronal MRI of a 20-year-old patient who showed progressive loss of vision in the right eye over the last several weeks. The patient was eventually diagnosed with MS. The white area within the red circle represents inflammation of the optic disc/nerve. The swollen right optic nerve (circled) is quite obvious compared to the invisibility of the left nerve on the image.

Optic neuritis

Swelling of the optic disc in association with eye pain is usually an inflammatory condition referred to as optic neuritis (Figure 2.9). Optic neuritis may affect one eye or involve both eyes at the same time. The condition may manifest as a subacute loss of vision (over hours to days), a deficiency in color vision (known as dyschromatopsia), an inability to discern visual contrast (Figure 2.10), and eye pain. The symptoms and level of distress vary with each individual and each episode of optic neuritis.

Optic neuritis can sometimes be diagnosed with an MRI of the orbit in which swelling of the orbital part of the nerve is apparent (Figure 2.9). A wide variety of conditions can cause the disorder, although the most common form is referred to as "isolated optic neuritis" or "idiopathic" or "demyelinating" optic neuritis; that is, there is no specific trigger that can be identified and shown to be the cause of the disorder. Often this condition is the first manifestation of multiple sclerosis (MS) (see Figure 2.9), a disease that results in demyelination of nerves in the CNS. Because the optic nerve is part of the CNS, it can be susceptible to demyelination events. In the idiopathic case, the patient is usually female between 25 and 45 years old. Spontaneous visual improvement typically begins within 3 weeks and may continue for a year. Treatment is typically with intravenous steroids. Despite the fact that 80% of patients show some recovery, some continue to complain of impaired contrast sensitivity, decreased color vision, difficulty with perceiving movement, and diminished light intensity.

Figure 2.10 The two halves of the image show how a patient with optic neuritis might see an object (right side) compared to how a normal person sees the same image (left side). The patient sees much less contrast and color than a normal person.

Deborah had idiopathic optic neuritis:

> I had an optic neuritis attack in my left eye exactly one year ago, with an MRI scan showing white matter lesions, though my doctor says diagnosis of MS is inconclusive (until further signs, etc.). I lost my sight in my left eye completely four days after intravenous and oral steroids were finished. I was overseas and couldn't access more steroids for five days. I then went on another course of oral steroids for five weeks, 30 mg down to 5 mg then stopped. My vision returned slowly over the course of the next 12 months.

Many optic neuritis patients, particularly those with MS may find their vision symptoms worsened temporarily with increased body temperature, athletic exertion, or stress. This condition has been called Uhthoff's phenomenon. As exemplified by the following case, optic neuritis and the subsequent atrophy of the optic nerve was an effect of poison gas during World War I.

> E.L., age 23, white, American, a citizen of the United States, enlisted in the Canadian service in August, 1914. He was assigned to the 13th Battalion, Infantry. At his examination for enlistment his vision was normal in the right eye, but reduced in the left.

Our patient landed in France on February 25, 1916, and was sent into the front line trenches on March 2, 1916. At this time his government had not completely equipped all regiments with gas masks. On March 6, 1916, he experienced his first gas attack, the effects of which were transitory and consisted of nausea and vomiting from dizziness, which lasted from ten days to two weeks. He describes the gas as a greenish cloud in both instances.

The second "gassing" occurred on May 22, 1916, at about dusk, at which time it was impossible to see the approach of the gas and take such measures as they could to prevent its full effects. The concentration was probably not great, as the case history shows. The first effects noticeable were irritation of the throat with shortness of breath, not severe. The worst immediate effect was the inability to see clearly. "It seemed like a dense haze was about every object," he says. There was also nausea most of the time with a sensation of floating, shortness of breath, and a smothering sensation which was not constant. During this stage he was taken to the dressing station, where consciousness was lost. This at about 7:30 p.m.

Upon regaining consciousness, he was only able to distinguish light from darkness. This condition lasted about seven weeks, by which time objects had become discernible, and in another three weeks vision in the right eye had improved to about what we find it. The left eye failed to improve beyond the ability to discern objects. In this condition he was returned to Canada, discharged from the service, and returned to his home in the States, only to be picked up by the draft.

Returning to the ocular condition, we find the conjunctiva normal, cornea clear, irises blue, react to light, accommodation and convergence prompt. Ocular movements normal in all directions. Vision, right eye 20/40, left eye, just hand movements at 50 cm. The right eye with a plus 1.75 D sphere gives 20/30 vision. It is not possible to improve the vision of the left eye.

Ocular efforts are followed now by marked distress of the right eye with eyelid spasms and irritation when in bright light.

Ophthalmoscopic examination of the left eye shows marked pigmentation in an area about the whole disc which is very pale, with a shallow physiologic cup. The nerve head is very prominent with an evident striated new tissue formation, indicating marked atropy.

Our case presents evidence of neuritis, and that traceable directly to gas. Whether that neuritis was caused by the effects of the gas upon the vaso-motor system, whether it was due to direct blood changes, or whether it gained entrance thru the naso-pharyngeal area is of less importance than the actual results; which we will have to face if degeneration of the visual apparatus proves a common end result of gas toxemia. (Kershner, 1918)

Anterior ischemic optic neuropathy

As the 1.2 million fibers from the light-sensitive cells of the retina coalesce at the back of the eye, they form the optic head. Because of this crowding and the limited number of small arteries nourishing this region, the blood supply to the optic head is easily compromised. Without nutrients and oxygen supplied in sufficient amounts, a portion of nerve tissue can die. This is referred to as a "stroke of the optic nerve." It is not related to a stroke in any other part of the brain and is not accompanied by weakness, paralysis, or loss of sensation. The condition is technically called "Anterior Ischemic Optic Neuropathy" (AION). AION may affect one or both eyes.

The most common form of AION occurs in patients 40–70 years of age with a mean age of 60 years. Often these people have diabetes. They also often have high blood pressure and a history of smoking. Vision loss typically occurs suddenly upon awakening in the morning and it is this suddenness that makes this condition particularly overwhelming. The frequent occurrence of the disease immediately upon awakening suggests that the decrease in blood pressure that occurs normally during sleep is the immediate cause of the condition although deposition of cholesterol within the small blood vessels supplying the optic disc and, in some cases, other pathological conditions account for the overall reduction in blood supply to the region.

AION is divided into a nonarteritic form (NAION), which is primarily due to noninflammatory disease of these arteries and an inflammatory or arteritic form (AAION). NAION has a higher incidence among Caucasians than among non-whites, possibly because of the relatively small optic disc in the former.

NAION usually manifests in one eye with a decrease in visual acuity and variable visual field loss, and is painless. It may worsen over a few days and then stabilize. Visual acuity may get better after a few years. In rare cases, the condition may recur and there is a 15–20% chance that within 5 years it will be present in the second eye. Bilateral occurrence at the same time is rare.

NAION is primarily diagnosed by the appearance of the optic disc upon ophthalmoscopy and examining arterial-blood-filling around the optic disc. It has been associated with the use of some drugs including erectile dysfunction agents, but no direct causal relationship has been established. Neither medication nor surgical decompression (surgically reducing the pressure on the optic head) has been shown to be consistently effective in treating NAION.

One patient who developed bilateral AION was an Emergency Room physician:

> He first noticed that his vision was abnormal when he accidentally went through a red light while driving. The next morning he noticed that objects seemed much brighter than normal and he made an immediate visit to his ophthalmologist, who saw upon examination that the patient's optic nerves were inflamed. The patient was immediately hospitalized and

given steroids to reduce the inflammation. This resulted in some recovery of normal vision and the patient returned to work but upon awakening the day after his shift in the Emergency Room he could barely see at all and returned to the ophthalmologist.

His optic nerves were found to be very swollen. The ophthalmologist prescribed eye drops containing anti-inflammatory medication (steroids), but the patient's vision became worse. He was again prescribed steroids but nothing improved his vision, which now consisted of seeing only shadows. He was technically about 95% blind in both eyes.

The ER doctor can no longer work. His life as a physician is over which, in itself, is devastating to him. In addition, because he is a physician it is especially hard for him to be optimistic about his future because he knows recovery from AION is limited at best.

A different AION patient who worked as a salesman tried surgical treatment:

His symptom was initially a blurry "blind" spot in the lower quadrant of his left visual field. He saw an ophthalmologist but no treatment was offered and when this patient's vision deteriorated to 50% of normal, the ophthalmologist mentioned that a retinal surgeon was doing experimental surgery that could possibly relieve the pressure on his optic nerve by surgically opening the "disc" at the back of the eye. The salesman opted for this surgery because his vision was further deteriorating on a daily basis. The surgeon used a laser to create a small opening in the back of the right eye in an attempt to relieve the pressure on the optic nerve. After the operation the surgeon looked into the patient's eye and told him that the pressure appeared to have been reduced on the nerve head. Immediately after surgery, however, the patient's vision in that eye worsened with cloudiness in his central vision. Two weeks later some of the central vision returned. At three weeks, the salesman's sight began to decline further with a sort of "wrapping around" of the central vision known as tunnel vision. Later he lost almost all of his vision in that eye. Then the patient was told that he had a 12% to 20% chance of the other eye being affected within two years.

After the patient's operation, a study was published showing that surgery for AION not only did not benefit patients, but generally caused the patient's visual acuity to decrease.

Below is a 2012 published case report of bilateral NAION after ingestion of Sildenafil for erectile dysfunction.

A 60 year-old diabetic man took one 50 mg tablet of Sildenafil (Viagra™) in the evening for 2 consecutive days without any effects and he was unable to have intercourse. On the third day he discontinued his diabetic medications, took another 50 mg tablet and engaged in sexual activity. Sixteen hours later he noted sudden decrease of vision in both eyes with a pronounced worsening in the right eye.

Seven days after the onset of symptoms, the patient was hospitalized because of visual difficulties. An ophthalmic exam showed optic disc edema and peripapillary nerve fiber layer hemorrhages in both eyes. Serous macular detachment was present in the right eye whereas peripapillary cotton wool like spots were found in the left eye. No evidence of diabetic retinopathy was noted. Blood pressure was within normal limits during the admission period. A diagnosis of bilateral NAION was made and he was treated for three days with steroids. Two weeks after the last steroid treatment for the optic disc edema, sub-retinal fluid and serous macular detachment resolved in the right eye and optic disc edema improved in the left. Three months later, visual acuity was stable (Tarantini *et al*., 2012).

It is unclear whether the steroids or "mother nature" was responsible for this patient's improvement.

AAION is typically associated with a condition called giant cell arteritis (GCA), formerly known as temporal arteritis. GCA is a vascular inflammation that commonly affects patients over 50 and causes visual loss in 14–20% of cases. The typical history of AAION is progressively severe visual loss with involvement of the contralateral eye within days or weeks, often associated with headache. Emergency intervention with steroids is necessary to try to prevent further visual loss and involvement of the second eye, although improvement of vision is limited. Superficial temporal artery biopsy confirms the diagnosis. The visual loss in AAION can be much more severe than in NAION.

A case of AAION from 2010 is described below:

An 80-year-old Chinese woman presented to the Emergency Department with a 3-week history of visual loss in the left eye. The visual loss was painless, and three days prior to presentation she reported complete loss of light perception in that eye. She did not have an associated headache [this is atypical], or scalp or jaw pain. She also did not have any general symptoms such as fever or loss of weight. Based on these findings a provisional diagnosis of AAION was made. There were no other pathological findings in this right eye. An urgent biopsy of the left superficial temporal artery was performed, which showed a pronounced inflammatory infiltrate in the vessel wall. Scattered giant cells were also noted.

The diagnosis of AAION was thus confirmed. On completion of the biopsy, the patient was started on oral corticosteroid medication. As expected, there was no visual improvement in the affected eye but the second eye did not become involved (Cullen *et al*., 2010).

Nontraumatic conditions affecting posterior part of nerve

At the posterior exit from the optic canal, the two optic nerves are separated by about 13 mm (part d in Figure 2.5). They extend posteriorly, superiorly, and medially to combine at the optic chiasm. The length of this intracranial portion of the nerve varies from 3 to 16 mm and is typically about 10 mm. The exact length is important because of the position of the chiasm relative to the underlying pituitary gland within the sella turcica (Figures I.35 and 2.11). Pituitary tumors arising from the gland can cause vision dysfunction if the tumor impinges on the optic nerve (Figure 2.11), and the exact relationship between the chiasm and the tumor determines the nature of the visual field loss (which is partially dependent on the length of this portion of the nerve). Bitemporal defects (loss of the temporal or outer visual fields) are the most common presenting finding (Figure 2.12).

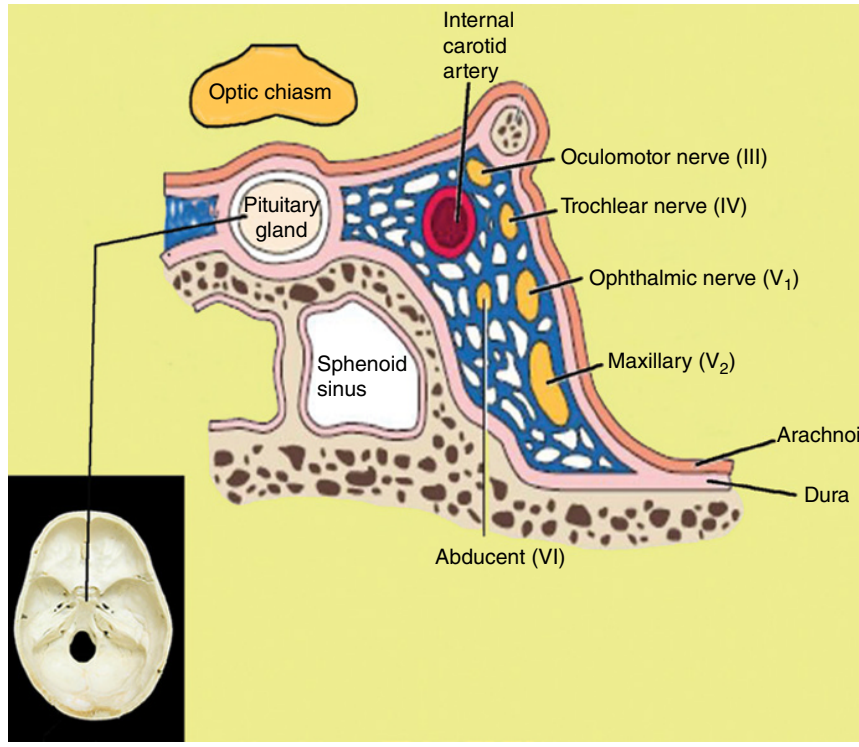

Figure 2.11 Schematic illustration showing where the pituitary gland is located in the sella turcica and in the skull (inset). The image also shows the venous filled spaces, called the *cavernous sinuses*, which are located along the sides of the sella turcica. This important space is discussed in subsequent chapters, especially Chapter 3. See also Figure I.35.

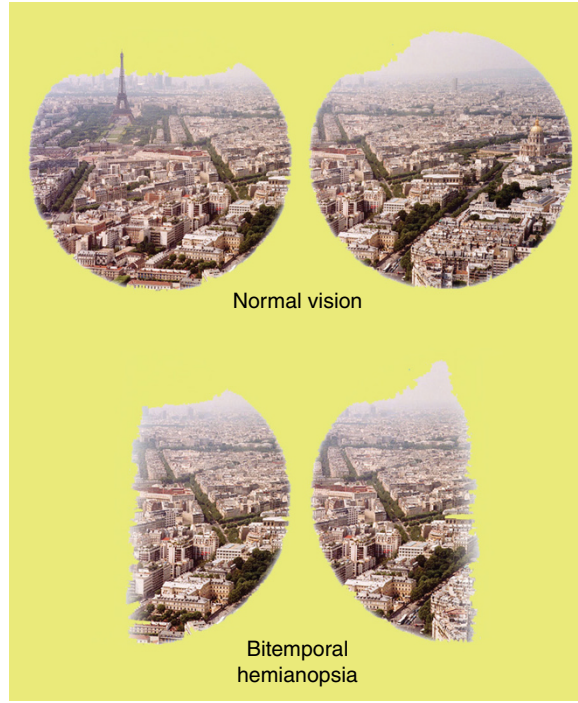

Figure 2.12 Paris views showing normal vision and loss of the temporal visual fields. Courtesy of Wikipedia.

A case of a pituitary tumor causing visual abnormalities published in 2002 is presented below:

> A 57-year old man with elevated blood pressure and high levels of cholesterol presented with sudden-onset blurred vision in his right eye that he described as "a curtain coming up" over his eye. Later he lost all vision in that eye. He also had headache and nausea. MRI showed a mass in the pituitary fossa impinging on the optic nerves and chiasm. He was immediately operated upon the next day. Histologic analysis revealed the existence of a necrotic pituitary adenoma with hemorrhage that was impinging on his optic chiasm. Upon discharge the patient still had a left visual field defect that was slowly improving (Rogg *et al*., 2002).

Pituitary gland tumors can also exert sufficient pressure to cause total blindness, in some cases, acutely, as shown by the case of Kevin Garwood as published in the *Daily Mirror* on March 2, 2012.

> One night in February 2000 I went to bed with a terrible headache. When I woke up the next day, I was blind. At first I was really confused and asked my wife to put the lights on. Then I was rushed to hospital, where I remember having scans that sounded like being in a washing machine.

My pituitary gland had been destroyed by a tumor that had grown and crushed my optic nerve. I had an operation within a few hours. I was frightened, but hoped it would mean I could see again. What I realized after the operation was that it had saved my life but my sight was gone. I had no warning. I couldn't say – "if only I'd done this, or a doctor had done that". There is no-one to blame. I wasn't bitter, I tried to focus on things I had to relearn. Just months before I'd been to Ireland, Switzerland and the USA, and there I was, if you put me across the road I couldn't find my front door. I had to give up my job, and my passions – motorbikes and photography. Friends and family were really important. Some were brilliant, but others couldn't cope, didn't know what to say. I went on a nine-week Royal National Institute of Blind People rehabilitation course. That made a big difference and I got to meet others who had lost their sight. But I'm still adjusting and that will never stop.

Adjacent to the intracranial part of the optic nerve are the anterior cerebral and anterior communicating arteries (Figure I.16). The nerve is also next to the internal carotid artery where it divides into the anterior cerebral and middle cerebral arteries, to the first part of the posterior cerebral artery and to the ophthalmic artery. These anatomic associations increase the possibility of pressure on the optic nerve from aneurysms (a weakening of the walls of the artery that causes them to balloon out and put pressure on neighboring structures) of these arteries. These aneurysms can cause slow but increasing loss of visual acuity.

A severe case of an internal carotid artery aneurysm at its junction with the ophthalmic artery was published in 2003.

A 48-year-old man was examined three weeks after onset of severe headache and neck stiffness. He exhibited a reduced visual acuity on the right. An MRI scan demonstrated a 1-cm cerebral aneurysm arising from the wall of the right internal carotid artery. The aneurysm appeared to be splitting the right optic nerve into two unequal bundles. The patient underwent surgery for aneurysm clipping. At three months postoperative he still had a visual field defect and reduced visual acuity but it had not progressed since surgery (Jea, Baskaya, and Morcos, 2003).

There are rare primary tumors that directly affect the optic nerve. The most common is an optic glioma. They are usually unilateral and present with decreased visual acuity and abnormality of the optic nerve head. Infiltrative tumors may also penetrate the nerve (e.g., metastatic carcinoma) causing visual abnormalities. Although rare, inflammatory/infectious conditions, such as sarcoidosis, and parasites, viruses, and fungi, can also cause optic nerve dysfunction.

Trauma

Optic nerve damage from trauma can cause vision loss. Head injury from falls or automobile accidents can cause indirect trauma. This most often occurs with a blow above the eye that is severe enough to cause loss of consciousness. The patient may awaken with loss of sight in the eye ipsilateral to the blow.

Direct optic nerve injury can occur with penetrating injury from foreign objects or orbital or facial fractures. Several types of direct injury are recognized, including optic nerve transection, avulsion, bleeding into the sheath covering the optic nerve or into the orbit, or air in the orbit (orbital emphysema).

In avulsion of the optic nerve, the axons rupture away from the retinal cells but the surrounding meninges remain intact, which is probably what occurred in the case from 1917 at the beginning of this chapter and in the case below that was published in 1989. The exact mechanism that causes this is not clear but it may result from extreme rotation of the globe. Vision loss is immediate and permanent.

A 76-year-old carpenter was struck on the nose side of his orbit by a drill head traveling at high velocity. He instantly lost vision in this left eye. Examination of the eye revealed a dark pit at the optic disc. CT of the orbit revealed that the optic nerve sheath was not ruptured. Examination of the eye four months after trauma showed a massive proliferation of fibrous tissue at the site of the optic disc (de Vries-Knoppert, 1989).

The third part of the optic nerve, the intracanicular part, is much more likely to be damaged from indirect trauma than the orbital part because the orbital part is long and not confined and because the fusion of the dura of the optic nerve with the lining (periosteum) of the optic canal results in the transmission of traumatic impact forces on to this portion of the optic nerve (thus an indirect injury). Contusion of the nerve axons leads to ischemia (compromised blood flow) and edema (swelling) as probably was the situation in the case of the 45-year-old woman described below:

At the scene of the rear-end collision the 45-year-old woman was awake but complained of back pain. On day two following the trauma the patient complained of blurred vision and a right lower quadrant visual field loss was found. MRI showed isolated unilateral edema of the right optic nerve. No fractures were noted. The patient responded to high-dose corticosteriods and recovered completely (Maegele, 2008).

If corticosteroids are ineffective in relieving nerve compression in the optic canal, a patient could be treated by surgical decompression of this portion of the optic nerve. However, studies have failed to

show any benefit to surgical decompression after the administration of corticosteroids.

Optic reflexes

Visual impulses elicit reflexes in addition to providing vision. Light impulses entering the brain in the optic nerve elicit reflexes that involve the smooth muscles within the eye, resulting in changes in the size of the pupil and the lens (focus). The precise pathways of these reflexes are shown in the block diagrams presented in Figures 2.13 and 2.14.

The *light reflex* (Figure 2.13), constriction of the pupil when light enters the eye, is mediated by a reflex arc in which light shone in the eye results in stimulation of the Edinger–Westphal nucleus (see Chapter 3). Preganglion parasympathetic fibers from this nucleus travel in the oculomotor nerve (Chapter 3) and synapse in the ciliary ganglia (see Figure 3.7). These fibers in turn stimulate the pupillary sphincter muscles of *both* eyes to cause constriction of the pupils.

The *accommodation reflex* (Figure 2.14) is the adaption of the eyes for looking at objects that are close to the eye, as when reading a book. The afferent link (the incoming information) is formed by the optic pathways to the cortex and the efferent link (the nerve impulse that will activate the appropriate muscles) is via the oculomotor nerve (CN III), and again involves the parasympathetic fibers. This reflex is also bilateral.

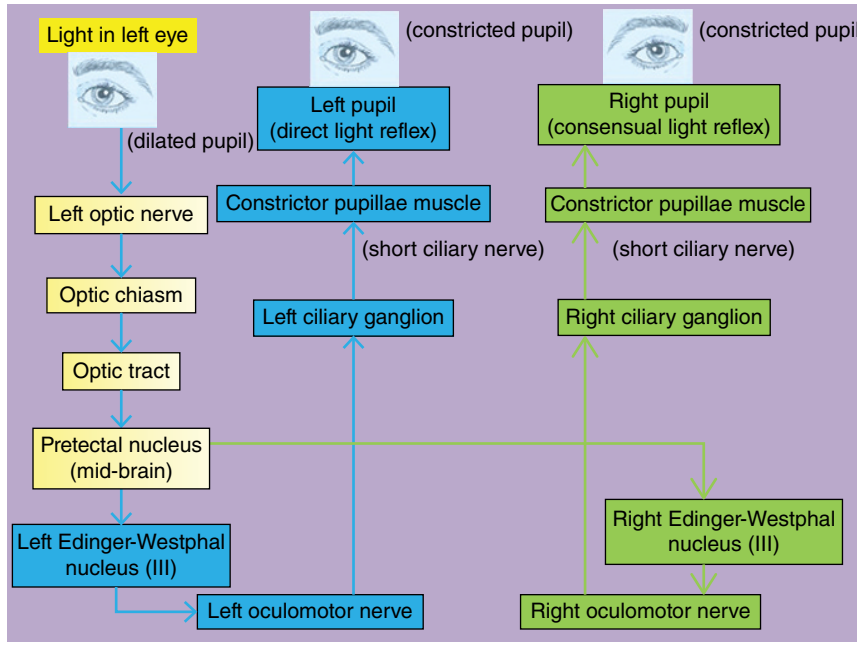

Figure 2.13 The light reflex. A light shone into either eye results in bilateral pupillary constriction.

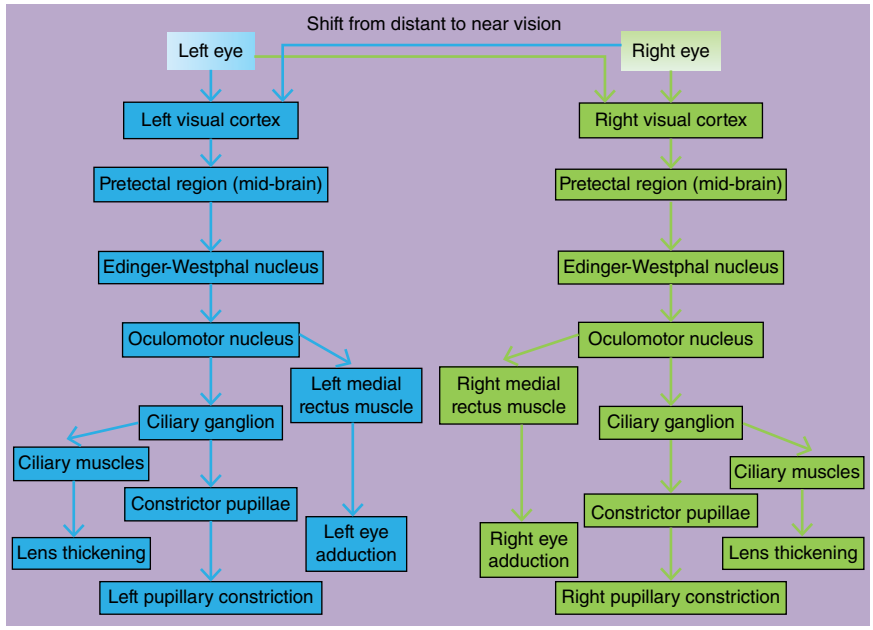

Figure 2.14 The accommodation reflex. Focusing on a near object results in pupillary constriction, movement of the eyes toward the nose (adduction), and thickening (swelling) of the lens of both eyes.

Clinical testing and analysis

The optic nerve is examined by testing visual acuity and the visual fields. In this examination, it is important to determine not only the extent of the visual fields in all directions but also for the clinician to ascertain whether there are "blind spots" within the visual fields. An important supplementary examination is ophthalmoscopy, which gives information on the appearance of the interior of the eye (hemorrhages, exudates (deposits from leaking blood vessels), choked discs, papilledema, and other pathological changes). Evaluating the light reflex may also provide other important information (see the following text).

An interruption of one optic nerve will result in complete blindness of the corresponding eye. The light reflex, when tested by illumination of the blind eye, will be absent in both eyes, while it can be elicited in both eyes if a light is shone into the good eye, provided that the efferent link in the reflex arc (the visceral efferent fibers in the oculomotor nerve) is intact.

Lesions from the optic chiasm to the occipital cortex can be localized based on examination of the visual fields. Loss of peripheral vision bilaterally (bitemporal hemianopsia) is caused by a lesion at the optic chiasm (see the case below). Lesions in the optic tract, optic radiation, or occipital cortex on one side of the brain cause visual defects in the contralateral visual field in both eyes (hemianopsia).

Below is a 1940 published case of trauma causing bitemporal hemianopsia (Figure 2.12) in which the authors were able to determine the site of the lesion based on this symptom:

A man aged 37 entered the Mayo Clinic on Oct. 31, 1939 complaining of limited fields of vision and of nonunion of a fracture of the left hip. He related that on March 14, 1938, while driving an automobile he had had a head-on collision with a truck. After this accident he had been unconscious for two weeks. On regaining consciousness he noted diplopia (double vision) and an inability to see in the temporal fields. Within a month the diplopia disappeared, but ever since he had felt as if he were wearing blinders. His physician had told him that he was suffering from a fracture of the skull and a fracture of the left hip.

His pupils reacted promptly on convergence and somewhat sluggishly to light. Ophthalmoscopic examination disclosed a moderate pallor of both optic discs, the left being slightly paler than the right, with a little loss of substance. Perivascular sheathing around the blood vessels at the margin of the optic discs suggested the presence of a previous papilledema. Examination of the visual fields demonstrated complete and absolute bitemporal hemianopsia. The defects in the visual fields indicated an interruption of all the crossing fibers at the optic chiasm (Henderson and Rucker, 1940).

This chapter focused on the nerve of the eye itself. Chapter 3 will teach you about the oculomotor nerve, which controls most of the muscles that move the eye, thus allowing you to move your head but remain focused on a single point in space.

REFERENCES

Blake EM (1918) A case of evulsion of the optic nerve. *Transactions of the American Ophthalmological Society* **16**: 82–6.

Cecha AH (1929) Choked disk; its importance as an aid in diagnosis; with report of two cases. *US Navy Medical Bulletin* **27**: 125–9.

Cullen JF, Chan BM, Wong CF, Chew WC (2010) Giant cell (temporal) arteritis in Singapore: an occult case and the rationale of treatment. *Singapore Medical Journal* **51**: 73–7.

de Vries-Knoppert WA (1989) Evulsion of the optic nerve. *Documenta Ophthalmologia* **72**: 241–5.

Henderson JW, Rucker W (1940) Bitemporal hemianopia of traumatic origin. *Archives Ophthalmology* **24**: 800–2.

Jea A, Baskaya MK, Morcos JJ (2003) Penetration of the optic nerve by an internal carotid artery-ophthalmic artery aneurysm: case report and literature review. *Neurosurgery*, **53**: 996–1002.

Kershner WE (1918) Secondary optic atrophy due to gassing. *American Journal of Ophthalmology* **1**: 168–70.

Maegele M (2008) Reversal of isolated unilateral optic nerve edema with concomitant visual impairment following blunt trauma: a case report. *Journal of Medical Case Reports* **2**: 50.

Oliver J, Cassidy L (2005) *Ophthalmology at a Glance*, Blackwell Science, Malden.

Rogg J, Tung GA, Anderson G, Cortez S (2002) Pituitary apoplexy: early detection with diffusion weighted MR imaging. *AJNR American Journal of Neuroradiology* **23**: 1240–5.

Selhorst, JB, Chen Y (2009) The optic nerve. *Seminars in Neurology* **29**: 29–35.

Tarantini A, Faraoni A, Menchin F, Lanzetta P (2012) Bilateral simultaneous nonarteritic anterior ischemic optic neuropathy after ingestion of sildenafil for erectile dysfunction. *Case Reports in Medicine* **2012**: 1–5.

3 The Oculomotor Nerve

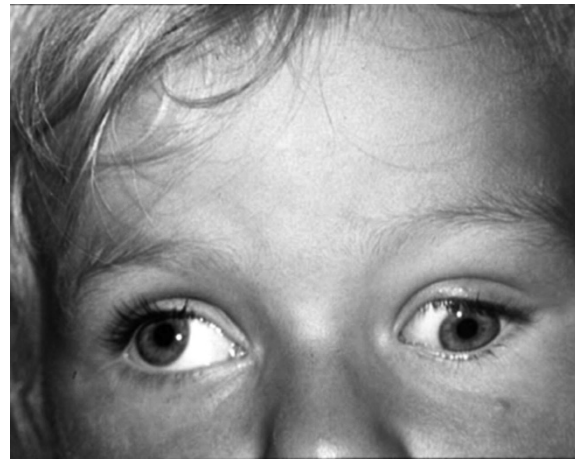

Figure 3.1 Child with congenital absence of left oculomotor nerve trying to look up. Note that the eyelid is more prominent on the left because the oculomotor nerve controls the muscle that raises the eyelid. Reprinted with permission from Langmann and Lindner (2004).

ANATOMY/FUNCTION SUMMARY

There are six "extraocular" muscles that control the position of the eyeball (globe) in the orbit. These muscles allow you to stay visually fixated on an object without moving your head. Of these six muscles, four are controlled by the oculomotor nerve (and there is no pragmatic reason why these four are controlled by one nerve and the other two muscles have their own nerves). The oculomotor nerve emanates from the brain stem, passes through the cavernous sinus, and enters the orbit through the superior orbital fissure (Figures 3.2, 3.3, 3.4, and 3.5; Figure I.34). Figure 3.1 shows the effect of congenital loss of the left oculomotor nerve in a child who is trying to look up.

Dr. James Keane, of the University of Southern California Medical School, said of the clinical aspects of the oculomotor nerve: "Third nerve palsy may be difficult to diagnosis, the causes are often elusive, the prognosis is potentially catastrophic, and the optimal workup is currently in flux." This chapter will show why he felt this way.

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
First Edition. Joel A. Vilensky, Wendy M. Robertson and Carlos A. Suárez-Quian.
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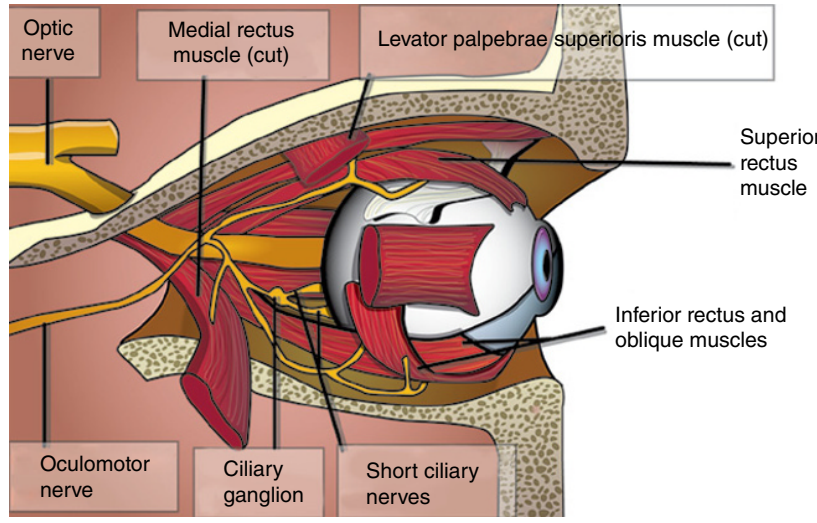

Figure 3.2 Schematic drawing of the oculomotor nerve showing its innervation of four of the extraocular muscles.

Dr. Edwin Cobb of Marshalltown, Iowa, published a description of a complete oculomotor nerve paralysis in 1914 in *The Ophthalmic Record*.

> On August 13, 1913, I was called to the hospital, in consultation by Dr. Chesire to see a patient who had been thrown out of a buggy in a runaway accident. Patient was a woman, age 46 years, and had been unconscious for ten hours. There was a small discoloration over the external and superior margins of the orbit. Patient was now conscious; examination revealed a complete ptosis (inability to raise the eyelid) of right lid, widely dilated pupil, with no reaction to light or accommodation, and diplopia (double vision) was present. The eye appeared prominent with slight bulging. The trochlear and abducent nerves responded ok.
>
> A diagnosis was made of complete paralysis of the oculomotor nerve, probably due to a rupture of a small vessel. Advised complete rest in bed. At the end of two weeks patient was discharged from hospital on strychnine hypodermically (injections) with increasing doses; massage; electrical treatments combined with galvanic and faradic currents. Also a tonic and daily laxative. Cautioned patient about diet and doing any heavy work. At present writing, September 22, there is slight improvement in the ptosis, the other lesions remaining about the same (Cobb, 1914).

You might wonder about the underlying rationale of treating the oculomotor palsy patient with laxatives. Ophthalmologists use this treatment on a regular basis because experience has taught them that the act of straining to empty the bowels may negatively impact recently treated areas of the orbit.

In addition to carrying somatic efferent fibers that innervate four extra-ocular muscles, the oculomotor nerve carries parasympathetic fibers that adjust the

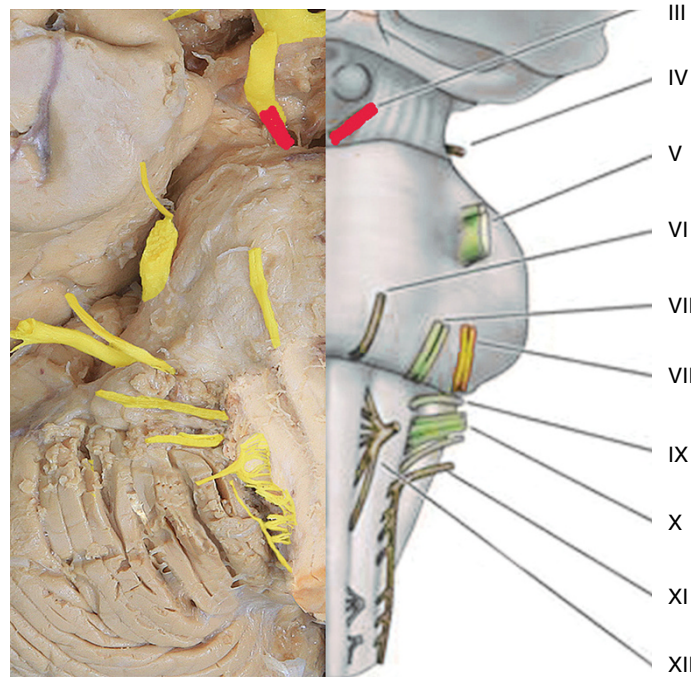

Figure 3.3 Photograph and drawing highlighting the origin of the oculomotor nerve from the brainstem.

size of the pupil in response to the amount of available light and also adjust the focal point of the lens of the eye in response to fixation on near or far objects.

Finally, the oculomotor nerve innervates the levator palpebrae superioris, a muscle that raises your upper eyelid. If this muscle is paralyzed, you can't open your eyelids fully, a condition known as ptosis. Look again at the patient's left eye in Figure 3.1 and note the lowered upper eyelid. People with oculomotor palsy have been described as having "bedroom" eyes because their eyelids can only be incompletely opened.

ANATOMY/FUNCTION

CN III begins in the oculomotor nucleus of the brainstem (Figure I.12), emerges on the ventral side of the midbrain (Figure 3.3) and runs in a rostral (toward the nose) direction. Usually, it leaves the brainstem in the interval between the posterior cerebral artery (above) and the superior cerebellar artery below (Figure 3.4). In this interval, the nerve lies very close to the posterior communicating artery (PCoA) (Figure 3.4) and it can be clearly seen how an aneurysm of this artery and/or the posterior cerebral artery can compress the nerve.

The oculomotor nerve pierces the dura as a smooth, round cord lateral to the posterior clinoid process of the dorsum sellae (Figure I.35) and enters the cavernous sinus (Figure 3.5).

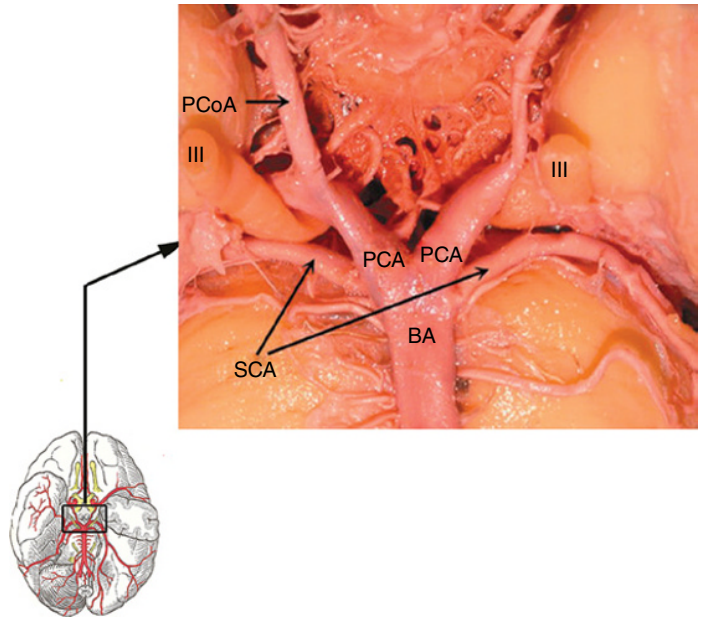

Figure 3.4 Close-up photograph showing the origin of the oculomotor nerve (III) between the superior cerebellar artery (SCA) and posterior cerebral artery (PCA), and adjacent to the posterior communicating artery (PCoA). The basilar artery (BA) is also in the view. The inset shows the location on the brainstem of the larger image. Reprinted with permission from Esmer *et al*. (2011).

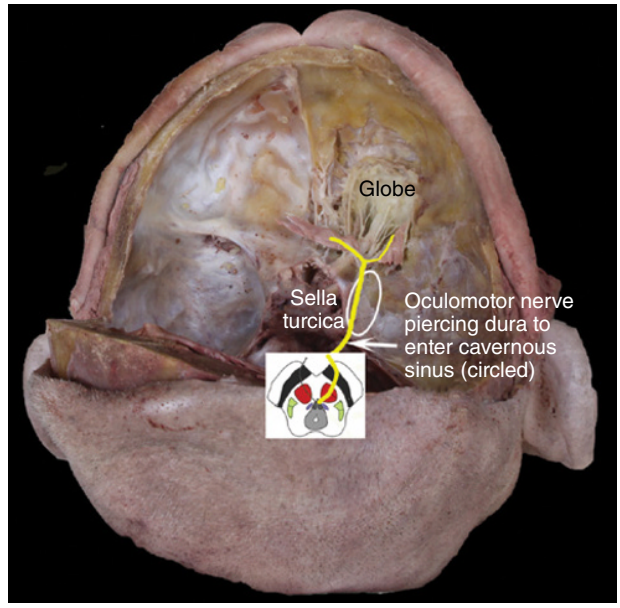

Figure 3.5 The path of the right oculomotor nerve. Illustrative drawings superimposed on a partially dissected head showing the path of the oculomotor nerve from the oculomotor nucleus in the brainstem to the orbit. The right and left nerves pass through two brainstem regions, the red nucleus (colored red) and also the substantia nigra (colored black). Each nerve, upon exiting the brainstem, then enters the subarachnoid space, the cavernous sinus, and, finally, the superior orbital fissure to enter the orbit.

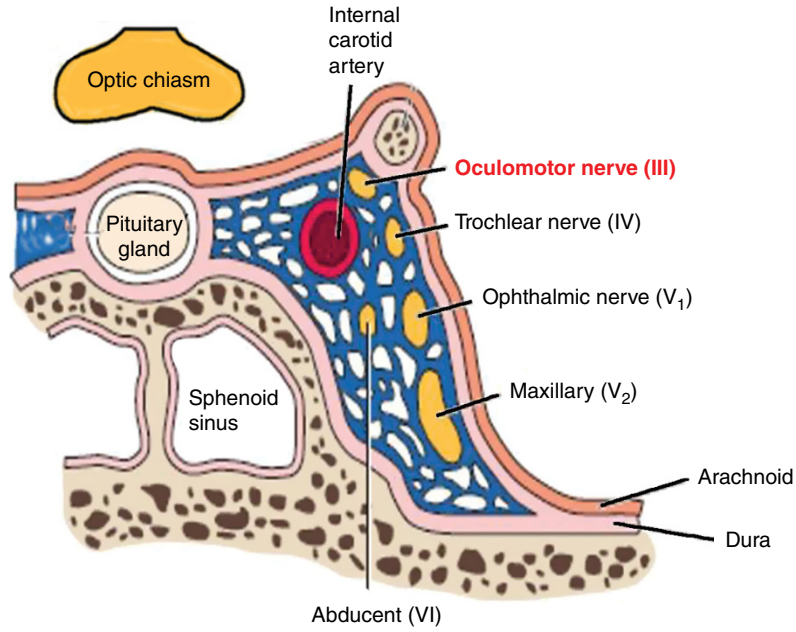

Figure 3.6 Coronal cross-sectional view of the cavernous sinus highlighting the position of the oculomotor nerve vis-à-vis the other cranial nerves and blood vessels located within the sinus.

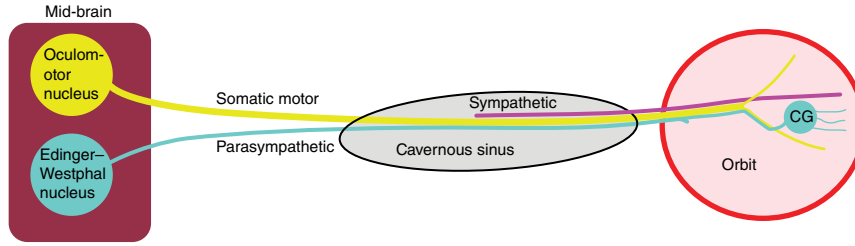

Figure 3.7 Components of the oculomotor nerve. The nerve contains somatic efferent fibers from the oculomotor nucleus in the midbrain. These are joined by preganglionic parasympathetic fibers from the Edinger–Westphal nucleus, also in the midbrain. As the nerve travels through the cavernous sinus it is joined by postganglionic sympathetic fibers. In the orbit the preganglionic parasympathetic fibers reach the ciliary ganglion (CG) where they synapse and then reach the eye via the short ciliary nerves.

The cavernous sinus (Figures 3.5 and 3.6) is a dura-lined, venous-blood-filled space on both sides of the sella turcica (Figure I.35) that contains a meshwork of connective tissue, nerves, and the internal carotid artery. The same Jacobus Winslow who first described the sympathetic nervous system also named the cavernous sinus (see "Introduction chapter"). In 1732, he likened it to the blood spaces within the penis (corpus cavernosa) that when engorged result in the erection of the penis. He wrote, "the internal carotid is bathed in the blood of the sinus together with the IIIrd, IVth, Vth and VIth pairs of nerves."

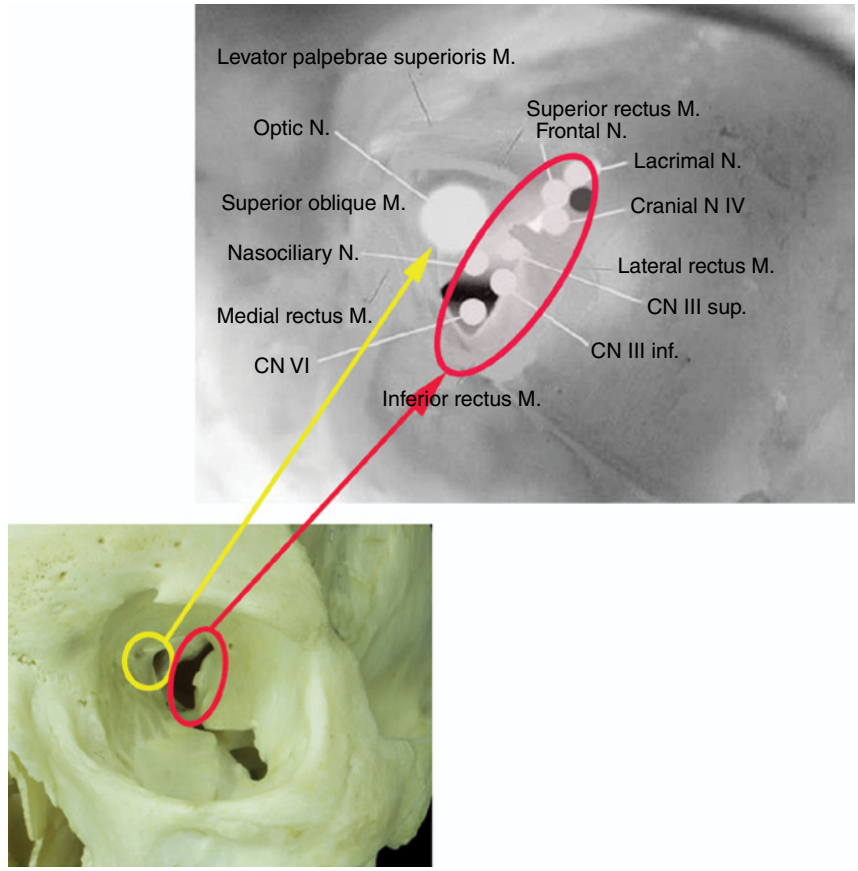

Figure 3.8 The main upper image shows an enhanced radiographic image in which the nerves entering the orbit through the superior orbital fissure and optic canal (optic nerve) are identified. The lower image shows these canals on a frontal view of the bony orbit. Main figure is reprinted with permission from Kelts (2010).

It is within the cavernous sinus that postganglionic, sympathetic fibers that travel to the head along the internal carotid artery are thought to transfer from the artery to many of the nerves running through the sinus, including the oculomotor nerve. The corresponding preganglionic fibers originally exited the spinal cord in the thoracic region and piggy-back on to the internal carotid artery to reach the cavernous sinus. The cavernous sinus can actually be thought of, at least partially, as a blood-filled funnel that directs these cranial nerves into the orbit (Figure 3.7).

The oculomotor nerve then travels from the cavernous sinus through the superior orbital fissure to enter the bony orbit and innervate four of the six extraocular muscles (Figure 3.8).

The extra-ocular muscles: a diversion

Before proceeding to discuss more about CN III, we must take a diversion and discuss the extraocular muscles (Figures 3.2 and 3.9). Every time you change your gaze, both eyes move in an identical manner; this is called conjugate

movement and allows the eyes to remain focused on the same part of the visual field. If this did not occur, your eyes would see different images, resulting in diplopia (double image vision; Figure 3.10). Six small, delicate muscles (Figures 3.2 and 3.9) enable the eyes to move in all directions.

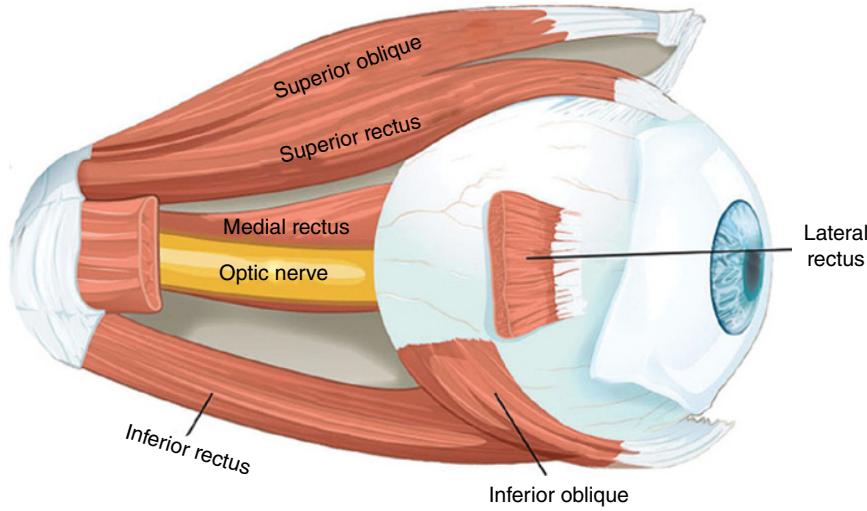

Figure 3.9 The extraocular muscles and their attachments on the eye.

Figure 3.10 Diplopia. Double "exposure" image showing how a person with oculomotor palsy might see a single image.

These muscles can move the eyeball so that the eye can elevate (look up), depress (look down), move toward the nose (adduct), and away from the nose (abduct), as shown in Figure 3.11. In addition the eye can rotate around the front–back axis so that a coin placed on top falls toward the nose (intorsion) or away from the nose (extorsion).

Of the three cranial nerves that control these six muscles, the third, the oculomotor nerve, controls the superior, medial, and inferior recti, the inferior oblique, and also another small muscle called the levator palpebrae superioris, which raises the upper eyelid (Table 3.1). The fourth cranial nerve, the trochlear, controls the superior oblique, and the sixth nerve, the abducent, controls the lateral rectus. And yes, this makes no sense. Why one nerve controls four muscles and the other nerves one muscle each appears to be a design flaw. Also, why mix obliques and recti in the same nerve? Finally, why are the nerves controlling these muscles numbered III, IV, and VI – what happened to V? To some extent, these answers lay in the coordinated evolution of the extraocular muscles and the parts of the brain that control them – starting with fish and moving through amphibians into land vertebrates. If an engineer was to design this system now, the design would undoubtedly be simpler, but unfortunately, especially for countless medical students, evolution works with systems that are already in place, and thus we have a system of nerves that control eye movements that seems counterintuitive. Nevertheless, the system is astonishing in its ability to control eye movements precisely through a large range of movements of the head and body.

Each of the six extraocular muscles rotates the eye around at least one axis (Figures 3.9 and 3.11; Table 3.1), thus allowing you to stay focused on an object in space while it moves or to keep your eyes on a single object while you move your head in any direction. It is this ability to rotate your eyes that allows you to lie down and watch television while the TV image remains upright. However, if you fully rotate your head 180°, as in standing on your head, you exceed the ability of your eyes to rotate around the front–back axis and the

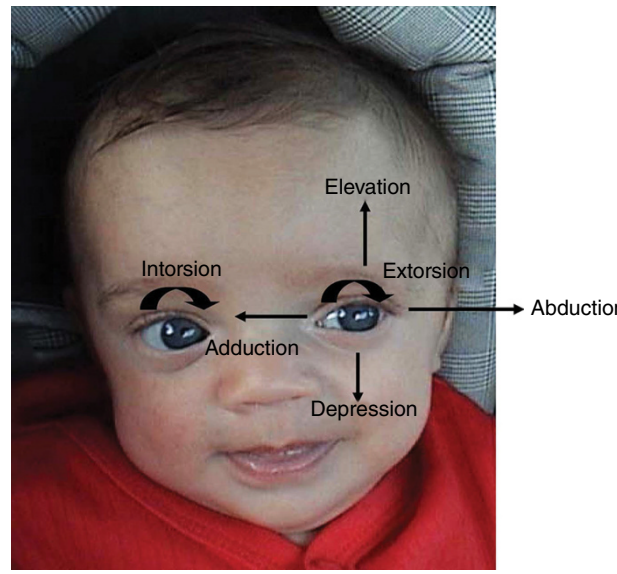

Figure 3.11 Eye movements. Courtesy of Charlie and Aaron Goldberg, M.D., University of California, San Diego School of Medicine.

Table 3.1 The actions of each of the six eye muscles around each axis.

	Main action		
Muscle	**Vertical axis**	**Horizontal axis**	**Anteroposterior axis**
Superior rectus	Elevates	Adducts	Rotates medially (intorsion)
Inferior rectus	Depresses	Adducts	Rotates laterally (extorsion)
Superior oblique	Depresses	Abducts	Rotates medially (intorsion)
Inferior oblique	Elevates	Abducts	Rotates laterally (extorsion)
Medial rectus	N/A	Adducts	N/A
Lateral rectus	N/A	Abducts	N/A

image is then upside down. These eye movements are coordinated by both the visual and vestibular systems.

As noted, in addition to controlling the superior rectus, the inferior rectus, the medial rectus, and the inferior oblique muscles, the oculomotor nerve innervates the muscle that raises the upper eyelid, the levator palpebrae superioris muscle. We use this muscle to voluntarily raise the eyelid. Closing of the eyelid is accomplished by a muscle of facial expression, the orbicularis oculi, which is controlled by another nerve, the facial nerve, and will be discussed in Chapter 7.

Oculomotor nerve anatomy continued

Upon entering the orbit, CN III subdivides into an upper and a lower branch (Figures 3.2, 3.8, and 3.12). The upper branch runs laterally to the optic nerve and the ophthalmic artery and innervates the superior rectus and the levator palpebrae muscles. The lower division gives rise to short branches to the inferior rectus muscle and the medial rectus muscle, and a longer branch to the inferior oblique muscle.

The division of the oculomotor nerve into superior and inferior rami may sometimes occur in the cavernous sinus or posterior orbit, and indeed even as early as when the nerve emerges from the midbrain.

From their origin in the midbrain (Edinger–Westphal nucleus), presynaptic (preganglionic) parasympathetic fibers travel within the oculomotor nerve and these fibers travel with the branch of the nerve to the inferior oblique muscle and then jump off that branch to enter a small ganglion (about 1 mm in diameter and thickness) located in the back of the orbit, called the ciliary ganglion (CG) (see Figures 3.2, 3.7, 3.12, and 3.13). These nerve fibers synapse with postganglionic neurons in the ganglion and travel to the eye directly as nerve filaments, known as short ciliary nerves (Figures 3.2, 3.7, 3.12, and 3.13). It is these nerve filaments that innervate the constrictor pupillary muscle that acts to reduce the size of the pupil and also innervate the ciliary muscles that change the shape of the lens of the eye for near vision (accommodation).

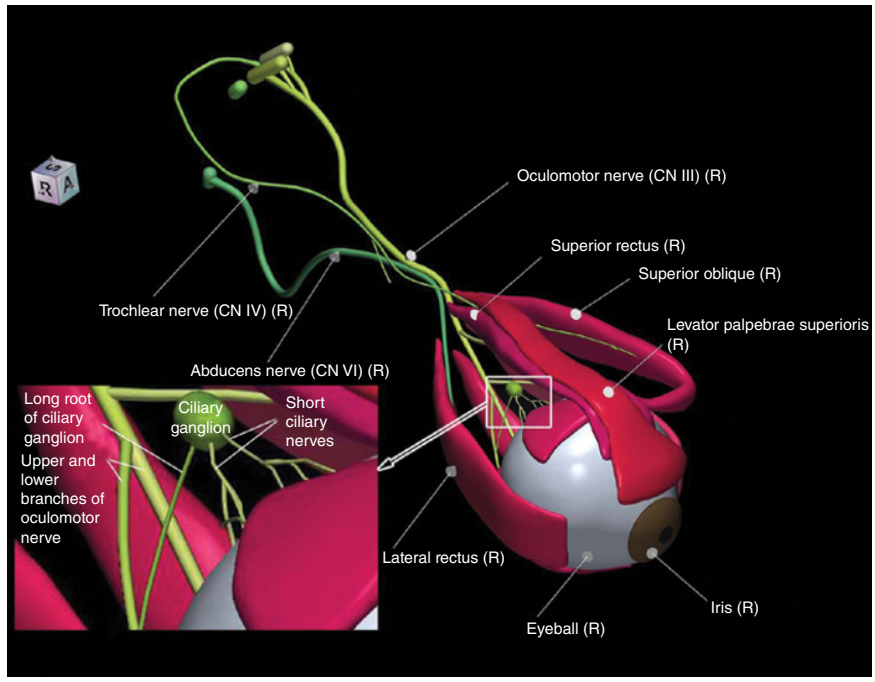

Figure 3.12 Computer-generated illustration of the nerves and muscles of the orbit. The inset is a magnified view showing the ciliary ganglion and related structures. Courtesy of Wieslaw Nowinski, Ph.D., Biomedical Imaging Laboratory, Singapore.

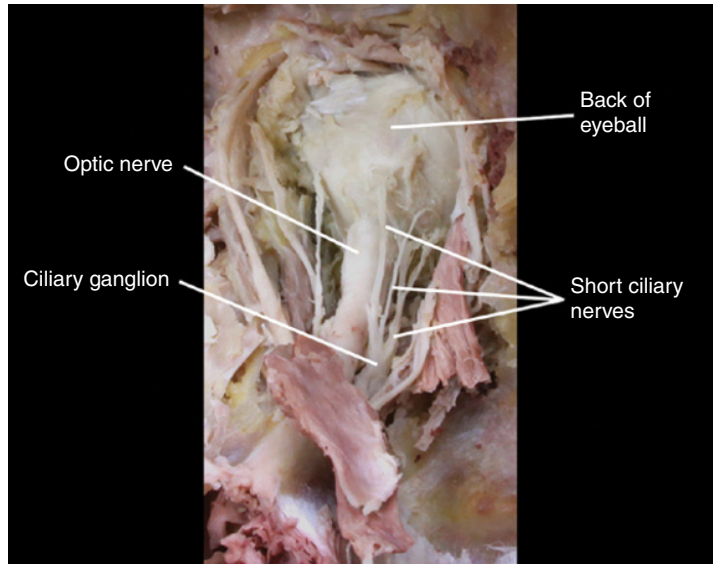

Figure 3.13 Cadaver dissection of the orbit showing the ciliary ganglion and short ciliary nerves.

CLINICAL ASPECTS

Signs and symptoms

The classic picture of oculomotor palsy is a patient whose upper lid hangs down loosely and has to be raised manually in order to see the eye, which is typically in a down-and-out position (Figures 3.1 and 3.14). The "down-and-out" eye position in a patient with complete third nerve palsy occurs because the lateral rectus muscle (innervated by the sixth cranial or abducent nerve) continues to work properly in opposition to the paralyzed medial rectus muscle, pulling the eye outward. The superior oblique muscle (innervated by the fourth cranial or trochlear nerve) functions without any opposing action by the nonfunctioning superior rectus and inferior oblique muscles, causing the eye to be pulled downward. The affected patient will also have drooping of the eyelid (ptosis) and dilation of the pupil (mydriasis).

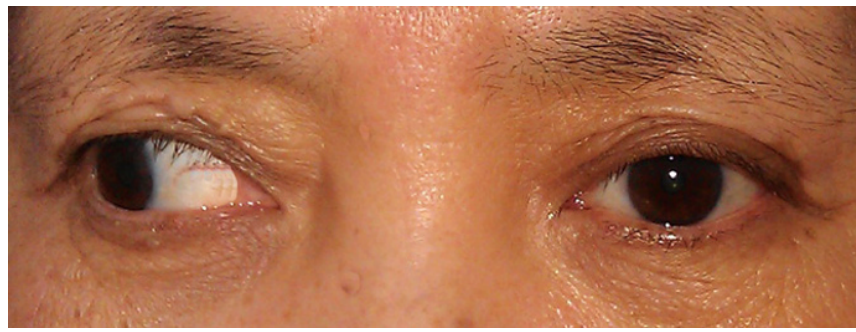

Figure 3.14 Patient with right oculomotor palsy. Note the down-and-out position of the right eye.

Although third nerve palsies occur in isolation (isolated CN III palsy), they are often found in association with other cranial nerve signs and symptoms (nonisolated), especially in association with the other motor nerves to the eye muscles (CN IV and CN VI).

Patients with oculomotor nerve palsy typically complain of diplopia (double vision) and often have headaches. They also often complain of eye pain. The diplopia results because the movements of both eyes are no longer conjugate in all directions – that is, the movements are no longer perfectly synchronized.

Although patients may have complete oculomotor nerve palsy, partial nerve palsies are also seen. The oculomotor nerve has branches that can be damaged at various locations. The mechanism of injury can also result in partial loss of function of the nerve. For example, compression of the oculomotor nerve causes dysfunction of the parasympathetic fibers, which lie on the exterior of the nerve. This results in mydriasis (a "blown" pupil) as an early sign, often before eye movement problems occur. On the other hand, vascular lesions of the nerve affect the interior of the nerve where the somatic motor fibers run and can result in eye movement problems without an enlarged pupil.

Some patients with partial eye muscle paralysis may not be conscious of diplopia and, in cases of congenital oculomotor palsy, children may learn to ignore the

second image and will not complain of diplopia. Thus, clinical testing may be needed to demonstrate eye muscle weakness or diplopia in some patients.

Causes of oculomotor palsy

Diabetes

Diabetes is a disease that is characterized by an excess of blood sugar either due to insufficient production (type I) or inadequate utilization (type II) of insulin. Both are associated with peripheral vascular disease and it is hypothesized that microvascular changes in the tiny arteries that supply the cranial nerves (especially those that supply the extraocular muscles) are responsible for the pareses (muscle weaknesses) commonly seen in diabetic patients. Presumably these changes result in a reduction in blood supply (ischemia) to the nerves. Why the arteries that supply the nerves to the extraocular muscles are particularly vulnerable to diabetic-related ischemia has not been explained.

A 1962 report describing a diabetic case of oculomotor palsy is presented below.

A 47-year-old Negro woman had been an inpatient as well as an outpatient at Marion County General Hospital for many years. Her first neurologic symptom appeared in 1942, when she was age 29; double vision when she looked upward and inward with the right eye suddenly developed. This disappeared in three weeks. In 1951, she had her second episode of double vision, the right eye deviating upward. This, too, disappeared in three weeks. In 1952, she had her third episode and was seen in the Ophthalmology Clinic where it was found that she had weakness of the right superior rectus and inferior oblique muscles. In 1956, the right eye deviated upward and the lid drooped. This lasted four months. In 1957, the right lid drooped and she described her right eye as standing still regardless of the direction in which she tried to look. This lasted two months. Over a three-month period in 1958, she had episodes of drooping of the right lid with immobility of the eye lasting two or three days and recurring at two-to-three week intervals. In January 1959, her left eye was affected for the first time; this consisted of drooping of the lid and inability to move the eye. This lasted about three days and was followed by drooping of the right lid. After two weeks, this disappeared, but ptosis on the left developed again for a few days. In June 1959, for five days, the right eye would not elevate but there was no ptosis. In January 1960, she had left ptosis with diplopia upon vertical deviation. This lasted about two months, then switched to the right side. In September 1960, she had left ptosis and weakness of the left superior rectus, left inferior oblique, and, possibly, left lateral rectus muscles. When seen in the Neurology Clinic a week later, she had no ptosis, but there was weakness of the left inferior rectus and left inferior oblique. Two weeks later, all movements were normal except for weakness of the left superior rectus. The pupils

reacted normally. There were no other neurologic deficits. In November 1960, she showed slight weakness of the left superior rectus and levator palpebrae. At no time did she have any eye pain. She had become rather accustomed to her recurrent ocular palsies and so did not report for examination on every occasion (Ross, 1962).

For this particular case, the patient's diabetes was not established until 1955. The waxing and waning of symptoms in diabetes-related oculomotor palsy can occur and is presumably related to recovery and renewed damage of the vascular supply to the nerve. Often and surprisingly, diabetic patients with oculomotor palsy may have relatively mild forms of diabetes.

Oculomotor palsy may be accompanied by very severe pain in the eye or orbit. This pain is classically ascribed to sensory fibers from the trigeminal nerve (CN V) that join CN III in the cavernous sinus, although there is only limited evidence supporting the existence of these fibers.

Interestingly, the parasympathetic (pupilomotor) fibers of the oculomotor nerve are generally not affected by diabetes-related eye muscle weakness. Thus, the size and reactivity of the ipsilateral pupil are generally considered reliable features that enable a clinician to distinguish between third nerve paresis caused by compression from that caused by microvascular disease associated with diabetes. The pupil is typically large and poorly reactive to light when an aneurysm compresses the nerve, but the sphincter pupillae muscle is usually unaffected by ischemic injury. This is referred to as the "Rule of the Pupil."

Unfortunately, the initial medical management of diabetes-related oculomotor palsy has virtually not changed since the condition was first described in 1866. It consists primarily of "watchful waiting" because there is no direct medical treatment that modifies the course of the disease. Clinicians may offer symptomatic relief of any eye pain and may use "paste-on" prism lenses to improve the disturbing diplopia. However, because the eyelid is often partially closed due to paralysis of the levator palpebrae muscle, diplopia is sometimes not perceived to be a problem. Fortunately, nearly all patients with diabetes-related oculomotor nerve problems undergo spontaneous remission, usually within 6–8 weeks.

Compressive lesions (aneurysms and tumors) and trauma

Oculomotor nucleus lesions can result from a variety of causes including midbrain infarction (loss of blood supply), tumor, vascular malformation, abscess, demyelinating disease (e.g., multiple sclerosis), and inflammatory/infectious disorders (e.g., meningitis). These disorders can produce relatively large lesions that have bilateral effects. For example, the most anterior subnucleus within the oculomotor nuclear complex in the midbrain is a midline structure that provides innervation to the levator palpebrae muscles of the eyelids. Thus, an injury to the oculomotor nuclear complex in the midbrain can cause bilateral ptosis.

Behcet's disease is a chronic, multisystem inflammatory disease that often involves the central nervous system (CNS) including the oculomotor nerve, and is a prime example illustrating how the close proximity of the different components making up the oculomotor nerve run the risk of global damage from a relatively localized lesion. A sample case is presented below:

A 25-year-old woman with Behcet's disease was admitted to the hospital with a history of recurrent oral canker sores, genital ulcerations, left eye ptosis, non-reactivity to light, and left upward and medial gaze palsy. The lesion to the oculomotor nucleus was confirmed using MRI and she was treated with oral steroids. After a year, the lesion was no longer apparent on MRI but the signs of oculomotor nerve palsy continued. The persistence of the palsy despite the disappearance of the lesion on MRI perplexed her physicians (Aydin and Aydin, 2003).

Once external to the midbrain, the third nerve is in the subarachnoid space and is very susceptible to an expanding aneurysm of the posterior communicating artery (PCoA) (Figure 3.4). Because the fibers within the nerve are organized based on the final destination of the fibers, the clinical effects of compression are variable (i.e., depending on where the compression is exerted) but, typically, the pupil is affected (as opposed to an ischemic lesion typically associated with diabetes). Thus, normal pupil responses with complete oculomotor eye muscle palsy usually exclude a diagnosis of PCoA aneurysm. In ruptured (and in some cases of unruptured) aneurysms, the patient presents with throbbing head pain often felt behind the eye and/or above the brow. It may be associated with neck pain and stiffness. The pain may also be intermittent and may be so severe as to be confused with trigeminal neuralgia (Chapter 5). Patients can develop ptosis, paresis of the eye muscles, and mydriasis (pupil dilation). Once the parasympathetic fibers are affected, patients may complain of blurry vision because of the absence of accommodation.

Compression of the oculomotor nerve by an aneurysm of this artery is a neurosurgical emergency and may be treated with surgical clipping or endovascular coiling of the aneurysm. Some recovery of aneurysmal-caused oculomotor palsy is typical unless the nerve has been completely transected by the aneurysm or its repair. The recovery process is usually completed within several weeks. Recovery may also result in aberrant regeneration as discussed below.

Jane is a young adult who had a case of aneurysmal-caused CN III palsy:

It started with severe headaches. Three weeks later my left upper eyelid would not rise. I could still see out of the eye when I forced the lid up. My physicians assumed it was an aneurysm because of the headache although my brain scans were not definitive. Accordingly, I was not an appropriate surgical candidate.

This condition made me feel very self-conscious. I worried how this condition would affect my life. "I know people will always stare and wonder etc. Also I wonder if I can work with computers with the one eye for eight hours a day."

I wondered why I couldn't recover. "It's really bothering me that it's lasting so long."

I am extremely frustrated that I still don't have a driver's license because I don't feel comfortable driving with one eye. "I'm still very clumsy because I have no depth perception. I trip over things, walk into things, knock things over and injure myself more than I used to. It's really annoying. So I don't feel safe driving as much as I want the freedom."

Closed head injury may cause oculomotor nerve palsy due to shearing forces, resulting in nerve fiber damage or avulsion of the nerve roots from the midbrain. This is apparently what happened in the runaway buggy case related at the beginning of the chapter.

A more recent but similar case is exemplified below:

A 55-year-old woman in China in 2002 while riding a motorcycle was struck from behind by a truck and lost consciousness for several minutes. She had abrasion wounds on her left frontal and periorbital regions and complete left eye ptosis with a fixed and dilated pupil. Her left eye could only abduct and move down and in. Skull radiographs and CT, and brain MRI were all normal. Three months after discharge from the hospital her ptosis was partially resolved and there was restoration of ocular adduction. After an additional four months all movements but upwards were normal, but the pupil dilation persisted (Liu, Lee, and Liu, 2004).

Oculomotor nerve lesions within the cavernous sinus typically also involve CN IV, the ophthalmic nerve (branch of trigeminal), and CN VI. Internal carotid artery aneurysms may affect the nerve within the sinus, as can tumors such as metastatic skull lesions from prostate or breast cancer.

In 1869, Dr. James Adams described the case of: *Aneurysm of the internal carotid in the cavernous sinus causing paralysis of the third, fourth, fifth and sixth nerves.*

A 56-year-old sign writer was seen on February 23, 1869. Six weeks prior to being seen he suffered from "giddiness and pain in the head." After these symptoms had persisted for a few days, the patient's right eyelid drooped and he lost motion of the globe. On his exam, his right eye was completely closed and the cornea was hazy and ulcerated. The patient could not move his right eye at all. Furthermore, the surface of the eye was totally insensitive. A month after this examination, the patient died

and Dr. Adams performed an autopsy. He noted that projecting from the patient's right cavernous sinus was a smooth, soft tumor, about the size of a walnut, pushing the dura mater from bone (Adams, 1869).

Cavernous sinus surgery has been called the last "unchartered territory in neurosurgery" because of the complexities of operating in this bloody and highly inaccessible location. Whether patients with cavernous sinus lesions benefit from surgery, however, remains questionable. Lesions in the orbit that affect the oculomotor nerve usually cause other ocular dysfunctions as well as eye bulging (proptosis, exophthalmos). Isolated paresis of those muscles affected solely by either the superior or inferior branch of the nerve has classically been attributed to an orbital process, but because these divisions are present throughout the nerve, a clinically apparent divisional lesion may occur at any location within the nerve. Orbital injuries to the nerve can occur due to infection, trauma, or tumor.

Miss H is a 16-year-old who while resting on the dance floor was stepped on by another dancer who was wearing stiletto heels. The heel penetrated Miss H's right orbit and she was taken to the emergency room complaining of headache and right eye pain (Figure 3.14).

Besides a clearly evident penetrating wound, Miss H showed complete right ptosis and a depressed and adducted eye. Elevation and abduction were absent and there was some slight defect in pupillary responses (Figure 3.15). Her vision per se was intact.

A CT demonstrated that the stiletto had likely penetrated the superior division of the third nerve and also the abducent nerve. Seven months after injury elevation and abduction were still limited and ptosis was still present. The ptosis caused occlusion (closing) of the right eye thus preventing diplopia.

The authors for this case noted that they thought this was the first report of a stiletto heel causing ocular penetration (Cleary, Nischal, and Jones, 2006).

Syphilis

Prior to the development of penicillin in the 1940s, syphilis was a common condition that was treated in some very unusual ways, including the purposeful inducement of malaria in patients because the induced fever raised body temperature to a level that could kill the bacteria causing syphilis. A particularly devastating sequalae to primary syphilis is neurosyphilis, in which patients develop serious neurological conditions such as dementia, gait disturbances, and also visual disturbances thought to be caused by bacterial infection of cranial nerves III, IV, and VI. Although syphilis is no

longer a devastating disease in the Western world, it is still very prevalent in developing countries and has assumed a new virulence in association with HIV. A 2004 case of syphilis-related oculomotor palsy is presented below. Note that this case was responsive to penicillin treatment.

The patient was a 54-year-old right handed homosexual man with a history of syphilis of unknown stage, treated with penicillin 25 years previously. He was well until six weeks prior to evaluation when he sustained minor head trauma in an automobile accident, followed by intermittent headaches, fatigue, photophobia, and anorexia. Four days before admission he developed worsening and persistent drooping of the right eyelid and double vision. The right pupil was round but enlarged at six mm and sluggishly constricted to two mm to light. The right eye showed moderate ptosis of the upper lid, and the globe was deviated laterally in primary gaze with markedly impaired adduction and elevation. In the left eye, ptosis was absent and ocular motility was normal. Other cranial nerve, sensory, motor and reflex functions and gait were normal. MRI of the head showed a spheroid contrast-enhancing lesion at the root of the right oculomotor nerve, which extended towards the cavernous sinus. Venereal Disease Research Laboratory Test (VDRL) was positive. Treatment with intravenous penicillin was administered for two weeks. By treatment day four, the adduction and elevation of the right eye were improving. At one month follow up, mild fatigue persisted. There was trace right ptosis. Elevation and adduction of the right eye had improved to nearly normal, but the pupil remained six mm wide and sluggishly responsive to light. At six months, no additional improvement in oculomotor nerve function was seen but fatigue had subsided. Repeat MRI seven months after hospital admission showed complete resolution of the oculomotor nerve abnormality (Seeley and Venna, 2004).

A late sign of syphilis related to the oculomotor nerve is a condition called the Argyll Robertson pupil, first described by Arygll Robertson in 1869. It was also known as "prostitute's pupil" for obvious reasons. In response, the pupil is small and irregular, does not constrict in reaction to light but does constrict normally to focus on near objects (normal accommodation). This is also known as light–near dissociation of the pupillary response. The exact mechanism that explains this peculiar condition (in which only a specific component of the parasympathetic fibers is affected) remains unexplained.

A benign condition that causes an enlarged (rather than a constricted) pupil that also does not react to light, but that does react to accommodation, is called Adie's pupil. This condition tends to occur in healthy young women. The cause is unknown but is possibly related to a viral infection of the ciliary ganglion.

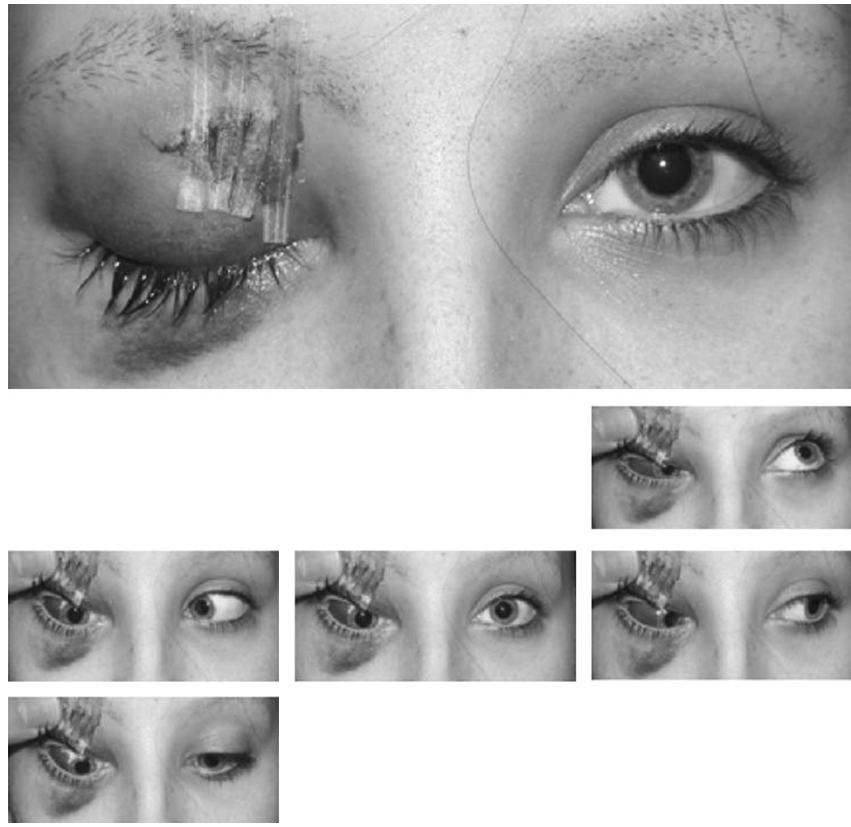

Figure 3.15 Photographs of the woman described in the case trying to look in various directions after having an eye injury caused by penetration by a stiletto heel. Reprinted with permission from Cleary, Nischal, and Jones (2006).

Congenital third nerve palsy

Although congenital oculomotor palsy may occur as a sole neurologic abnormality, it is commonly associated with oculomotor nerve aberrant regeneration (see below), pupillary involvement and other neurological abnormalities such as hemiplegia (weakness on one side of the body).

Aberrant regeneration of third nerve

In 1935, German-born ophthalmologist, Alfred Bielschowsky, stated:

"In the course of healing, some of the nerve fibers which proceed from the central part of the trunk of the third nerve do not find their original sheaths in the peripheral part of the nerve but go astray, so that they arrive at muscles to which they do not belong. For instance, the fibers from the nucleus intended for the internal [medial] rectus arrive not at this muscle

but at the levator of the upper lid, so that the impulse for adduction produces lifting of the upper lid, even if it cannot be lifted by a direct innervation effort because the fibers coming from the levator nucleus have gone astray. In some cases a part of the nerve fibers intended for the levator arrives at this muscle together with fibers of a different origin, so that there is no ptosis but an abnormal retraction of the upper lid as soon as an impulse is sent to certain other eye muscles. It seems that the nerve fibers in the course of healing prefer certain "routes" for growing in the wrong sheaths, so that in the majority of cases the impulse to look down and in produces the strongest contraction of the upper lid levator (Bielschowsky, 1935)."

Aberrant regeneration (also known as synkinesis) of CN III occurs most commonly in severe injuries. Synkinesis is classically associated with rupture of an intracranial aneurysm, commonly of the posterior communicating artery. In addition, it can be seen after the development of brain masses and sometimes after ischemic lesions such as those found in diabetic oculomotor palsy.

Signs of aberrant regeneration of the third nerve include: (1) elevation of the eyelid when moving the eye toward the nose (adduction); (2) elevation and inward movement of the eyelid when looking downward; (3) retraction (pulling back) of the eye with attempts to look up or down, with limited ability to do so; (4) adduction of the eye when trying to look up or down; and (5) constriction of the pupil with eye movement, typically adduction (pseudo-Argyll Robertson pupil).

Whereas aberrant regeneration-associated lid retraction is rarely more than a cosmetic inconvenience, co-contraction of the superior and inferior recti muscles produces permanent limitation of vertical gaze, which can be difficult to correct surgically.

Although typically occurring after the development of CN III palsy, cases of oculomotor synkinesis have developed without any prior palsy. These cases bring into question the concept of misdirection of the injured fibers growing along a disrupted CN III tract. A different theory known as epiphatic neuronal transmission has been suggested in which impulses are theorized to jump directly from one injured axon to another. A third theory is that the synkinetic movements of the oculomotor nerve are movements that are actively inhibited under normal circumstances but become active after injury. Thus, the abnormal clinical findings might simply be a "release phenomenon" in which phylogenetically primitive patterns are uncovered by a lesion.

A case of aberrant regeneration from Turkey is presented below:

A 17-year-old female in Turkey had had severe head trauma at 2-years of age. Currently she shows mild left-sided hemiparesis and right oculomotor palsy. The right eye showed severe ptosis, restricted depression

and elevation. Eye adduction was accompanied by retraction of the upper lid and abduction was accompanied by lid depression. Her right pupil was dilated and nonreactive to light (Atalay *et al.*, 2003).

The treatment options for aberrant regeneration are varied and depend on the unique clinical manifestations and the goals and expectations of each patient. Diplopia may be temporarily treated by patching of the affected eye or by the use of prism lenses.

Surgery may also be done to correct diplopia caused by aberrant regeneration or any condition affecting extraocular muscle dysfunction. The surgical procedures involve moving the attachment of the deficient or normal muscles so that movements as close to normal as possible are restored. By moving the attachments, the surgeon can change the torque exerted by a muscle (weakening or strengthening it) for a given level of neural innervation. Sometimes a compromise choice has to be made by the patients as to whether they are more concerned with cosmetic appearance (so that the eyes appear in a normal position) or whether they wish more attention paid to the correction of diplopia. The surgery may involve operating on the normal eye so that the movements of both eyes appear similar, even if there is more overall disability.

The main problem with such surgical corrections is that despite various algorithms used by surgeons to determine how many millimeters to move a muscle's attachment, the outcome of such procedures is very difficult to accurately predict and there is a moderate possibility of the patient being worse off postoperatively.

Whereas the oculomotor nerve is complex the next cranial nerve, the trochlear, is very simple, only innervating one eye muscle.

REFERENCES

Adams J (1869) Aneurism of internal carotid in the cavernous sinus causing paralysis of the third, fourth, fifth, and sixth nerves. *Lancet* **2**: 768.

Atalay B, Gedek S, Caner H, *et al.* (2003) Aberrant regeneration of the third cranial nerve in a patient with severe head injury. *Turkish Neurosurgery* **13**: 49–52.

Aydin MD, Aydin N (2003) A neuro-Behcet's lesion in oculomotor nerve nucleus. *Acta Neurologica Scandinavica* **108**: 139–41.

Bielschowsky A (1935) Lectures on motor anomalies of the eyes: II. Paralysis of individual eye muscles. *Archives of Ophthalmology* **13**: 33.

Cleary G, Nischal KK, Jones CA (2006) Penetrating orbital trauma by stiletto causing complex cranial neuropathies. *Emergency Medicine Journal* **23**: e28.

Cobb E (1914) Complete paralysis of the oculomotor nerve following injury. *Ophthalmic Record* **23**: 15.

Esmer AF, Tulin S, Comert A, *et al.* (2011) The neurovascular relationships of the oculomotor nerve. *Clinical Anatomy* **24**: 583–9.

Kelts EA (2010) The basic anatomy of the optic nerve and visual system (or, why Thoreau was wrong). *NeuroRehabilitation* **27**: 217–22.

Langmann A, Lindner S (2004) Congenital third nerve palsy in septo-optic dysplasia. *British Journal of Ophthalmology* **88**: 969.

Liu Y-T, Lee Y-C, Liu H-C (2004) Isolated oculomotor nerve palsy due to head injury. *Journal of the Chinese Medical Association* **67**: 149–51.

Ross AT (1962) Recurrent cranial nerve palsies in diabetes mellitus. *Neurology* **12**: 180–5.

Seeley WW, Venna, N (2004) Neurosyphilis presenting with gummatous oculomotor nerve palsy. *Journal of Neurology, Neurosurgery and Psychiatry* **75**: 788–93.

4 The Trochlear Nerve

Figure 4.1 Doll with large eyes showing how the eyes of a patient with left trochlear nerve palsy might appear (note slightly elevated left eye).

ANATOMY/FUNCTION SUMMARY

The IVth cranial nerve, the trochlear nerve, is a very long, slender nerve that serves only to innervate a single extraocular muscle, the superior oblique (Figure 4.2). Its very long intracranial course and its delicacy make it particularly susceptible to injury. The name of the nerve is derived from the fact that the intertendon of the superior oblique muscle traverses through a connective tissue tunnel resembling a pulley. Pulley in Latin is *trochlea*. The trochlea of the superior oblique muscle not only helps to redirect the force of the muscle to allow movement of the eyeball toward the nose, but also provides mechanical advantage to the muscle by acting as a cleat at the point of the intertendon. Without a functioning trochlear nerve, the patient tends to have an eye at rest that is slightly more elevated than it should be (Figure 4.1).

Trochlear nerve palsy produces diplopia, as do oculomotor and abducent nerve palsies, and occurs occasionally in patients with diabetes, as exemplified in the case of Don below, who is a very good friend of the first author of this book:

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
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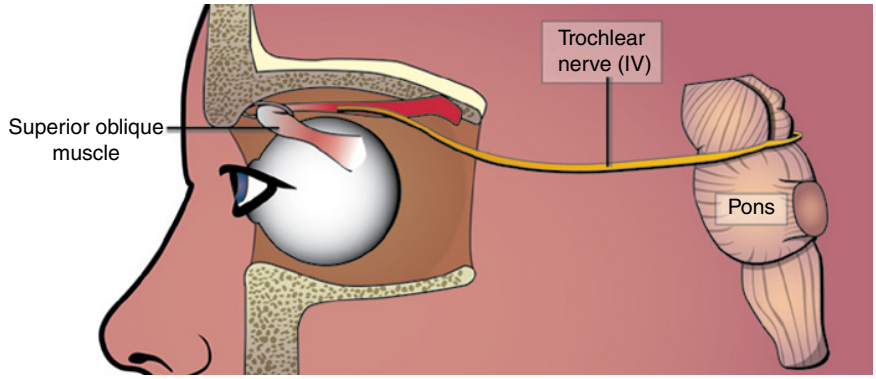

Figure 4.2 The complete path of the trochlear nerve is shown in the drawing. Note that it is the only cranial nerve that originates from the back of the brainstem. Because the examination of the brain is most frequently done from a frontal view, the origin of the trochlear nerve helps explain why this nerve is difficult to discern from standard views of the base of the brain.

Don, a 60-year diabetic, was lying on his side watching TV when the images diverged, but with a little effort, he could realign them. But, every time Don relaxed in that position it happened again. When he sat up, however, the double vision went away. He repeatedly experienced these events over a period of a few months.

Then one day Don was outside watering new plantings around his house. As he looked down, he saw two images of the plant and the watering hose and he felt a bit light-headed. A couple of days later, he experienced the same symptoms. Then he became concerned.

After a series of doctor visits and tests to rule out conditions like tumors and myasthenia gravis, his ophthalmologist made the diagnosis of superior oblique, or IVth nerve, palsy. The standard initial treatment for this condition is to do nothing for six months to a year, because most cases occur without a known cause and a high percentage of them resolve spontaneously (albeit sometimes with aberrant regeneration; see Chapter 3). Don did not find this to be a very reassuring treatment plan.

Don really didn't think much about his vision before his IVth nerve palsy occurred. Now when he descended the stairs at his office, he saw double upon looking down, making it difficult for him to know where he was in space and requiring him to use the handrail to steady himself. This was a new and a frightening experience for him.

Don did not feel safe driving at night so that he became dependent on his wife to drive when they went out in the evening. A big issue for Don was grocery shopping. The varying heights of shelves in the store reproduced his sense of disorientation, making it difficult for him to enjoy and participate in this activity.

His wife had to pour drinks and sign credit card receipts at restaurants. Don felt a loss of his self-reliance and independence that he had prior to this condition.

Don's condition lasted a bit longer than most patients, about a year. Then slowly the diplopia began to resolve and at about 14 months very little remained.

ANATOMY/FUNCTION

The trochlear nerve is a delicate fiber bundle. It consists of only between 1700 and 3400 fibers and has a very slender connection to the brainstem. Furthermore, the nerve has the longest intracranial course of any of the cranial nerves, about 60 mm. Thus, it is very fragile and susceptible to trauma.

When Galen (AD 177–92) first enumerated the cranial nerves, he omitted the trochlear. This probably occurred because it was inadvertently avulsed when Galen removed the brain. Thomas Willis, in 1664, expanded the cranial nerve count and accurately illustrated (with Christopher Wren) and described the fourth nerve, which he referred to as the "pathetic" nerve because, "… the proper office of these is to move the eyes pathetically, according to the force of the passions and instinct of nature." The IVth nerve was known as the "pathetic" nerve throughout the 19th century.

The trochlear nerve is the only cranial nerve that leaves the brainstem from its dorsal surface. The left and right nerves emanate from their respective trochlear nuclei within the midbrain and ultimately end up on the contralateral side from where they began (Figure 4.2). Because the left and right nerves are very close together at the point of decussation, a single lesion can impair both nerves. From their respective brainstem exits, each nerve then winds laterally around the pons (Figures 4.2 and 4.3), continues in a forward direction, and penetrates the dura mater a little above the Vth (trigeminal) nerve to enter the cavernous sinus (Figure 4.4).

Once the nerve enters the cavernous sinus (Figures 4.4 and 4.5), it runs in a ventral direction above the abducent nerve and along the upper border of the ophthalmic branch of the trigeminal nerve, to which it is attached by connective tissue. It enters the orbit by passing through the superior orbital fissure above the origin of the levator palpebrae muscle and continues in a ventral and medial direction to innervate the superior oblique muscle (Figures 3.9 and 4.6). Some sympathetic fibers join the trochlear nerve in the cavernous sinus, and it is likely that some proprioceptive/general sensory fibers from CN V also join it.

Because the trochlear nerve is so thin, imaging it using MRI has been nearly impossible. Thus, pathology resulting from CN IV lesions was more frequently assumed rather than demonstrated. In 2010, however, Dr. J.H. Kim and his colleagues at the Seoul National University showed that using special MR techniques and a very powerful MR magnet, the nerve could be consistently visualized (Figure 4.7).

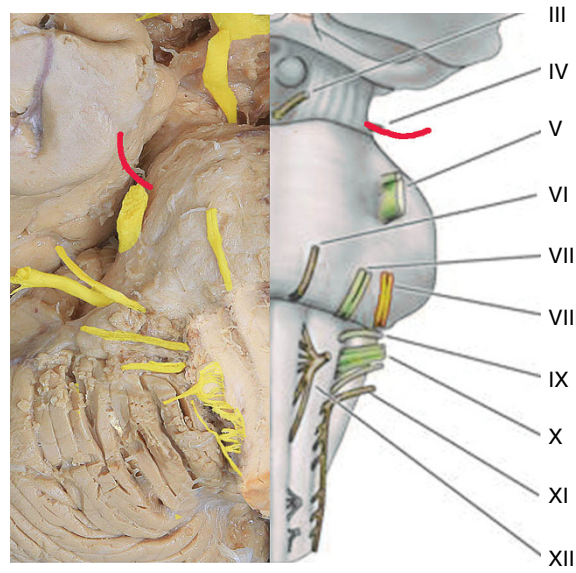

Figure 4.3 Brainstem photograph and drawing highlighting the origin of the trochlear nerve. There is some asymmetry between the idealized drawing on the right and the photograph on the left.

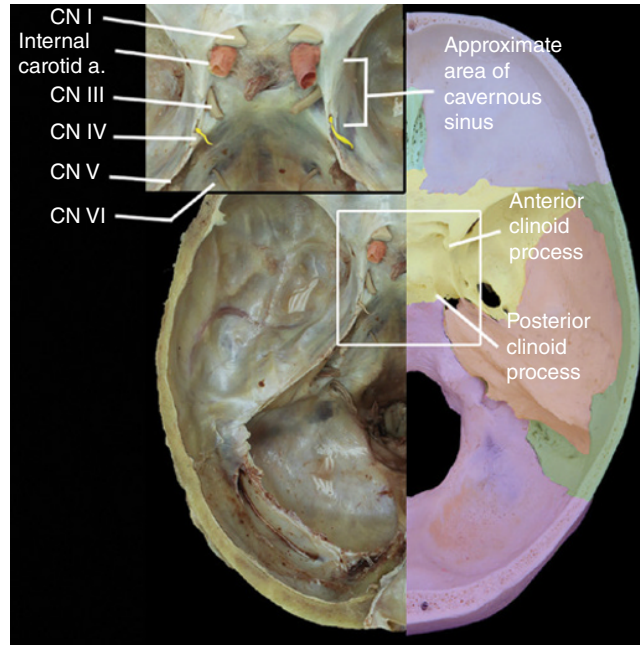

Figure 4.4 Cadaver-based photograph of the skull base and an inset showing a magnified view of a highlighted trochlear nerve piercing the dura and entering the cavernous sinus.

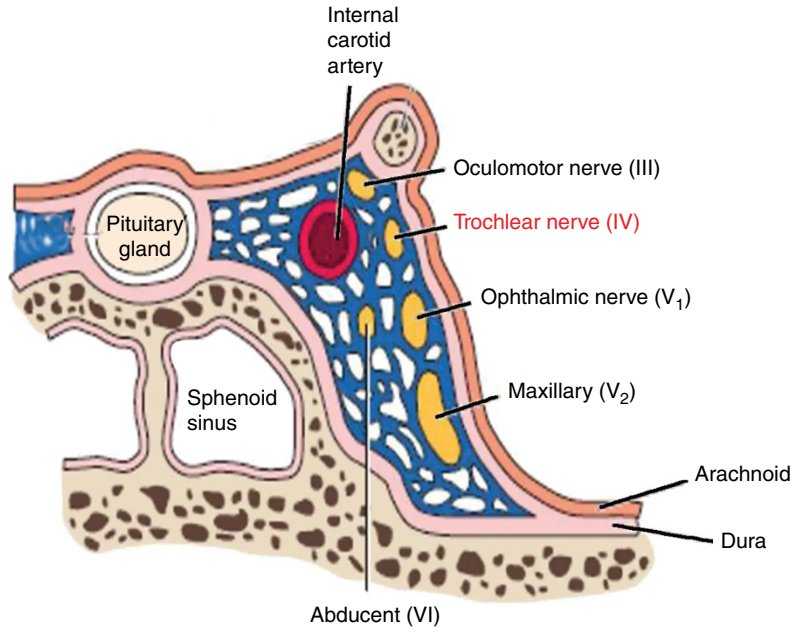

Figure 4.5 Coronal cross-sectional view of the cavernous sinus highlighting the position of the trochlear nerve vis-à-vis the other cranial nerves and blood vessels located within the sinus.

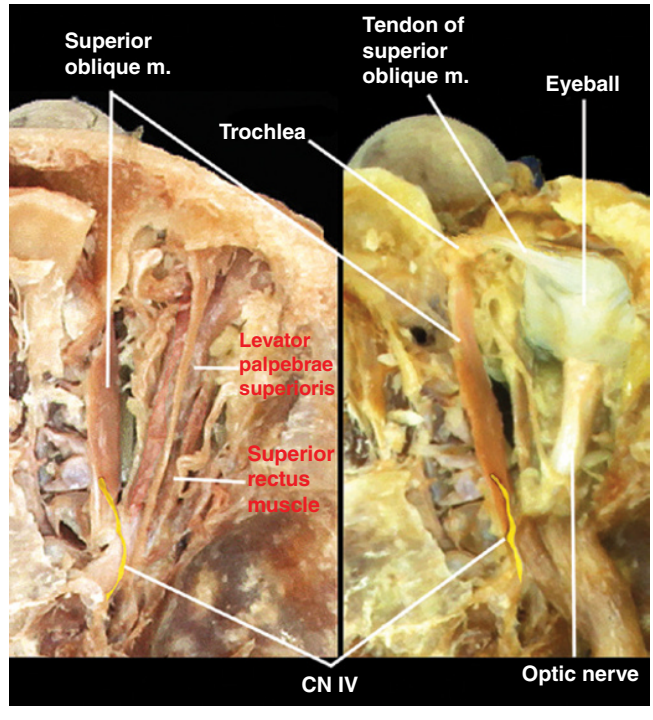

Figure 4.6 A superficial (left) and deep dissection of the orbit (from above) highlighting the position of the trochlear nerve and superior oblique muscle.

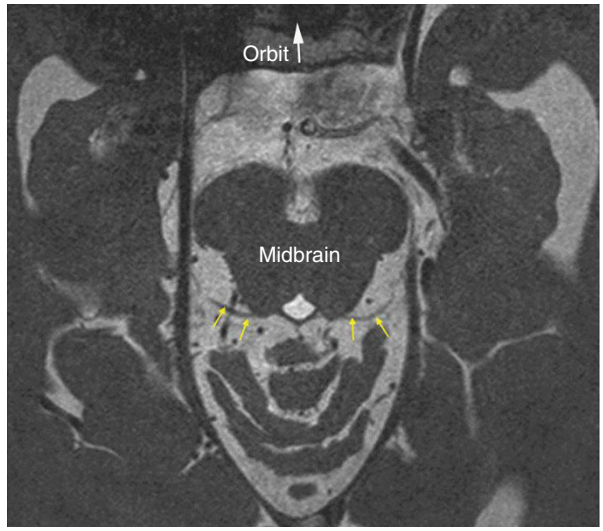

Figure 4.7 High-resolution MRI showing the right and left trochlear nerves (yellow arrow) arising from the dorsal midbrain. Courtesy of Jae Hyoung Kim, M.D., Department of Radiology, Seoul National University Bundang Hospital, South Korea.

In accordance with the IVth nerve's uniqueness, the muscle it innervates, the superior oblique, is the longest and thinnest extraocular muscle. The length of this muscle is not due to its belly but its tendon (Figures 4.2 and 4.6). The muscle belly of the superior oblique arises from the back of the roof of the orbit and this belly then passes forward between the roof and medial wall to the pulley (trochlea) of the superior oblique (Figure 4.6). This trochlea consists of a U-shaped piece of fibrocartilage, which is attached to the medial aspect of the upper front of the orbit. The tendon of the muscle passes through the pulley and then bends downward, backward, and laterally, passing under the superior rectus, and spreads out to attach to the upper back of the eyeball (Figure 4.6). Because this muscle is attached posteriorly, it elevates the back of the eye, depressing the front of the eyeball (rotation around a side-to-side axis). The superior oblique muscle also abducts and intorts the eye (moves it so that it moves away from the nose and rotates it such that a penny placed on the top of the eye would fall toward the nose). Further, because of the specific axes through which the eyeball moves, the superior oblique is the only muscle that can depress the eyeball when it is adducted (nearest to the nose). Thus, although technically an abductor of the eyeball, its function (and that of the trochlear nerve) is actually tested by having the patient look down and in.

CLINICAL ASPECTS

When a patient with a trochlear nerve palsy looks straight at you (eyes in neutral position) the eye with the paralyzed muscle is slightly higher than normal, as shown in the upper image in Figure 4.8 (left eye; also see Figure 4.1). This results because the normal depressing action of the superior oblique is

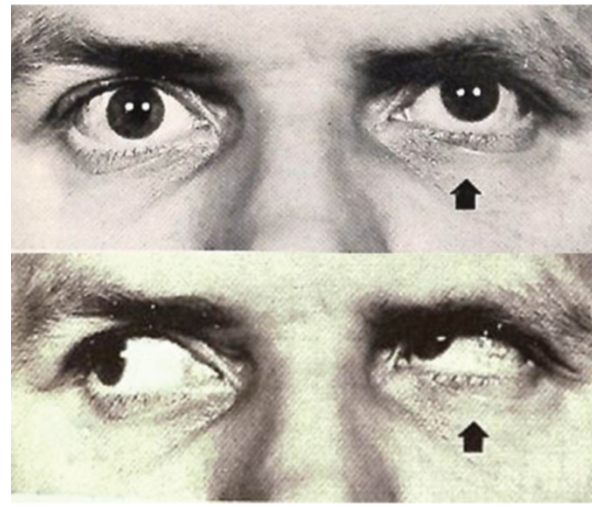

Figure 4.8 Photographs of a patient demonstrating left trochlear nerve palsy. The upper image shows the patient's eyes in a neutral position and the lower image shows the patient looking to the left (adducted left eye). Reprinted with permission from Younge (1977).

not present. More significant defects occur when the eye with the paralyzed muscle is adducted, as shown in the lower image. Note in that image how much higher the left eye is than the right. This occurs because the inferior rectus muscle has a very poor axis of pull when the eye is adducted and, without the depressing action of the superior oblique, the eye is much more elevated than it should be.

The causes of trochlear nerve palsy are typically divided among congenital, trauma, presumed microvascular (diabetic), and undetermined causes. Virtually all of the microvascular cases of superior oblique palsy resolve without treatment. It should be noted that microvascular causes are presumed due to diabetes (because diabetes affects blood vessels), but there is no direct evidence showing that these cases are due to ischemia (loss of blood supply) of the nerve.

The response of the body to a paralyzed superior oblique muscle is to compensate as much as possible for the disturbing effects of diplopia. This can be accomplished by either suppressing the image of one eye or by the patient tilting his head so that that the diplopia is abolished or lessened. Head tilting can be marked and is of diagnostic value in cases of superior oblique muscle paralysis. The head can be tilted to the side opposite the paralyzed muscle because by doing so the patient minimizes the diplopia (Figure 4.9).

For both acquired and congenital superior oblique palsies, the most common primary surgical reparative procedure is weakening of the inferior oblique muscle. This procedure is relatively effective, with one study reporting that 85% of patients had a successful outcome.

Babies can be born with trochlear nerve palsy (almost always unilateral). The cause is generally unknown. In children, as described in the case below, the initial diagnosis may be torticollis (wry neck) rather than a superior oblique palsy because of their appearance (Figures 4.9 and 4.10).

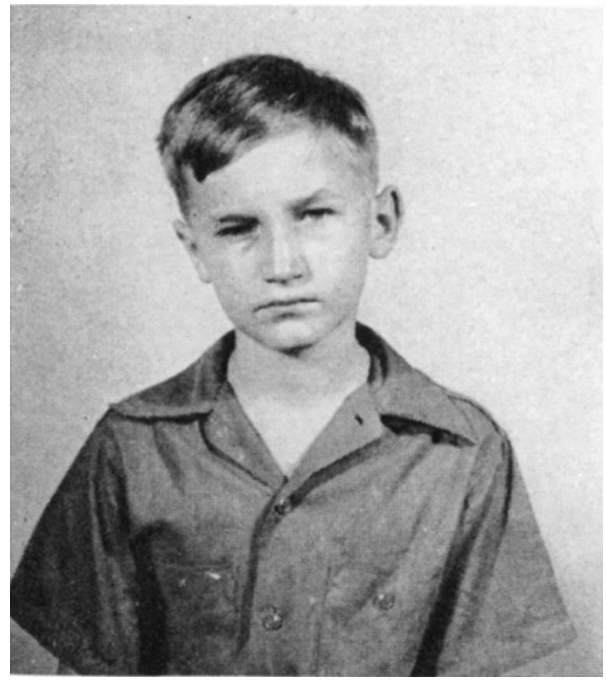

Figure 4.9 Boy with a left trochlear nerve palsy showing head tilt to the opposite side. Reprinted with permission from Adler (1945).

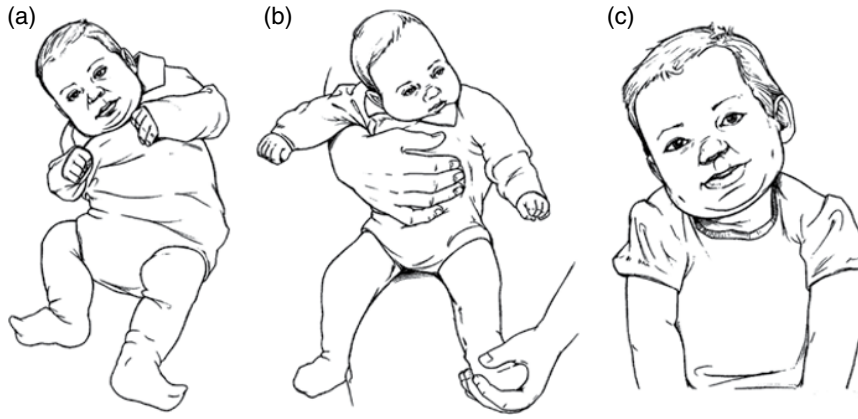

Figure 4.10 Child with congenital left superior trochlear nerve palsy at 3 weeks (a), 3 months (b), and 6 months (c). Reprinted with permission from Brodsky and Karlsson (2009).

A 2.5-year-old child was referred to the Mayo clinic because her eyes were not aligned. According to her parents she had maintained a right head tilt since birth. An orthopedic surgeon had previously diagnosed congenital torticollis [wry neck] (Figure 4.10). On normal gaze her left eye was higher than her right. Brain and orbit MRI showed underdevelopment of the left superior oblique muscle. She had surgery to reduce the strength of her left inferior oblique muscle which resolved the head tilt (Brodsky and Karlsson, 2009).

Head trauma is the most frequent cause of trochlear nerve palsy. The fragile nature of the trochlear nerve makes it susceptible to rapid deceleration movements of the head such as can occur in a motor vehicle accident. The case below illustrates how this might occur, although, in this instance, the sudden deceleration injury took place from a boxing injury rather than from an automobile accident.

A fly-weight boxer, formerly of considerable renown ("Boy Walley, of Singapore") in June 1932, received a heavy blow in the face during the third round of a fight. He immediately saw double. This diplopia persisted, preventing his judging distances, and halting any further boxing bouts. In August 1933, he was diagnosed with diplopia corresponding with paralysis of the superior oblique in the right eye.

He began wearing an eyeshade to avoid diplopia. In September 1933, the right superior rectus was separated from its insertion into the sclera under cocaine and retrobulbar novocaine anesthesia. Two mattress sutures of silk were passed through the superficial sclera about three mm behind the original muscle insertion, then through the freed distal end of the muscle and loosely out through the conjunctiva. The muscle was allowed to slip back a considerable distance behind its original insertion. The loose sutures were then tightened and tied.

Walley recovered single vision and discarded his shade (Savin, 1934).

In this case, the surgeon eliminated the boxer's diplopia by repositioning the superior rectus muscle so that the patient's eye was not abnormally elevated in the neutral position (Figure 4.8).

In cases of bilateral traumatic fourth nerve palsies, both nerves are typically injured where they decussate. Traumatic fourth nerve palsies may occur after minor head injuries without loss of consciousness or skull fracture.

Direct trauma as from a projectile (bullet) can also damage the nerve, as shown by the case presented below:

A 30-year-old man was dragged from his car and shot in the head. He did not lose consciousness but immediately experienced numbness of the entire right side of his body, vertical diplopia and unsteadiness during gait. On arrival at the hospital he was lethargic, but oriented and able to converse. A left trochlear nerve palsy was the cause of his double vision. A CT scan showed that the bullet had traveled through the left paramedian cerebellum to lodge immediately behind the left side of the midbrain. The bullet was left in place. Five months later, the patient's trochlear palsy and other neurological signs remained unchanged (Keane, 1986).

As mentioned above, the trochlear nerve is associated with diabetic-related eye muscle palsy. It is affected less commonly than the oculomotor or abducent nerves. Vasculopathic fourth nerve palsy usually resolves in a few months and these patients, who are typically more than 50 years old, do not need any additional treatment.

The next nerve, the fifth or trigeminal nerve, provides sensation to the entire face as well as controlling chewing muscles.

REFERENCES

Adler FH (1945) Some physiologic factors in differential diagnosis of superior rectus and superior oblique palsy. *Transactions of the American Ophthalmologic Society* **43**: 255–70.

Brodsky MC, Karlsson, V (2009) Perinatal head tilt in congenital superior oblique palsy. *Journal of Neuro-Ophthamology* **29**: 767.

Keane R (1986) Trochlear nerve paresis with brainstem lesions. *Journal of Clinical Neuro-Ophthalmology* **6**: 242–6.

Savin LH (1934) A case of diplopia from paralysis of the right superior oblique relieved by recession of the superior rectus. *Proceedings of the Royal Society of Medicine* **27**: 1058.

Younge BE (1977) Fourth nerve palsy. *Mayo Clinic Proceedings* **52**: 11–18.

5 The Trigeminal Nerve

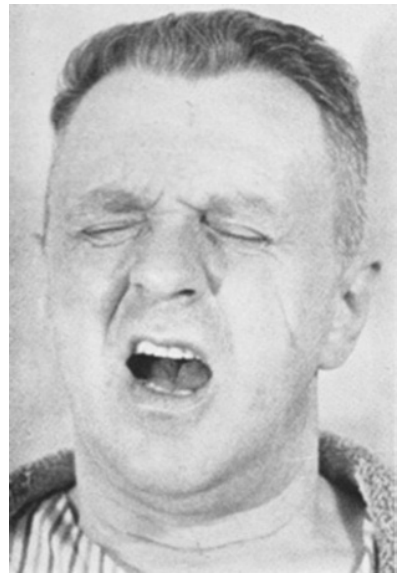

Figure 5.1 Photograph of a patient undergoing an episode of trigeminal neuralgia. Reprinted with permission from Stookey and Ransohoff (1959).

ANATOMY/FUNCTION SUMMARY

The Vth cranial nerve, the trigeminal (literally, "three born together," also known as the trifacial nerve) supplies the face and its cavities with general sensation. It also innervates the chewing muscles (muscles of mastication), a muscle that opens the Eustachian tube, and one that dampens sounds so that the sensitive cells of the inner ear are not damaged by excessively loud noises (Figure 5.2). And yes, this is a strange combination of functions to be found in a single nerve. The trigeminal nerve may be considered the sensory branch of the purely motor cranial nerves, III, IV, VI, and VII. It is the largest of the cranial nerves.

The trigeminal nerve is involved in an excruciatingly painful condition known as trigeminal neuralgia (TN). The pain associated with this condition

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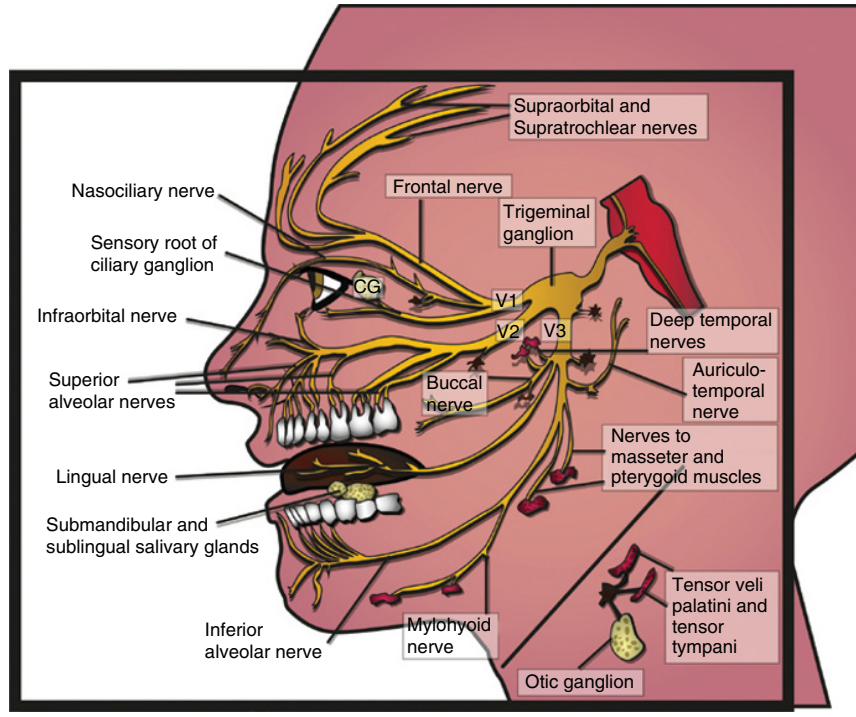

Figure 5.2 Schematic drawing of the anatomy of the trigeminal nerve.

is episodic (paroxysmal), but when it occurs, the patient often winces, which gives the condition its other name, *tic douloureux* (painful twitch). The patient depicted in Figure 5.1 is experiencing a TN episode.

John Locke (1632–1704), the famous English physician and philosopher, in a series of letters in 1677 about his patient, the Countess of Northumberland, wife of the Ambassador to France, described her condition (TN) as follows:

> …On Thursday night last I was sent for by My Lady Ambassador, whom I found in a fit of such violent and exquisite torment that…it forced her to such cries and shrieks as you would expect from one upon the rack, to which I believe hers was an equal torment, which extended itself all over the right side of her face and mouth. When the fit came, there was, to use My Lady's own expression of it, as it were a flash of fire all of sudden shot into all those parts, and at every one of those twitches made her shriek out, her mouth was constantly drawn on the right side towards the right ear by repeated convulsive motions…. These violent fits terminated on a sudden, and then My Lady seemed to be perfectly well…. Speaking was apt to put her into these fits; sometimes opening her mouth to take anything, or touching her gums, especially in places where she used to find these

> throbbings; pressing the side of her face by lying on it were also apt to put her in these fits. These fits lasted sometimes longer, sometimes shorter… at intervals between them not half an hour, commonly much shorter….

ANATOMY/FUNCTION

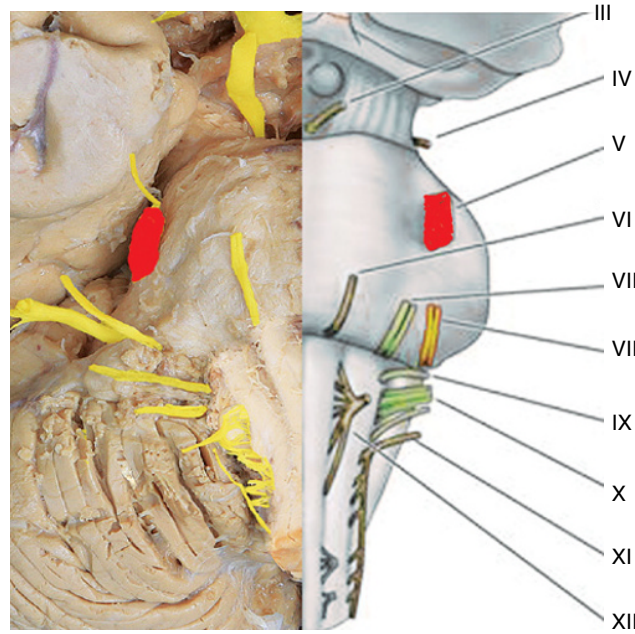

Figure 5.3 Brainstem photograph (right) and schematized drawing (left) highlighting the origin of the trigeminal nerve.

The trigeminal nerve exits the brainstem about halfway between the lower and upper borders of the pons on its ventrolateral aspect (Figure 5.3). Even with the naked eye, it is clear that the fibers segregate into two bundles, a larger lateral sensory root and a much smaller, medial motor root that variably blend as they approach the trigeminal (Gasserian, semilunar) ganglion (Figure 5.4; this drawing, although from 1829, is remarkable in its detail, showing the sensory and motor roots of the nerve).

From its origin, the nerve takes a ventral and slightly ascending course through (piercing) the dura mater to enter a dural "cave" where the trigeminal ganglion is located (Figure 5.5). This ganglion contains the cell bodies of all the sensory fibers in the nerve. The ganglion appears flattened and is enclosed in the dural cave (Meckel's cave), residing in a small groove on the petrous portion of the temporal bone (Figure I.33). The trigeminal ganglion is the size and, somewhat, the shape of a small, skinned fava bean and is bathed in cerebrospinal fluid (CSF) (Figure 5.5).

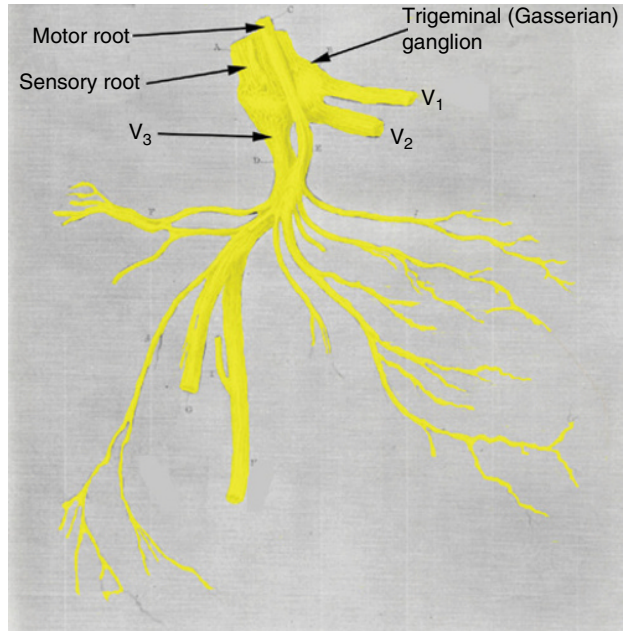

Figure 5.4 Image showing the origin of the right trigeminal nerve and its divisions. Modified and colorized from the original by Bell (1829).

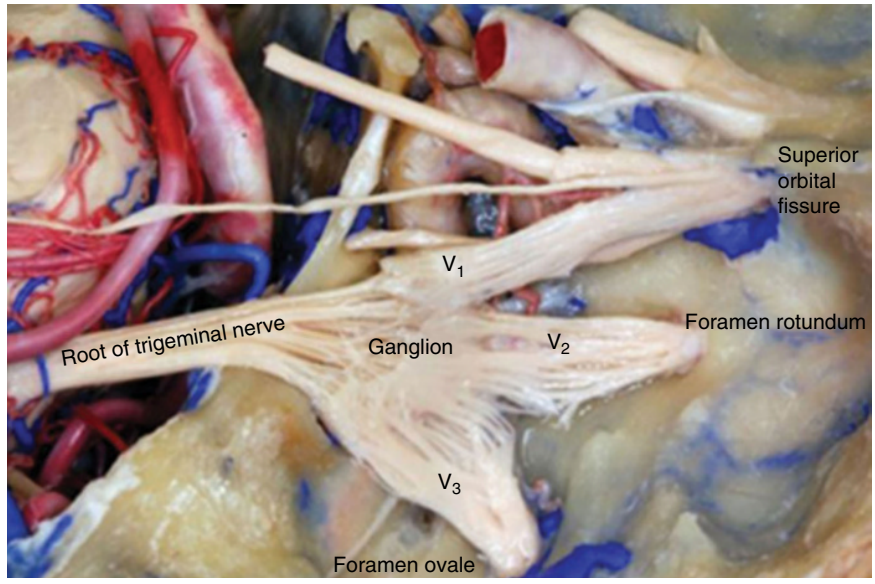

Figure 5.5 Photograph showing the root of the trigeminal nerve, the ganglion, the three divisions, and the foramina (opening) each passes through. Courtesy of Dr. Wonil Joo, Catholic University of Korea, South Korea.

Three divisions of the trigeminal nerve arise from the ganglion: the first division (V_1), the ophthalmic nerve; the second division (V_2), the maxillary nerve; and the third division (V_3), the mandibular nerve (Figures 5.2, 5.4, and 5.5).

Trigeminal components

Motor component

The motor component of the fifth nerve arises from the motor nucleus in the pons (Figure I.12) and leaves the pons adjacent to the sensory root. It passes diagonally under the nerve to reach the Gasserian ganglion and then joins with the mandibular branch (Figure 5.4).

The motor component innervates almost all of the muscles that allow you to chew and grind food: the muscles of mastication. They are the temporalis, masseter, and medial and lateral pterygoids (Figure 5.6). In addition, the mylohyoid and anterior belly of the digastric muscles are also innervated by the motor component of CN V (see Figure 11.3). These two muscles are attached to the lower jaw and thus contribute to the process of mastication, but are not truly considered major muscles of mastication. Instead, their function is mostly to move the hyoid bone within the neck and may be more appropriately considered muscles of deglutition, or swallowing.

The motor division also innervates two very small muscles, both of which begin with the word tensor (to tense), the tensor veli palatini (Figure 5.7) and the tensor tympani. The former is a muscle of the upper throat and functions to tense the soft palate and also to open the Eustachian tube when the mouth is opened widely, as in yawning. The opening of this tube allows pressure in the middle ear to be equalized with atmospheric pressure. This is why it is recommended that we open our mouths when an airplane is ascending or descending and there are changes in cabin pressure. A second muscle that moves the soft palate, the levator veli palatini, is innervated by a different cranial nerve, CN X, and will be discussed later in Chapter 10.

The tensor tympani is a small muscle that is attached to the malleus bone in the middle ear cavity (see Chapter 8). It plays a role in the tympanic reflex, which reduces the movements of the tympanic membrane (eardrum) in response to loud noises, thus protecting the delicate hair cells of the cochlea.

If the motor root of the trigeminal nerve is inadvertently sectioned in a sensory root surgical resection or in removal of the ganglion (both can be done to treat TN), there will be complete and permanent paralysis of the muscles of mastication on the respective side with clearly apparent atrophy. When motor paralysis is present, upon opening the mouth, the jaw will deviate to the paralyzed side because of unopposed action of the contralateral chewing muscles. However, unilateral paralysis of the chewing muscles is generally not a serious disability.

Ophthalmic division (nerve)

The ophthalmic division (V_1) travels forward through the cavernous sinus (Figure 5.8), where it receives some fibers from the sympathetic plexus traveling

with the internal carotid artery. In the sinus, the nerve is located inferior to the trochlear nerve and lateral to the abducent and oculomotor nerves. The ophthalmic nerves give off a small tentorial ramus that supplies part of the dura mater and continues through the superior orbital fissure (Figure I.34) to the orbit, where it subdivides into three terminal branches: the lacrimal, the frontal, and the nasociliary nerves (Figures 5.9 and 5.10).

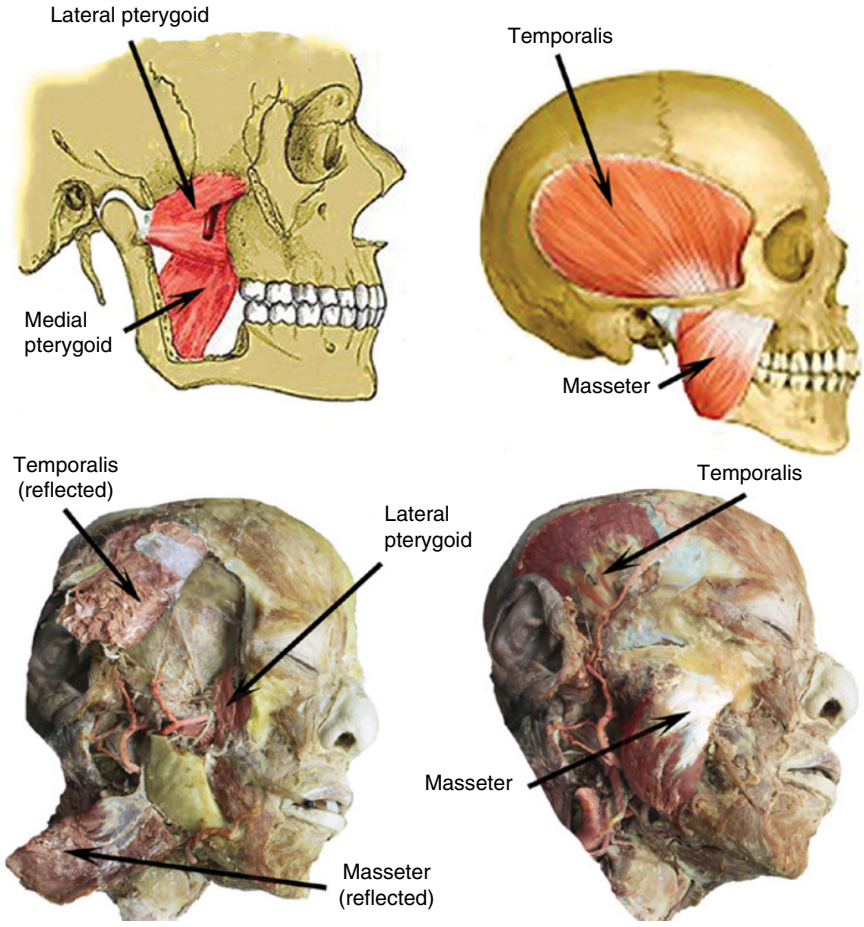

Figure 5.6 The major muscles of mastication shown on a drawing (top) and on a dissection (bottom).

The lacrimal nerve (Figures 5.9, 5.10, and 5.11) is the most lateral of these, traveling beneath the roof of the orbit to the lacrimal gland. It receives a branch from the zygomatic nerve, which contains postganglionic parasympathetic neurons that originate in the facial nerve and innervate the lacrimal gland, which produces tears (ZC in Figure 5.10). The nerve enters the lacrimal gland and gives off several filaments, which supply sensory innervation to the gland and the conjunctiva of the eye. Then it exits the anterior aspect of the orbit and terminates in the skin of the upper eyelid, supplying sensation to this region and joining with filaments of the facial nerve (Figure 5.11).

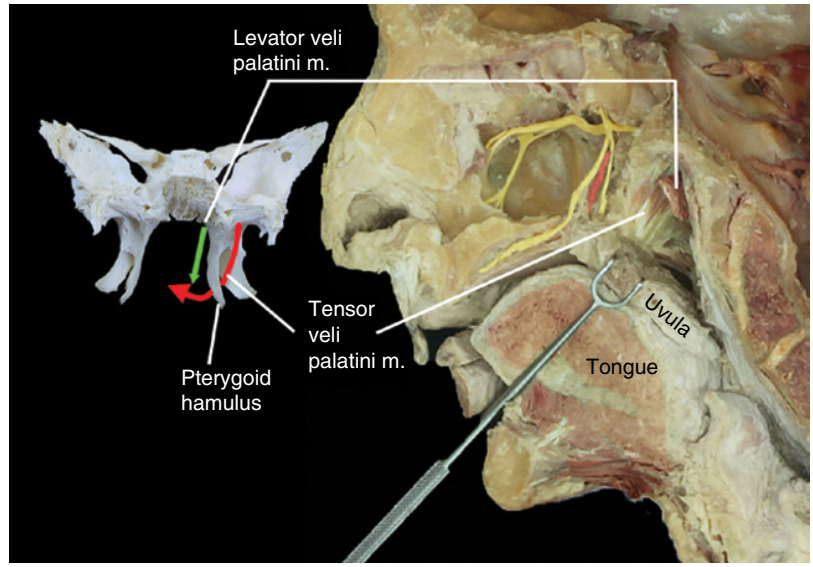

Figure 5.7 Sagittal dissection showing the tensor and levator veli palatini muscles. Inset shows how the tensor uses the medial pterygoid plate as a pulley so that it can tense the soft palate (uvula).

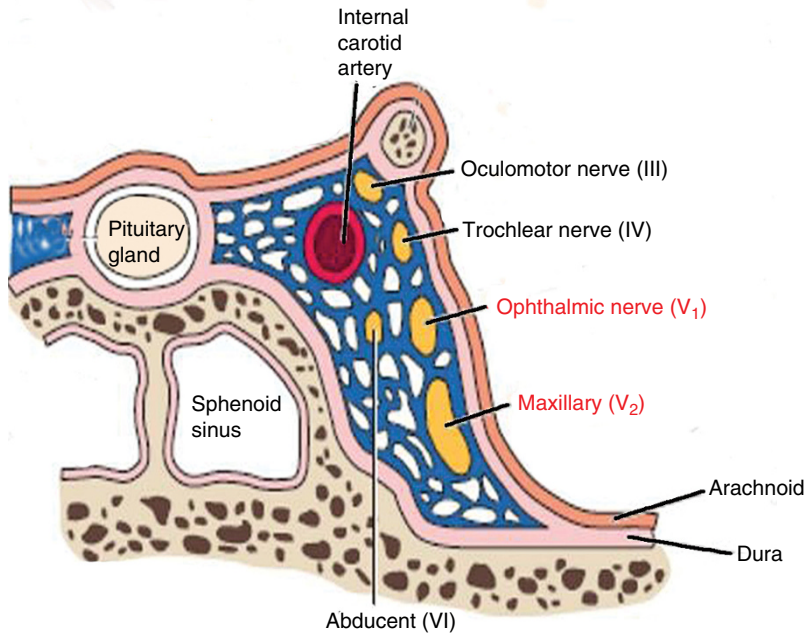

Figure 5.8 Coronal cross-sectional view of the cavernous sinus highlighting the location of V_1 and V_2 vis-à-vis the other cranial nerves and blood vessels located within the sinus.

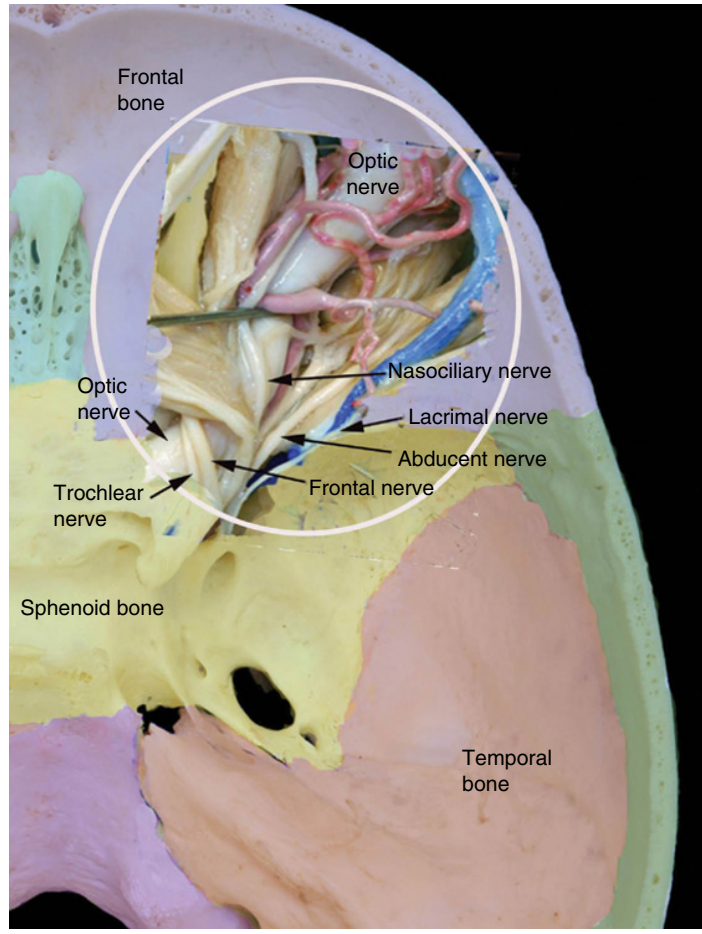

Figure 5.9 Orbital dissection showing the branches of the ophthalmic division of the trigeminal nerve and some additional orbital nerves superimposed (white circle) on a view of the bony anterior and middle cranial fossae.

The frontal nerve is the largest of the three branches of the ophthalmic nerve. It runs ventrally beneath the roof of the orbit and divides into several branches (Figures 5.9 and 5.10). The largest of these is the supraorbital nerve, which traverses the foramen (or notch) of the same name to emerge on the forehead and supply the skin of the forehead (Figure I.22). The smaller supratrochlear branch of the frontal nerve takes a more medial course to the medial part of this region and the medial angle of the eye and innervates the skin and the conjunctiva.

The nasociliary nerve is the most medial branch of the ophthalmic nerve (Figures 5.10 and 5.11). It approaches the medial wall of the orbit and exits the orbit as the infratrochlear nerve (Figure 5.11). The infratrochlear nerve innervates the skin of the eyelids and side of the nose, the conjunctiva, lacrimal sac (collects tears), and tip of the nose. This latter branch is very useful clinically because if the tip of the nose is sensitive it indicates that this branch of V_1 is functional.

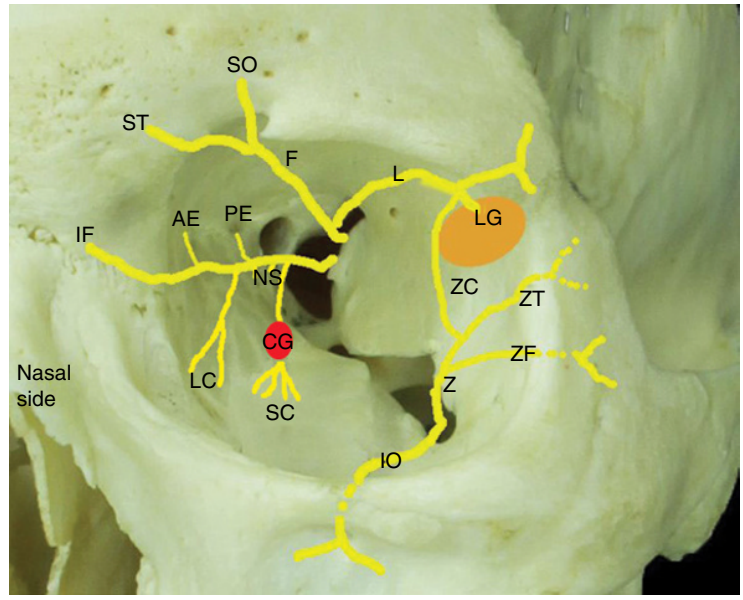

Figure 5.10 Branches of the ophthalmic and maxillary divisions of the trigeminal nerve within the orbit. Abbreviations: AE, anterior ethmoidal; CG, ciliary ganglion; F, frontal; IF, infratrochlear; IO, infraorbital; L, lacrimal; LC, long ciliary; LG, lacrimal gland; NS, nasociliary; PE, posterior ethmoidal; SC, short ciliary; ST, supratrochlear; SO, supraorbital; Z, zygomatic; ZC, zygomatic communicating branch; ZF, zygomaticofacial; ZT, zygomaticotemporal.

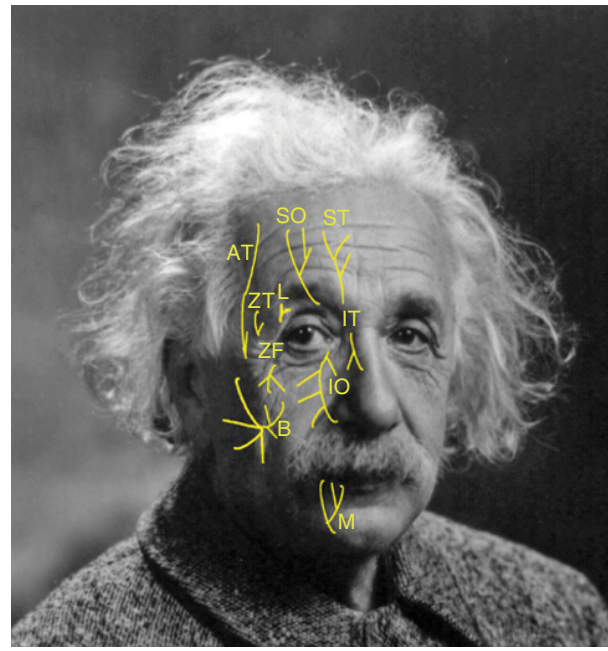

Figure 5.11 The major cutaneous nerves of the face (branches of the trigeminal nerve) superimposed on a photograph of Albert Einstein. Abbreviations: AT, auriculotemporal; B, buccal; IO, infraorbital; IT, infratrochlear; L, lacrimal; M, mental; SO, supraorbitial; ST, supratrochlear; ZF, zygomaticofacial; ZT, zygomaticotemporal.

Within the orbit, the nasociliary nerve gives off some small sensory branches that penetrate the medial bony wall and supply part of the nasal sinuses, the long ciliary nerves that supply the eye with sensory, and probably some sympathetic fibers and a branch to the ciliary ganglion (sensory root) that passes through the ganglion and exits from it as short ciliary nerves that also supply sensory and sympathetic fibers to the orbit (Figures 5.10 and 3.13). The short ciliary nerves additionally carry postganglionic parasympathetic fibers from the oculomotor nerve (see Chapter 3). The short and long ciliary nerves take part in the corneal blink reflex (see the following text).

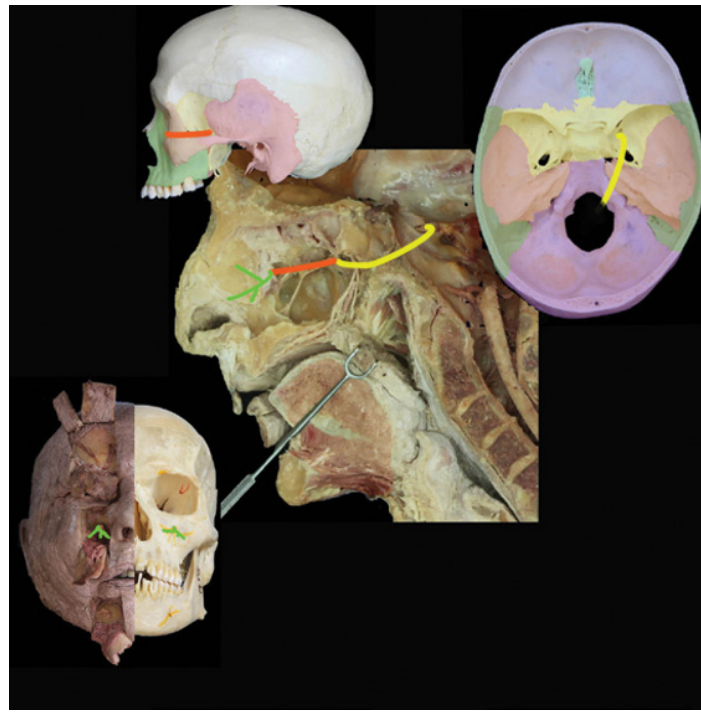

Figure 5.12 Path of the maxillary nerve. The nerve exits the brainstem as part of the main trigeminal root (yellow) and passes through the cavernous sinus and foramen rotundum; it then enters the orbit as the infraorbital nerve (orange) through the inferior orbital fissure and traverses the floor of the orbit, becoming cutaneous on the face through the infraorbital foramen (green).

Maxillary division (nerve)

The maxillary nerve (V_2) (Figures 5.2, 5.4, 5.5, and 5.12) travels from the cavernous sinus (where it gives off a small meningeal branch) through the foramen rotundum to the pterygopalatine fossa (Figure I.33). The bulk of the fibers continue as the large infraorbital nerve (Figure 5.12) that runs in the infraorbital groove (Figure I.22), on the floor of the orbit and then in the infraorbital canal. It emerges through the infraorbital foramen and splits into several branches that supply the skin on the surface of the maxilla as far down as the mouth and up to the lower eyelid (Figures 5.10 and 5.11).

A relatively large branch of the maxillary (or infraorbital) nerve is the zygomatic nerve (Figure 5.10). It runs along the lateral wall of the orbit and gives off small branches that penetrate the zygomatic bone and supply the skin covering this bone and the anterior part of the temple (zygomaticotemporal and zygomaticofacial nerves; Figures 5.10 and 5.11). The zygomatic nerve, as mentioned previously, has a connection with the lacrimal nerve.

Several superior alveolar nerves emanate from the infraorbital nerve (Figure 5.13). They supply the teeth in the maxilla. The fibers form a dental plexus above the roots of the teeth and innervate them and the surrounding gums.

The greater and lesser palatine nerves supply the hard and soft palates with general sensation and taste (Figure 5.13; see Chapter 7). They also carry postganglionic parasympathetic fibers that emerged from the pterygopalatine ganglion (Figure 5.13; this ganglion may also be referred to as the sphenopalatine ganglion). The corresponding preganglionic fibers originally entered the ganglion after departing from CN VII. What is interesting about some of the postganglionic fibers of the pterygopalatine ganglion is that they are responsible for the uncomfortable symptoms associated with hay fever in the spring. Small postganglionic fibers enter the nasal cavity to supply the nasal epithelium. The allergens that cause hay fever enter the nasal cavity through the air we inspire, elicit the parasympathetic response in the nasal cavity, and we start producing mucous and have difficulty breathing.

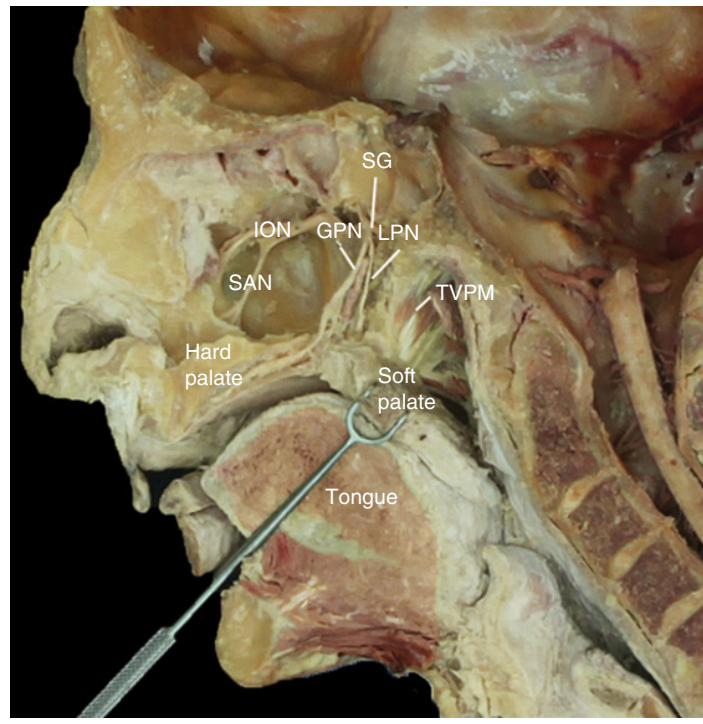

Figure 5.13 Sagittal section of the head showing some of the branches of the maxillary nerve. Abbreviations: GPN, greater palatine nerve; ION, infraorbital nerve; LPN, lesser palatine nerve; SAN, superior alveolar nerve; SG, sphenopalatine (pterygopalatine) ganglion; TVPM, tensor veli palatini.

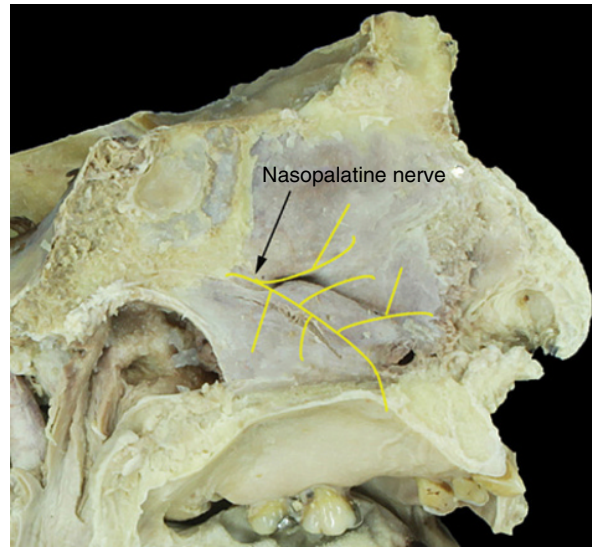

Figure 5.14 The nasopalatine nerve is highlighted as it traverses the nasal septum and the incisive foramen to innervate part of the septum and the anterior part of the maxilla.

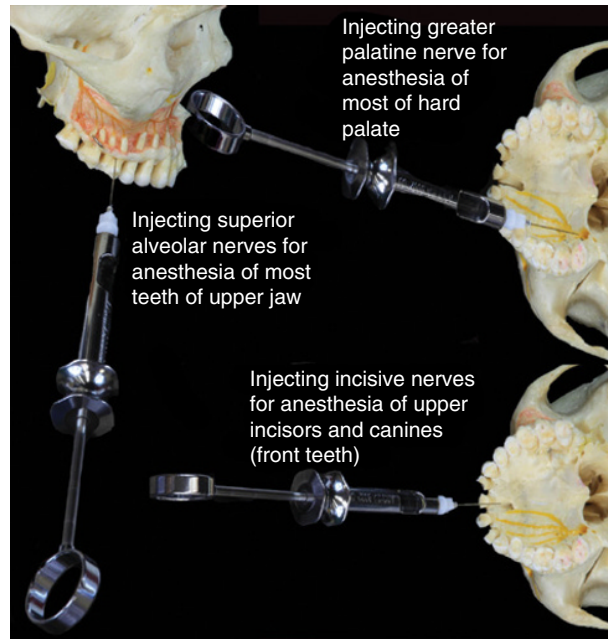

Figure 5.15 Image showing where dental injections are made to anesthetize the upper teeth and hard palate.

The sphenopalatine branches of V_2 take a descending course (not shown in Figure 5.13); some of them traverse the pterygopalatine ganglion (again, see Chapter 7), but most of them bypass it. These branches supply the nasal cavity and nasal septum (nasopalatine nerve) with general sensation. The nasopalatine nerve (Figure 5.14) traverses the nasal septum and then descends in the

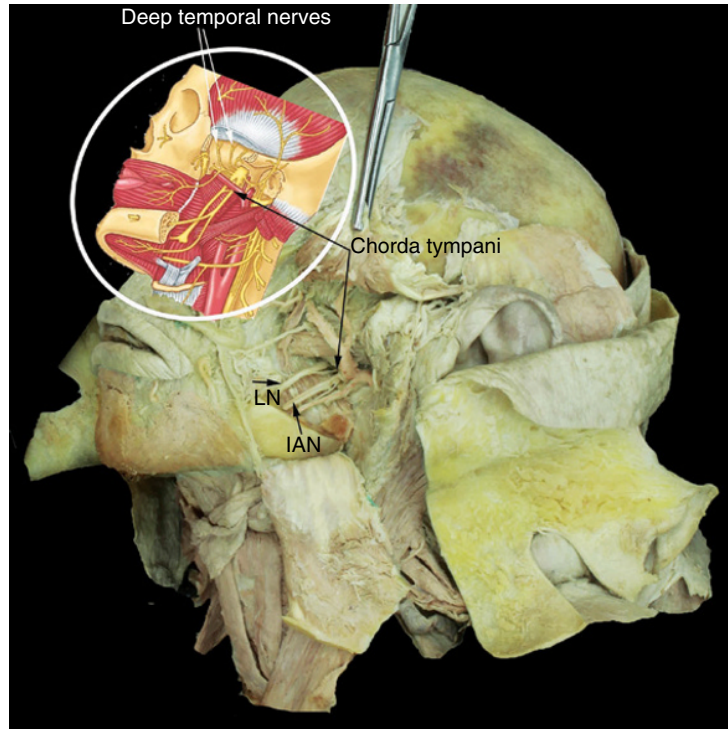

Figure 5.16 The main figure shows a dissection of the infratemporal fossa, highlighting the chorda tympani nerve and the lingual (LN) and inferior alveolar (IAN) branches of the mandibular nerve. The inset (circled in white) shows these same nerves, as well as the deep temporal nerves, which innervate the temporalis muscle. The inset diagram is courtesy of http://what-when-how.com/dental-anatomy-physiology-and-occlusion/dento-osseous-structures-blood-vessels-and-nerves-dental-anatomy-physiology-and-occlusion-part-5/.

incisive canal (Figure I.32) to supply the anterior parts of the hard palate and also the upper incisor teeth (Figure 5.14).

Many of the branches of the maxillary nerves are anesthetized by your dentist when you have work done on the upper teeth, the specific branches being dependent on the teeth being worked on (Figure 5.15).

Mandibular division (nerve)

The mandibular division (V_3) (Figures 5.2, 5.4, and 5.5) carries all the motor fibers of the trigeminal nerve and is the largest of the three principal trigeminal divisions. It leaves the skull through the foramen ovale in the base of the skull (Figure I.34) to emerge on the side of the face deep to the upper part of the mandible and gives off several branches (Figure 5.16). For example, there are branches that carry motor fibers to the four masticatory muscles (the temporalis, masseter, and lateral and medial pterygoids), as well as to the tensor veli palatini (to tense the soft palate and then allow it to be raised and prevent food from entering the nasal cavity from behind during swallowing) and the tensor tympani muscles (to the ear to dampen sounds) (Figure 5.2).

The lingual nerve (Figures 5.2 and 5.16, 5.17, and 5.18) takes a ventral and descending course between the two pterygoid muscles to the base of the tongue. It gains entry to the tongue and supplies the mucous membrane of the anterior two-thirds with general sensory fibers. During its curved course, the lingual nerve receives the chorda tympani nerve, a branch of the facial nerve (Chapter 7; Figures 5.16 and 5.18), which carries taste fibers from the anterior two-thirds of the tongue and (parasympathetic) visceral efferent fibers into the nerve, which stimulates two of the three large salivary glands, the submandibular and sublingual (Figure 5.18).

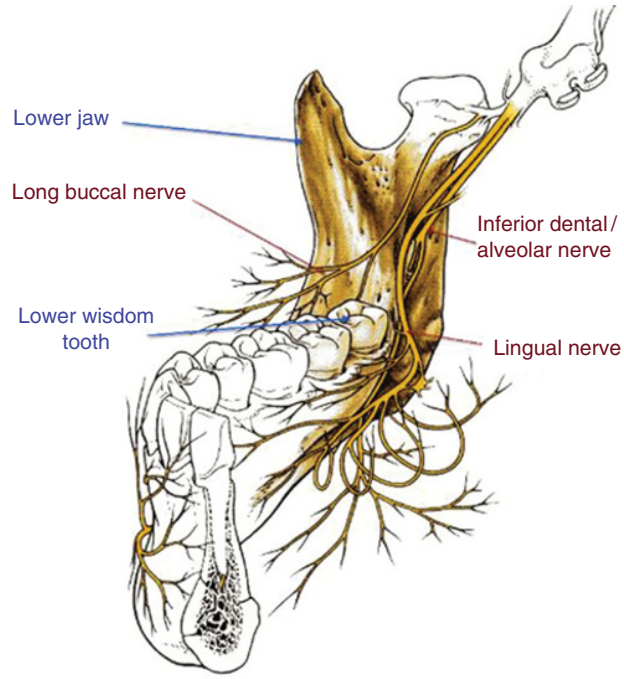

Figure 5.17 Illustration showing the path of the lingual nerve and inferior alveolar nerves. The inferior alveolar (dental) nerve is shown entering the mandibular canal and exiting the mental foramen to appear on the chin (see Figure I.24). Courtesy of http://exodontia.info/Dental_Nerve_Injuries.html.

Another branch of V_3, the (long) buccal nerve (Figures 5.2 and 5.17) travels to the outer surface of the buccinator muscle, which is within the cheek. It splits into many branches that penetrate the muscle and supply the mucous membrane on the inside of the cheek and the skin on the outside of the cheek (Figures 5.2 and 5.11). The nerve is purely sensory. (The buccinator muscle, a muscle of facial expression, is innervated by the buccal branch of the facial nerve; Chapter 7.)

The inferior alveolar nerve (Figures 5.16, 5.17, 5.18, and 5.19) is the largest branch of the mandibular nerve. Similar to the lingual nerve, it takes an arched course in an anterior and inferior direction, but it uniquely enters a canal within the mandible, the mandibular canal (Figure I.27). Before it enters the canal, it gives off the mylohyoid nerve that runs under the mylohyoid muscle, under the chin, and innervates this muscle and the anterior belly of

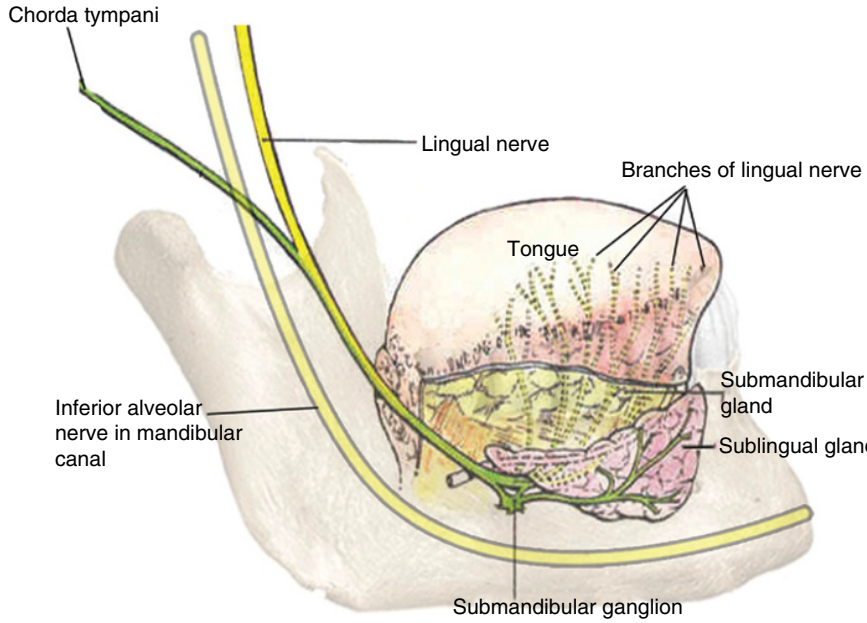

Figure 5.18 Illustration showing the chorda tympani nerve joining the lingual nerve and traveling with the nerve to the submandibular ganglion, where its postganglionic parasympathetic fibers innervate the submandibular and sublingual salivary glands. The lingual nerve provides sensation to the tongue as shown. The inferior alveolar nerve is shown as it traverses the mandibular canal and exits the mental foramen.

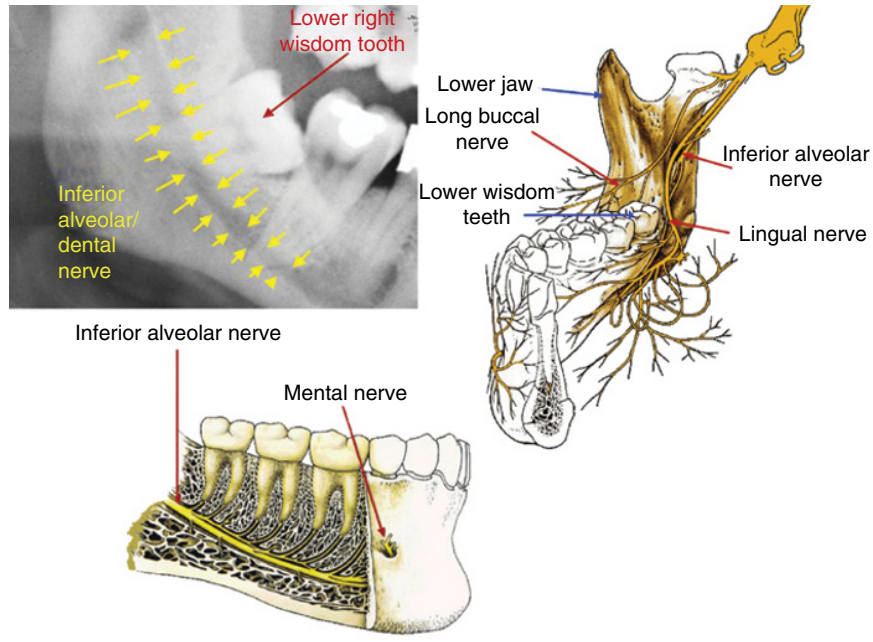

Figure 5.19 Illustrations show the path of the inferior alveolar nerve as it traverses the mandibular canal and innervates the lower teeth before exiting the canal as the mental nerve. The inset in the upper image left shows how an impacted lower molar can compress the nerve. Courtesy of http://exodontia.info/Dental_Nerve_Injuries.html.

the digastric muscle (Figure 5.2). In the canal, the inferior alveolar nerve gives off numerous branches to the lower teeth (Figure 5.19). The terminal branch of the nerve, the mental nerve, exits the bony canal through the mental foramen and supplies the skin of the lower lip and the chin (Figure 5.19).

The auriculotemporal nerve is a purely sensory branch (Figure 5.2) that bends laterally and enters the parotid gland (Figure 9.11), the largest of the glands that produce saliva. The auriculotemporal nerve also emerges from the foramen ovale along with the other branches of the mandibular nerve to enter the infratemporal fossa (Figure I.26) and then straddles the middle meningeal artery as the latter enters the foramen spinosum into the middle cranial fossa. After the two auriculotemporal branches come together again, the nerve ascends from the parotid gland to supply the skin of the temple and the anterior upper part of the outer ear. The nerve has a connection with the otic ganglion in the infratemporal fossa so that postganglionic, secretory fibers from this ganglion (the preganglionic fibers are from the glossopharyngeal nerve; Chapter 9) travel to the parotid gland and cause salivation during eating (Figure 9.11).

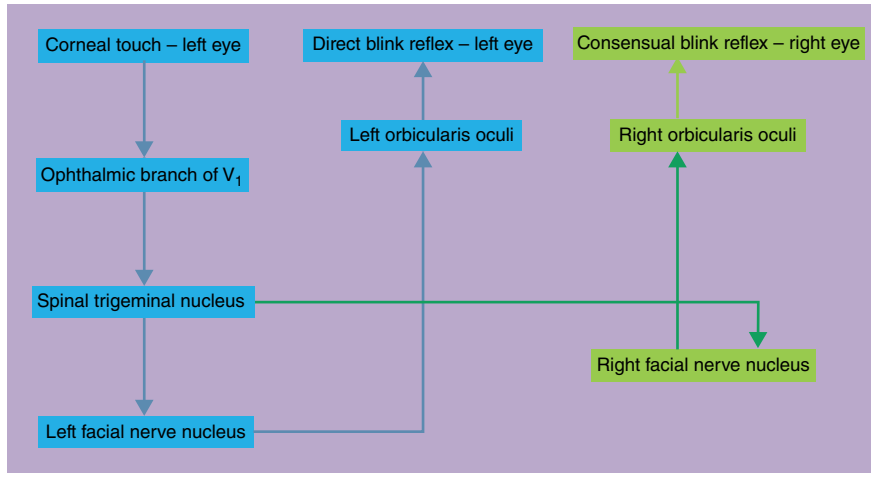

Figure 5.20 The pathway of the corneal (blink) reflex.

CLINICAL ASPECTS

Reflexes involving the trigeminal nerve

In Chapter 2, we discussed the pupillary and accommodation reflexes. The trigeminal nerve is not involved in those reflexes but is involved in the corneal (blink) reflex (Figure 5.20).

The corneal (blink) reflex is an involuntary closing of the eyelids resulting from stimulation of the sensory nerves of the cornea (short and long ciliary

nerves), which are branches of the ophthalmic division (V_1). Stimulation should result in both direct and indirect (consensual) blinking (both eyes blink; Figure 5.20). The motor component of this reflex involves the branches of the facial nerve to the orbicularis oculi muscle, which closes the eyelids (Figure 7.10). The reflex occurs at a rapid rate of 0.1 s. The evolutionary purpose of this reflex is to protect the eyes from foreign bodies.

The glabellar reflex (the glabella [Latin for smooth] region is the smooth ridge of the brow between the eyes and just above the nose; this reflex is also known as the "glabellar tap sign") is produced by repetitive tapping on the forehead. Patients blink in response to the first several taps and then stop blinking. Typically, this reflex disappears within the first few months after birth, but it is often seen in people who have Parkinson's disease. The afferent sensory signals are transmitted by the supraorbital/supratrochlear branches of V_1 and the efferent signals reach the orbicularis oculi muscle via the facial nerve.

The oculocardiac reflex, also known as the Aschner or Aschner-Dagnini reflex, is a reduction in pulse rate that occurs with compression of the eyeball. The reflex involves presumed neural connections between the ophthalmic and vagus nerves. This reflex is especially prevalent in neonates and children.

The jaw-jerk reflex or the masseter reflex occurs when the mandible is tapped at a downward angle at the chin while the mouth is kept slightly open. In response, both masseter muscles will respond and jerk the mandible upward. Normally, this reflex is minimal. However, in patients with CNS lesions, the jaw-jerk reflex can be very prominent.

Abnormalities in trigeminal reflexes provide some indication that a patient may have a trigeminal nerve problem although they are not specific to this nerve as they involve CNS connections as well as other cranial nerves.

Nerve testing

Besides testing for reflexes, testing of the trigeminal nerve involves testing both its motor and sensory aspects. The motor functions of CN V are examined by testing the masticatory muscles. A paresis or a paralysis of the temporal or masseter muscles can be ascertained by palpating the muscles when the patient tries forcefully to close the mouth. The affected muscles will be soft and eventually will atrophy. The lateral and, to a lesser extent, the medial pterygoid muscles are tested by asking the patient to open the mouth. If these muscles on one side are paretic, the jaw will move to the affected side. Unilateral paralysis of these muscles has very little functional effect because patients are readily able to compensate using the opposite side.

The sensory functions of the trigeminal nerve are examined by testing the response to touch, pain, and temperature stimuli in its areas of innervation. Each division of the nerve supplies an area of the face as shown in Figure 5.21, based on the distribution of its branches as shown in Figure 5.11.

An interruption of sensory trigeminal fibers will produce a more or less marked sensory loss in the area of the affected branch. In lesions of the ophthalmic nerve, the corneal reflex (reflex blinking on touching the cornea) will be abolished. This can lead to corneal ulcerations and possible blindness

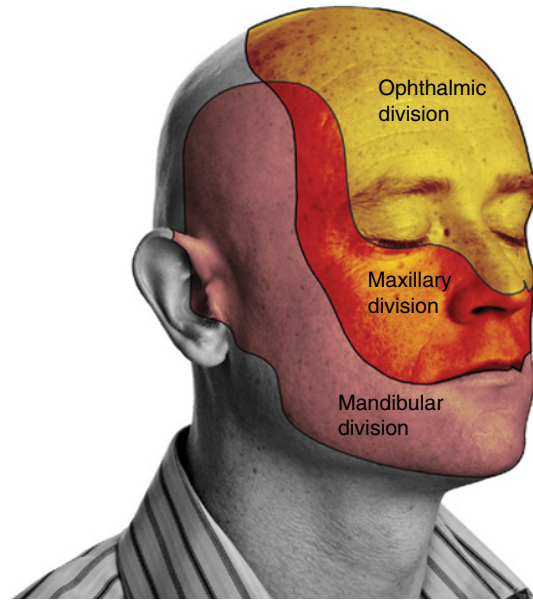

Figure 5.21 Illustration showing the cutaneous distribution of the three branches of the trigeminal nerve. Reprinted with permission from Genese and Goldstein (2013). © 2013 Vertical Health Media, LLC. Original image is individually licensed through Dreamstime. Illustration and treatment applied by Vertical Health Media, LLC.

because, without reflex blinking and associated tearing, any corneal irritants remain on the corneal surface longer than normal.

Trigeminal neuralgia

Signs and symptoms

> *To be able to distinguish and to cure with some degree of certainty, a disease that during the time it lasts is extremely excruciating is an addition, however small, to the utility of our profession.*
>
> —John Fothergill (1712–80)

This chapter began with a case of trigeminal neuralgia (TN) from the 17th century. TN is being discussed separately from other conditions affecting the trigeminal nerve because almost all nontraumatic sensory conditions affecting the trigeminal nerve are considered in relationship to TN (they are often referred to as atypical facial pain). TN is an incredibly perplexing and painful condition that has been treated with what would seem very radical procedures for the past few hundred years because the pain can be so severe that patients will do anything rather than endure the pain. The disease was known historically as the "suicide disease."

Although the term *tic douloureux* is used as a synonym for TN, it is not an accurate designation of the condition. This term refers to the secondary convulsive and spasmodic components, which may be entirely absent and, regardless, never precede the main feature of pain.

The diagnosis of TN depends exclusively on the history and the nature of the pain. Not infrequently, the patient will bring with them a family member to represent them and explain the character of the attacks, or they may prefer to write replies to the examiner's questions, obviously afraid that talking will trigger the pain.

Importantly, the pain must be paroxysmal (generally meaning sudden onset) with intervals of relief. The attacks seem to strike similar to a flash of lightning out of a cloudless sky and disappear just as suddenly as they come. In chronic cases, an attack may last from thirty minutes to an hour, although such duration is not common. The pain seldom occurs at night. Often, patients may be reluctant to acknowledge that they are free from pain between attacks but detailed questioning will elucidate the fact that actually they were pain free in these intervals – but retain the unyielding fear that it will return. In a few patients, a constant dull ache may remain between attacks.

Pain must be confined to the area of the trigeminal nerve in one or more of its divisions. Fortunately, TN generally affects only one side at a time. Only in rare cases does the pain switch from one side to the other and, even then, it is consistently worse on one side than on the other.

Whereas trigger areas around the lower lip, upper lip, nostrils, eyebrow, or scalp are not always apparent, their presence is one of the most important signs in diagnosing TN. These are considered areas in which a slight irritation starts the pain. Sometimes, these zones are strangely restricted, a spot no larger than a fingernail. Initially, pain may be confined to the point from which it started (the *trigger area*). The pain may be initiated by the lightest contact. Not infrequently, the patient will shield the head and face to avoid a sudden draft of air or other triggering factor.

The manner in which the patient describes the pain is significant. Often, the patient will hold the face fixed while talking, only barely moving the lips or jaws, and will point to the painful area but never touch it. One side of the face may be obviously unwashed, showing an accumulation of dead skin. If the mandibular division is involved, the tongue may be heavily coated on the side of involvement and the teeth may be dirty because brushing them can trigger the pain.

In TN there is not any objective evidence of disturbed function of the trigeminal nerve as determined by routine clinical examination. Indeed, the presence of sensory changes within the trigeminal nerve distribution or weakness of the masticatory muscles should raise doubt about the diagnosis of TN.

The ophthalmic division, fortunately, is least often involved in TN compared to the maxillary and mandibular divisions. Only if the pain is over the eye, in the eye, or over the forehead can one be certain that the ophthalmic division is the affected branch.

The second and third divisions are involved with about equal frequency. Pain originating in the second division is felt in the upper lip, nostrils, and cheek and, less often, in the gum and palate (Figure 5.21). The slightest contact around the nose or upper lip may induce an attack. Touching the teeth or palate rarely causes pain. Third division pain is felt in the lower lip and usually this is the trigger area. The teeth and gums are often involved and the pain is felt deeply. The tongue is rarely painful.

The pain of TN is so pervasive that the condition became a topic of discussion in the House of Commons in England in 2010. Minister James Fitzpatrick discussed the condition, which he had, from the podium in July of that year:

> I am very pleased to have secured this debate, and I hope it might provide some comfort to many people across the UK who suffer from the condition of trigeminal neuralgia or TN. I should declare my interest: I have been a fellow sufferer. It is an interest I would gladly disown.
>
> Trigeminal neuralgia affects one or more of the three branches of the trigeminal nerve in the head and has been called "the worst pain known to man." It is characterized by sudden, excruciating spasms of electric shock-like pain, usually just on one side of the face. I remember my first referral to a maxillofacial consultant at the Royal London hospital. He asked me to describe my symptoms. I told him and the medical students who were with him, "It makes me cry." "There you are," he told his team, "a classic definition of the condition. You either have a London bus parked on your foot or you have trigeminal neuralgia."
>
> Any facial movement, such as eating, talking, smiling or kissing, shaving, washing the face or brushing one's teeth can provoke an attack, and that can completely destroy any quality of life. There were several occasions in this place when I was preparing to speak and was fearful that I would be prevented from doing so because of the sense of an impending attack. That might have improved others' quality of life in not having to listen to me, but for some patients being unable to live normally leads to their becoming isolated and depressed, sometimes to the point of suicide.
>
> Normal painkillers do not bring any relief and initially anticonvulsants used to treat epilepsy are prescribed. However, these often have unpleasant side effects and lose their efficacy with time so ever larger doses are required. When the medication is no longer effective, or if the side effects cannot be tolerated, various surgical procedures can be considered, although these carry a risk of complication and results are not always long lasting.

Etiology of TN

Boddy in 1901 said the following about the causes of TN:

> Heredity is responsible for a tendency to neuralgia. Members of neuropathic families are most subject to the disease. It is prone to occur in the so-called nervous person – one who is of an easily excitable, anxious, and worrying disposition. It is often the first indication of an enfeebled nervous system. The poorly fed, over-worked, anemic, and debilitated are perhaps the most frequent sufferers from this trouble.

> Rheumatism, gout, diabetes, syphilis, chronic nephritis, alcohol and tobacco, and lead poisoning are sometimes causative factors in the disease. The essential cause of trifacial neuralgia is too often either hypothetical or is absolutely unknown. It very often occurs with no assignable cause whatever in an individual of good personal and family history (Boddy, 1901).

Boddy, in accord with the social and cultural mores of the period, generally attributed the development of TN to general poor health and to those of lower socioeconomic status.

Thirty-six years later Wilfred Harris wrote in his book, *The Facial Neuralgias*:

> The branches affected with the neuralgia are practically always the second and third divisions, the first division being almost never involved alone, and only in association with the second division. The striking difference in the distribution of the first division from that of the second and third is that the two lower divisions supply the teeth and that their terminal branches are continually being exposed to sepsis [pathogenic organisms or their toxins in the blood] from caries [cavities], pyrorrhea [gum disease], anthral infection, etc. No other nerve in the body is so subject to frequent sepsis [the mouth is notorious for harboring numerous pathogenic organisms] and the fact so many sufferers from trigeminal neuralgia have previously been the subject of severe dental troubles and often serious dental operations, is a suggestive point that dental sepsis is a primary factor in the origin of the disease (Harris, 1937).

Based on this view that teeth were the source of TN, many patients had teeth, in some cases all of them, removed to treat the disease, typically with little beneficial result. Yet today there are many personal accounts on the Internet of patients who believe their TN started from a dental procedure of some kind, often wisdom teeth extraction.

Below is a case from 1911 in which facial pain was originally misdiagnosed as TN; it was shown by extraction to be dental in origin.

> Mrs. B of New Haven, age 25, consulted me four years ago for ocular pain and neuralgia in the side of the face and head. Her general heath had been splendid up to these attacks. No children; no miscarriages; no specific trouble. At times she was in frightful agony. When I first saw her I thought of tic douloureux, as her face was drawn on that side, which completely changed her expression. She said to me "I never expect to get my face straight again." When I applied pressure over the supraorbital nerve she fainted and was practically in a state of collapse. I gave her a hypodermic injection of morphine to control her suffering. I found her eyes about normal. I saw it could not be her eyes that were at fault. I advised her to consult a dental surgeon, which she did, and this is what he found. The wisdom tooth in the upper jaw wanted to come through. The jaw bone was too short, so that the crown of the wisdom tooth was turning outward and backward, and as he could not get at the wisdom

> tooth to extract it, he extracted the adjoining molar, which was absolutely perfect. The relief was almost instantaneous. The space in the jaw is now filled in by the wisdom tooth. That was four years ago and the pain has never come back. But for surgical interference this woman could not have lived much longer, as she was practically exhausted by the pain and suffering (Bell, 1911).

TN is more commonly found to be on the right than on the left. In his 1937 book, *The Facial Neuralgias*, Harris noted that it had been suggested that the reason for this is that the majority of people are right handed and are therefore able to manipulate the toothbrush better on the left side of the mouth than on the right. Dental infections were therefore more likely to occur and to result in TN on the right. Harris' view was in accord with his opinion that dental problems caused TN. However, a 1974 study found no correlation between handedness and TN.

In contrast to these earlier views on the etiology of TN, today TN is generally thought to be due to demyelination of trigeminal sensory fibers within the nerve root (at the origin of the nerve from the brainstem), although sometimes within the brainstem. This demyelination, when it occurs outside the brainstem, is believed to be caused by compression from an overlying artery or vein (referred to as microvascular compression). However, a tumor or multiple sclerosis (MS) can also cause demyelination resulting in TN. Histological studies of trigeminal nerve roots from patients with arterial compression of the nerve have revealed focal demyelination in the area of compression. Similar demyelination was found in MS patients. The derangement of the myelin sheath theoretically results in the generation of abnormal spontaneous nerve impulses and their conduction to adjacent fibers, which are presumably associated with pain.

Although the surgical and histological evidence in support of microvascular compression causing TN is compelling, we must be cautious because it is based primarily on surgical outcome data and that is difficult to assess accurately because of the waning and waxing nature of TN pain. Dr. Harvey Cushing, who is well recognized as the father of modern neurosurgery, expressed this view in 1920:

> Few maladies can vie with trigeminal neuralgia for the number of therapeutic measures which have been earnestly advocated. The long and short of it is that in the early stages of the disease both patient and physician may be deceived, for if any medicinal measure is persisted in long enough, particularly if the patient is kept quiet meanwhile, a cure will appear to have been effected, for the malady is characterized by remissions from pain which may be as abrupt as their onset, and if the remission happens to coincide with the taking of a new drug or novel therapeutic measure, it will be

given credit. Thus doctors are likely to gain erroneous impressions of the therapeutic value of a given measure, for the patient on the return of pain is prone to seek a new physician with a new remedy (Cushing, 1920).

Furthermore, there are both cadaver and MRI findings showing patients with microvascular compression of the trigeminal nerve who do not have any symptoms of TN. Unfortunately, despite being an ancient condition, the cause of TN remains somewhat elusive.

Treatment

Because of the effectiveness of carbamazepine (Tegretol) or oxycarbazepine (Trileptal), these anticonvulsant drugs are usually the first choice for treatment of TN. Other anticonvulsants or muscle relaxants may be tried, but are usually less effective. When oral medications are unable to control the pain, additional nonsurgical and surgical measures are used, some with long histories of use. Over the last 200 years peripheral nerve avulsion, heating, cooling, compression, decompression, chemical ablation, and irradiation have all had varying degrees of success.

The same Wilfred Harris mentioned earlier was known during the early 20th century for performing alcohol injections (chemical ablation) through the foramen ovale into the trigeminal ganglion to treat TN (Figure 5.22).

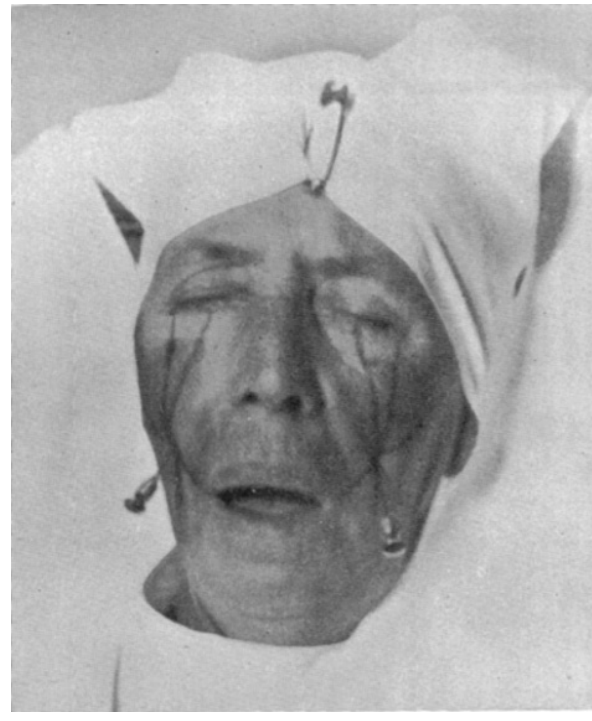

Figure 5.22 Patient about to undergo bilateral alcohol injections to treat her TN. Reprinted with permission from Harris (1937).

Today, alcohol (or glycerol) injection into the trigeminal ganglion is typically done under fluoroscopic guidance (Harris and others of his generation did it based on anatomy). Under conscious sedation, a needle is inserted into the nerve in the base of the skull and a small amount of glycerol injected. Eighty-five percent of patients get immediate pain relief. Persistent numbness in the face can occur. Recurrence rates are high with about one-half of patients having recurrence of pain within a few years. With repeated injections, effectiveness declines further.

The motor component of the Vth nerve is also typically affected by these injections but because the cell bodies of the motor fibers of the nerve are in the pons rather than in the injected ganglion (as with the sensory fibers), the motor component typically recovers within about three months.

Despite its past and current use, the utilization of alcohol injections to treat TN was highly criticized in 1920 by Cushing in the same article cited earlier. "Anyone who is familiar with the appearance of the [trigeminal] ganglion in the living, bathed as it is with cerebro-spinal fluid, would be terror-stricken at the idea of blindly injecting alcohol into its arachnoid capsule…. It is difficult to believe that a procedure fraught with so many possibilities of disaster could have been so seriously advocated."

With respect to the alcohol-ablation technique, Harris in his book did admit that there were always two terrified people involved, one at each end of the needle, and Cushing later in his career did treat some of his patients using alcohol injections.

Radiofrequency rhizotomy (rhizotomy refers to cutting of nerve roots – in this case radiofrequency pulses are used to cut the nerve) is another contemporary nonsurgical technique used to treat TN. In this procedure, a needle-electrode is inserted into the ganglion through the foramen ovale. A radiofrequency electric current heats the needle tip and selectively destroys the small, unmyelinated pain fibers. Patients typically develop some sensory loss. The initial success rate is very high (nearly all patients) with a recurrence rate of about 20% within a few years.

A third nonsurgical therapeutic technique, with similar success and recurrence rates, is balloon compression of the trigeminal ganglion. A small balloon, inserted into the foramen ovale through a catheter, is inflated to compress the trigeminal ganglion and then removed. Numbness in the face, unfortunately, can be a side effect of these techniques when general sensory fibers are destroyed along with the pain fibers. Infection is another possible complication.

Gamma-knife radiosurgery can successfully treat TN by ablating the pain fibers of the nerve. This technique uses radiation to perform brain surgery without opening the skull. A single, noninvasive treatment typically results in excellent pain relief. Temporary facial numbness is rare. In the case described below, the patient was treated with some of the treatments described here, including gamma-knife surgery:

My mother has suffered from trigeminal neuralgia pain since 1981. As with most patients, her affliction was misdiagnosed and mistreated for many years. A dental surgeon in St. Louis did a root canal, and when that was unsuccessful, he said (insightfully) that it could be a "nerve problem." However, nothing effective was done to alleviate it.

My parents moved to the San Francisco Bay area where her problems continued. She had a tooth pulled and the pain went away for a while. In 1984, her condition was correctly diagnosed as trigeminal neuralgia. She was started on Tegretol, which managed the trigeminal neuralgia more or less effectively for five years.

My parents moved again to Thousand Oaks, just north of Los Angeles. The pain returned intensely in 1989. She saw a neurologist for four years who kept her on Tegretol while the pain steadily worsened. In 1993 she saw a neurosurgeon in Santa Monica, who performed a successful rhizotomy on the middle branch of her right trigeminal nerve. However, two years later, he had to perform a rhizotomy on the lower branch of the trigeminal nerve and this was not very successful. Mom had pain afterwards in the right side of her face, ear, tongue and chin. When those problems subsided the trigeminal neuralgia came back.

Finally, with Mom taking 800 to 900 mg of Tegretol per day, and liver function becoming an issue, I convinced her to consider gamma knife treatment. After much hesitation, she agreed. She tolerated the procedure quite well, but felt bad that the nurses had to get up so early and work so hard. She did extremely well post-op and went out to dinner the next night. Slowly, her pain decreased and she dropped down on her medication. Now, she no longer takes Tegretol and has not had any attacks in quite a while. My mother and father now have the confidence to plan a two week cruise to Alaska, something they never would have done while she was in such pain.

An older technique that is not currently used in Western countries is sensory root avulsion in which the sensory root is cut between the ganglion and the brain stem. Cushing used this technique and a case of his is presented below:

In November 1909, a 67-year old woman presented with neuralgia in the right side of her face for the past seven years. After various trips to her dentist, she was told that she had Riggs disease, and had all of her teeth removed. She was unable to wash her face, speak, or chew without worry of paroxysms of pain and described the previous day's train ride to Baltimore as unbearable. Following the operation, the patient had no discomfort except a slight backache. Two years later, the patient wrote that, "there has not often been a day of [my] life since that time in which [I have] not remembered you and appreciated the great thing you did for me" (Adams *et al.*, 2011).

The most common surgical approach currently to treat TN is microvascular decompression (MVD) based on the vascular compression hypothesis. As described previously, it is thought that chronic vascular compression causes an area of demyelination of the nerve from which abnormal impulses are generated causing pain. To alleviate the vascular compression, surgery is performed under general anesthesia. A small opening of bone is removed from behind the ear to access the lower brainstem and trigeminal nerve. Using a microscope, the surgeon separates the offending blood vessel from the nerve and inserts a cushion of Teflon between them. About 80% of patients have immediate pain relief with a recurrence rate of about 15% over several years. Facial numbness is rare, as are other complications, including unilateral hearing loss, CSF leak, or other complications associated with any cranial surgery. This procedure has a mortality rate of about 1% but this value is modulated by the fact that most patients are relatively elderly.

In 2009, Dr. Marc Sindou published an article titled, "Trigeminal neuralgia: a plea for microvascular decompression as the first surgical option. Anatomy should prevail." The article concluded with the following:

> It is now well accepted that vascular compressions are the origin of a large majority of the so-called primary TNs. This has been documented through a number of publications and validated by the solidity of the percentages of permanent cures obtained by pure MVD surgery in the main series. Therefore, we do think that MVD – because of its conservative nature – should be considered as the first surgical choice when the patient's conditions are satisfactory. In experienced hands, complications are uncommon.
>
> Percutaneous lesioning techniques or radiosurgery is indicated in patients in whom imaging does not provide clear-cut evidence of a vascular compression. They constitute a providential recourse when patients are in precarious conditions.
>
> MVD being a conservative method, it can be considered the gold standard. In the field of surgery, history shows that anatomical-based operations ultimately prevail, provided they are performed by well-trained teams (Sindou, 2009).

Dr. Sindou's plea seems reasonable and justified although we wish more efforts were directed at understanding the physiological basis of TN. Clearly, as delineated earlier, questions remain as to how presumptive vascular compression is associated with this painful condition.

Additional nontraumatic conditions affecting the trigeminal nerve

Atypical trigeminal neuralgia (ATN)

In atypical trigeminal neuralgia (ATN), the pain differs quite markedly from TN, although the pain may similarly be confined to one of the divisions of the trigeminal nerve. This pain is deep and nagging. The patients are often at a loss to describe the nature of their suffering. Dull, aching, pulling, drawing, pressing,

boring, throbbing, burning, and unbearable are among the descriptive terms used. The sporadic attacks increase in intensity and the area involved may increase with them. The pain may become bilateral. There is usually no trigger zone. If the patient is asked to locate the painful area, instead of just pointing to the area as in TN, the patient will press firmly on it as if unconsciously trying to punish or destroy the region.

Neurosurgeons Byron Stookey and Joseph Ransohoff in their 1959 book on TN describe an interesting contrast between these patients and those with TN:

> The impact of continuing relentless pain upon the personality is inevitable damaging so that the atypical facial neuralgia patient, when seen after years of constant suffering, impresses one as worrisome, nagging and complaining, whereas the patient with true trigeminal neuralgia, though suffering greatly, is more likely to have adjusted to his affliction and does not whine nor seek understanding and sympathy. This apparent stoicism may be related to the obvious severe and excruciating pain, which, when it strikes, does so with such evident violence as to elicit sympathy and understanding on the part of the observer. In the atypical case there is no visible attack; the pain is, as it were, concealed, compelling the patient to call attention to its severity. The oft-repeated story, unsupported by outward manifestations of suffering, eventually evokes only skepticism, making it difficult to evaluate either the personality or the pain (Stookey and Ransohoff, 1959).

An Internet case of ATN is described below:

> I have been diagnosed with atypical TN. My pain is a constant, throbbing, burning, boring sensation – but centered in my right ear and the immediate area surrounding it. Oh, and along with the constant pain are the intermittent ice picks to the ear. Turning my head to the left, talking, and OMG smiling is excruciating. Thankfully, my episodes are very sporadic usually at least once a month for 4–8 hours at a time and sometimes several days in a row and then may not have another for 3 months. No triggers are apparent when it flares up. I take the extended release Tegretol but only when I have an episode. Heat applied to my ear with the meds usually soothes somewhat until the episode is over.

Other conditions

Congenital lesions involving the trigeminal nerve are rare and include aplasia (absence) and hypoplasia (reduced size) of the nerve and brainstem nuclei. Aplasia and hypoplasia of the nerve have been described in conjunction with Goldenhar syndrome (incomplete development of the ear, nose, soft palate, lip, and mandible), also called oculo-auriculo-vertebral syndrome, or as a sole abnormality. In these conditions, children will require surgical intervention to

repair/replace the missing nerve elements, but if there is aplasia of the trigeminal ganglia, it is virtually impossible for any effective surgical remedy.

Numerous conditions may affect the intracranial segment of the trigeminal nerve. These include an aberrant vessel causing TN (presumably), aneurysm (a weakening in the wall of an artery causing it to bulge out and apply pressure to nearby structures), schwannoma (a benign tumor of the supporting cells surrounding the nerve), meningioma (usually benign tumors of the meningeal layer surrounding the trigeminal ganglia), carcinomatous meningitis (where metastasis of a primary cancer involves the meningeal layer and applies pressure to the trigeminal ganglia), perineural spread from extracranial primary malignancy, and many other infectious and inflammatory lesions. In addition to facial sensory loss, involvement of other nearby cranial nerves can cause facial weakness (CN VII), hearing loss, or dizziness (CN VIII).

Malignancies (cancers) involving the trigeminal nerve include brainstem gliomas (a very aggressive type of brain cancer originating from the support cells of the CNS), especially pontine gliomas, lymphomas (cancer of lymph cells), and metastases (a catch-all term to indicate that the primary tumor arose somewhere else in the body and spread to distant sites).

Tumors may affect the maxillary nerve in the pterygopalatine fossa (Figure I.32). Nasopharyngeal cancer and other head-and-neck cancers can spread to the trigeminal ganglion.

Disease processes may impact the peripheral branches of CN V. For example, the superior alveolar nerves may be involved in inflammation in the maxillary sinus (sinusitis). Acute (short-term) and chronic (long-term) osteomyelitis (infection of the bone) may progress to involve the mandibular canal and the inferior alveolar nerve, causing intense pain and numbness in the chin and lips.

Within the cranial cavity, inflammation of the meninges and other processes may involve the trigeminal nerve. Within the cavernous sinus, an aneurysm of the internal carotid artery can affect branches of the nerve (Figure 5.8).

The trigeminal ganglion may be the location of inflammatory disease. Primary Sjogrens syndrome (an autoimmune disease where the individual's cells attack its own vital organs), systemic lupus erythematous (another autoimmune disease), systemic sclerosis (scleroderma, another autoimmune disease that predominantly affects the skin), and sarcoidosis (an inflammatory disease) can all have symptoms related to their effect on CN V branches.

The most common infection of the trigeminal ganglion is herpes zoster, commonly known as shingles. This is due to reactivation of the varicella zoster virus that causes chicken pox (Figure 5.23). After someone has chicken pox (usually in childhood), the virus settles in sensory nerve root ganglia throughout the body, where it can reside for years or even a lifetime without causing problems. It can be reactivated in some people, particularly the elderly or immunocompromised individuals, causing burning or sharp, stabbing pain and a vesicular skin rash in the area supplied by the nerve involved. In patients with trigeminal nerve shingles, the ophthalmic branch is involved 80% of the time, but the maxillary and mandibular branches can also be involved. Herpes ophthalmicus (involving the V_1 branch) can cause scarring

of the cornea, leading to vision loss. In approximately 10–15% of patients with shingles, a postherpetic neuralgia (pain syndrome) occurs.

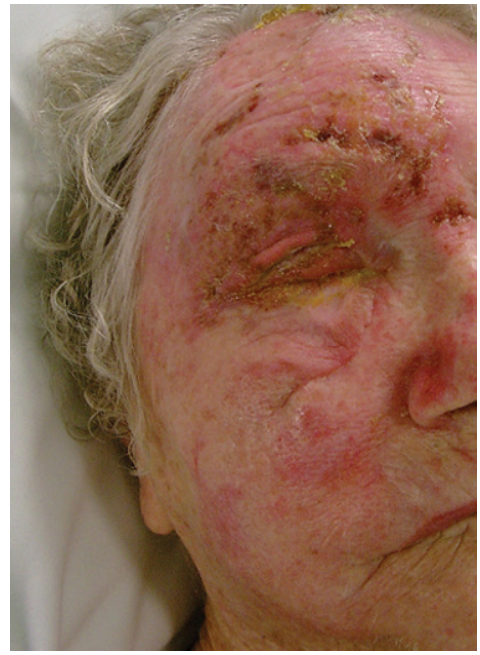

Figure 5.23 Photograph of a patient with herpes zoster ophthalmicus on her right side. Note the confinement of the lesions to the cutaneous distribution of V_1. Reprinted with permission from http://lifeinthefastlane.com/ophthalmology-befuddler-011/.

Mental nerve neuropathy (MNN), also known as numb chin syndrome, results from loss of function of the terminal sensory division of the inferior alveolar branch of V_3 (Figures 5.11 and 5.19), causing isolated numbness on one side of the chin and lower lip. Surprisingly, this seemingly harmless syndrome familiar to anyone having local dental anesthesia may indicate more significant underlying disease. It is most often an indicator of tumor metastasis and may occur before the diagnosis of cancer, as indicated by this case:

A 56-year-old woman presented with a three month history of cough, progressive difficulty breathing, fatigue and multiple bone pain. One month before admission she suddenly noted a feeling of anesthesia, intermittently associated with a prickling sensation like pins and needles, at the right corner of her mouth. A week later this feeling extended bilaterally to the lower lip and chin. Physical examination revealed a painless superficial hypoesthesia [reduction in feeling] of her chin and lower lip. CT revealed a 5-cm diameter mass of the left lung. Further radiologic studies revealed numerous metastases to skull and spine but not to mandible. But later there was evidence of a painful lesion of the left lower jaw. The patient died eight months after discovery of the tumor (Laurencet *et al.*, 2000).

The mechanism of how MNN occurs in association with cancer is often believed to entail direct compression or invasion of the nerve. In metastatic cancers such as those of the breast, thyroid, or lung, for example, the growing metastasis may impede nerve action at the location of tumor growth. Direct invasion by the cancer may be an important process in primary tumors of the inferior alveolar nerve and mental nerves. In addition, cancer can be associated with a significant inflammatory response throughout the body. Swelling associated with this response in the mandibular bony canal may cause nerve damage.

The Sturge–Weber syndrome is a neurological disorder recognized at birth by a port-wine stain birthmark, usually on one side of the face, that is limited to one or more divisions of the trigeminal nerve. The birthmark is caused by too many capillaries around the trigeminal nerve branches just below the skin surface of the face (Figure 5.24). Abnormal blood vessels also occur on the brain surface causing loss of neurons and calcification of tissue in the cerebral cortex. Neurological symptoms may include developmental delay and mental retardation. Focal seizures may occur, causing involuntary motor activity on the side of the body opposite (contralateral to) the birthmark. Contralateral hemiparesis (weakness) can also occur. On the other hand, some patients never develop neurological symptoms.

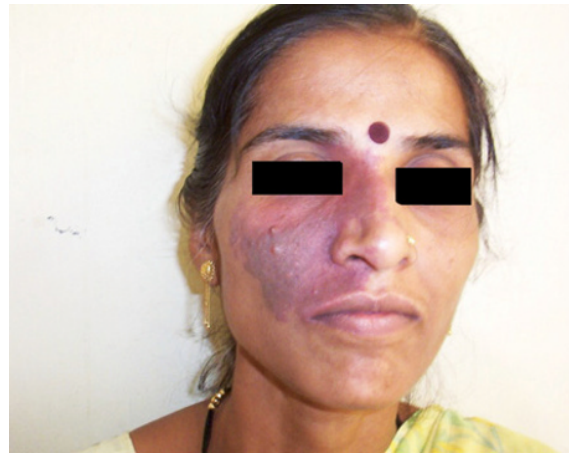

Figure 5.24 Patient with Sturge–Weber syndrome. Reprinted with permission from Kothari (2012).

In 1907, Count Giuseppe Gradenigo described a syndrome of drainage from the ear, pain behind the eye, and diplopia, which he attributed to infection of the apex of the petrous portion of the temporal bone. Middle ear infection or mastoiditis can spread to this area, causing inflammation near the adjacent trigeminal ganglion and abducent nerve (CN VI). Irritation of the ophthalmic branch of CN V_1 is thought to cause the eye pain. This condition, also known as petrous apicitis, was more common at the beginning of the 20th century, but is now very rare because of the availability of antibiotics to treat ear infections.

Interestingly, despite apparent pressure on the trigeminal ganglion/nerve, there are no reported cases of this syndrome producing the classic symptoms of TN. A case of Gradenigo's syndrome is presented below:

A 60-year-old woman presented with seven days of right-sided headache, facial pain, and diplopia. She reported that the headache was behind the right eye and in the right temporal region. She stated that she awoke with the headache and facial pain seven days earlier. The retro-orbital and facial pain had markedly worsened in the two days before presentation. She postponed going to the emergency department, believing that the symptoms would resolve spontaneously. At the time of evaluation, she reported constant pain in the right facial and retro-orbital areas. She denied any preceding infection symptoms, including ear pain, sinus congestion, sore throat and cough. She also did not recall having fevers and chills. She reported no weakness, numbness or hearing loss.

On physical examination, she was afebrile with normal pulse, blood pressure, and respiratory rate. Her head and neck examination demonstrated right eye lateral gaze palsy. Reproducible diplopia occurred with rightward gaze. There were no sensory deficits. No other cranial nerve deficits were noted. There was no tenderness or erythema [redness] over the mastoid regions and she had no posterior auricular, pre-auricular, or cervical lymph node enlargement.

A MRI study confirmed a moderate amount of fluid in the right petrous portion of the temporal bone consistent with Gradenigo's syndrome. The patient was treated with antibiotics. After five days, the patient reported significant improvement in her symptoms. She reported complete resolution of her facial pain and right abducent nerve palsy after two months (Tomabene and Vike, 2010).

Traumatic lesions of the trigeminal nerve

General trauma

Most peripheral trigeminal nerve injuries are associated with trauma to the maxilla or mandible, which stretches, compresses, or ruptures the nerve. Dental procedures may also damage the branches of V_3 (see the next subsection).

The supraorbital nerve may be injured in orbital roof fractures and superior orbital rim fractures. Other facial and skull base fractures can injure branches of the nerve. Fracture through the skull base may extend through the foramen rotundum, crushing or disrupting the maxillary nerve. In addition, V_2 may be injured with "blowout" fractures of the orbital floor, as exemplified in the case of an amateur boxer described next (see Figure I.23):

After losing a mid-season bout by a split decision, a 20-year-old cadet at the United States Military Academy reported to ringside medical personnel for standard postbout medical screening. The subjective examination

revealed numbness in the boxer's lower eyelid and under his eye but no blurred or double vision. He was instructed not to blow his nose for the next 48 hours and to have a follow-up visit the next day. His orbital swelling persisted for about 24 hours and the numbness essentially resolved in about 72 hours with some persistence for about one week. Fourteen months postinjury there were no indications of any residual effects of the injury (Karsteter and Yunker, 2006).

Fractures of the central skull base may also extend through the foramen ovale, contusing, crushing, or disrupting the mandibular nerve. Mandibular nerve injury may also occur from displaced mandibular neck fractures. Fractures of the mandibular canal between the mandibular and mental foramina may cause numbness and paresthesia (unusual sensations) of the inferior alveolar nerve.

Dental trauma

The lingual and inferior alveolar nerves are the primary nerves injured during dental procedures. These procedures range from complex jaw surgeries to more mundane procedures such as third molar extractions, root canal procedures, and local anesthetic injections (Figures 5.17, 5.25, and 5.26).

A case of inferior alveolar nerve injury resulting from a root-canal procedure is presented below (Figure 5.25):

A 23-year-old woman presented to a dental clinic in September 2009 with pain in both sides of her mouth because of inflammation in the pulp cavities of her lower left tooth. Radiographic examination revealed a broken endodontic instrument (a very small drill bit) present in the root of her left lower second molar in direct contact with her left inferior alveolar nerve. The patient was asked about prior dental work and she recalled that in 2003 she had prior endodontic work performed and that since then she occasionally noticed numbness on her left chin and lower lip. This had concerned her enough to see a neurologist. Surgery was performed to remove the instrument and the patient fully recovered (Marques and Gomes, 2011).

Functional problems associated with dental injuries to the inferior alveolar or lingual nerves include difficulty holding food or drink in the mouth, biting the lip or tongue when chewing, and difficulty pronouncing words.

The lingual and inferior alveolar nerves are especially susceptible to inadvertent injury during dental anesthetic injection (Figure 5.26). The incidence of injury to these nerves may be as few as 1/30,000 injections. Sometimes, when there is injury, the patient will complain of an "electric shock" type of sensation, presumably associated with the needle penetrating the nerve, although injury has been demonstrated in patients who experience no unusual sensation during the anesthetic injection.

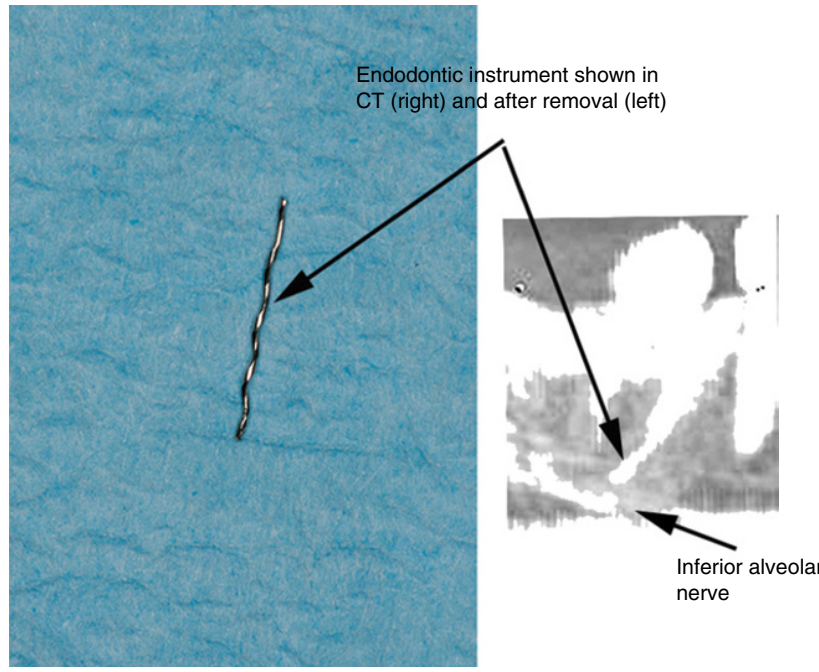

Figure 5.25 Images showing compression of the inferior alveolar nerve by a dental instrument that was inadvertently left in the patient. Courtesy of Dr. T.M. Marques, Portuguese Catholic University, Portugal.

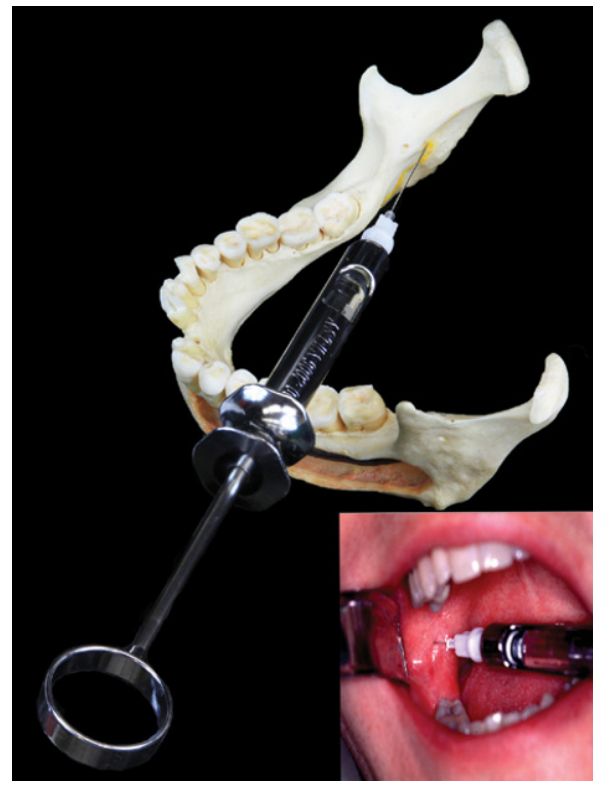

Figure 5.26 Photograph showing the osteology involved in an inferior alveolar nerve injection and an inset showing an actual injection.

Fortunately, most cases of injection injury recover within 8 weeks or less. Some cases do persist, however, and sensory retraining or surgery may be used for treatment (see the following section).

Treatment

Most minor traumatic (or nontraumatic) trigeminal nerve injuries recover without intervention. Sensory retraining may be used in cases where recovery appears to be prolonged. Sensory retraining therapy is a cognitive behavior therapy technique that helps the patient with a nerve injury to meaningfully interpret the altered neural impulses (due to the injury) that reach a conscious level. This technique has been extensively used with patients who have had nerve injuries affecting the hand. It has also been successful in patients with sensory injuries to the trigeminal nerve.

Surgical treatment of conditions associated with the trigeminal nerve, if needed, may require a series of surgical steps: exploration and decompression, internal neurolysis (cutting of a nerve), resection (partially cutting a nerve), neurorrhaphy (suturing a nerve), and nerve graft reconstruction. The specific treatment is related to the anatomic location of the injury and patient factors such as age, discomfort, motivation, etc. The best results occur when a direct connection can be made between two ends of the nerve, if it has been cut. If there is a gap between the two ends of the nerve, a nerve graft may be helpful. In addition to various artificial materials used for grafts, a donor nerve segment can be obtained from one of the patient's own sensory cutaneous nerves – usually the sural nerve in the lower leg or the greater auricular nerve in the neck.

From this very involved cranial nerve, the trigeminal, we again move to one of the simpler nerves, the abducent, which, similar to the trochlear nerve, only functions to control a single eye muscle.

REFERENCES

Adams H, Pendleton C, Latimer K, *et al.* (2011) Harvey Cushing's case series of trigeminal neuralgia at the Johns Hopkins Hospital: a surgeon's quest to advance the treatment of the "suicide disease". *Acta Neurochirurgica* **153**: 1043–50.

Bell C (1829) On the nerves of the face, being a second paper on the subject. *Philosophical Transactions of the Royal Society of London* 1317–30.

Bell G (1911) Ocular manifestations of the peripheral affections of the fifth cranial nerve. *Medical Record* 863–6.

Boddy E (1901) Lesions of the fifth pair of nerves. *Dental Cosmos* **xliii**: 926–35.

Cushing H (1920) The major trigeminal neuralgias and their surgical treatment based on experiences with 332 Gasserian operations: the varieties of facial neuralgia. *American Journal of the Medical Sciences* **160**: 157–83.

Genese F, Goldstein LB (2013) Trigeminal neuralgia: a closer look at this enigmatic and debilitating disease. *Practice Pain Management* **12**: 34–8.

Harris W (1937) *The Facial Neuralgias*, Oxford University Press, London.

Karsteter PA, Yunker C (2006) Recognition and management of an orbital blowout fracture in an amateur boxer. *Journal of Orthopaedic and Sports Physical Therapy* **36**: 611–18.

Kothari P (2012) Classical picture of port wine stain. *WebmedCentral Dentistry* **3**(1): WMC002897.

Laurencet FM, Anchisi S, Tullen E, Dietrich, PY (2000) Mental neuropathy: report of five cases and review of the literature. *Critical Reviews in Oncology and Hematology* **34**: 71–9.

Marques YMS, Gomes JM (2011) Decompression of inferior alveolar nerve: case report. *Journal of the Canadian Dental Association* **77**: b34.

Sindou M (2009) Trigeminal neuralgia: a plea for microvascular decompression as the first surgical option. Anatomy should prevail. *Acta Neurochirurgica* **152**: 1–4.

Stookey BP, Ransohoff J (1959) *Trigeminal Neuralgia: Its History and Treatment*. C.C. Thomas, Springfield, IL.

Tomabene S, Vike TM (2010) Gradenigo's syndrome. *Journal of Emergency Medicine* **38**: 449–51.

6 The Abducent Nerve

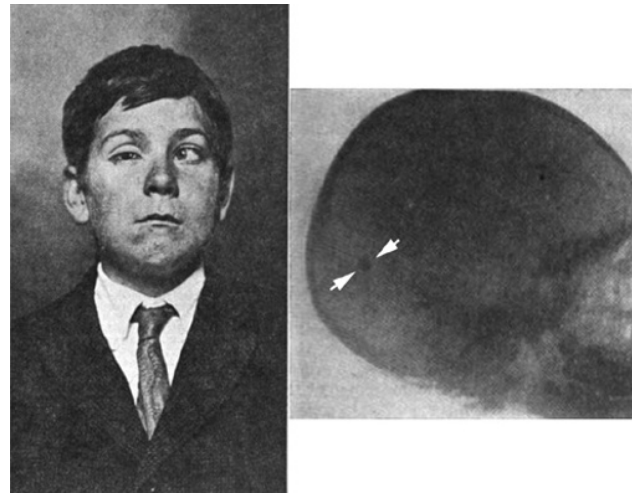

Figure 6.1 Photograph of a boy with a left abducent nerve palsy (left image) due to a bullet located in his brain, as shown in the 1914 radiographic image (right image). He also has ptosis on the right, which is not from the CN VI injury.

ANATOMY/FUNCTION SUMMARY

The abducent (abducens) nerve exits the brainstem and then enters the cavernous sinus. From there, it enters the superior orbital fissure and then the orbit to innervate the lateral rectus muscle (Figures 6.2 and 6.3). The abducent nerve is the most commonly injured nerve to an extra-ocular muscle, probably because it turns sharply over the petrous portion of the temporal bone before entering the cavernous sinus. It is the sole cranial nerve to an extra-ocular muscle to be commonly affected bilaterally. If the lateral rectus muscle is not functioning, horizontal eye movements are uncoordinated and the deficient eye cannot move very far laterally. Its name is derived from the fact that the only function of the nerve is to innervate the lateral rectus muscle, the abductor of the eyeball.

In 1914, Dr. E.H. Cary described a fascinating case of abducent nerve palsy that resulted from a gunshot wound.

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
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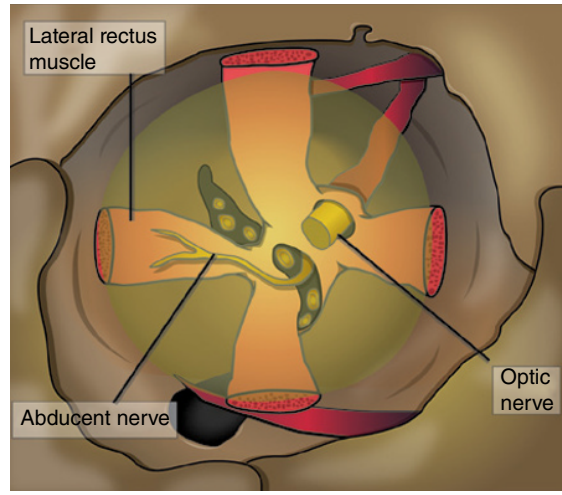

Figure 6.2 Schematic illustration showing the abducent nerve passing into the orbit and innervating the lateral rectus muscle.

On December 26, 1913, a boy, 14 years of age was shot in the head with a 22 caliber rifle. The bullet entered the left side of the nose and passed directly backward through the nose midway between the base of the nostril and the tip of the nose. The bullet then passed through the posterior part of the nasal septum back through the upper part of the right sphenoidal sinus and then penetrated the cavernous sinus, wounding or severing the sixth nerve. The bullet then penetrated the brain and remained there (Figure 6.1).

This boy, five days later, entered the Texas Baptist Memorial Sanitarium in the service of Dr. Doolittle. On admission to the hospital the patient was conscious and answered questions intelligently. His pain became evident on the second day following the injury, continued for nine days and disappeared as suddenly as it came. The patient stated that when he was shot he felt a sharp pain in the right parietal region and thought the bullet entered there. He fell when the bullet struck, but got up immediately without loss of consciousness. He further stated that immediately following the injury there was profuse bleeding from his nose and mouth.

On the day of admission, December 31, 1913, examination showed inequality in size of pupils – the right about 2 mm, the left about 4 mm in diameter, and both pupils reacted to light. The patient's right eye deviated to the medial side of the orbit due to the loss of the abducent nerve (Figure 6.1).

On January 2nd, patient slept fairly well, complained of pain between the shoulders and of headache. The patient was discharged but before going home was instructed as to the care of his eye, the prognosis being based on its proper care (Cary, 1914).

The author of the report noted that this was an extremely interesting case, "…the like of which none of us will ever see again; if we take the results into consideration. You cannot drive a probe through a skull with a brain in it in the same direction this bullet went without striking something more vital than the bullet did."

ANATOMY/FUNCTION

The abducent nerve leaves the brain stem as a thin bundle of fibers at the lower border of the pons to enter the subarachnoid space. It runs ventrally and a little laterally and pierces the dura mater a little below and medial to the trigeminal nerve to enter the cavernous sinus (Figures 6.4 and 6.5).

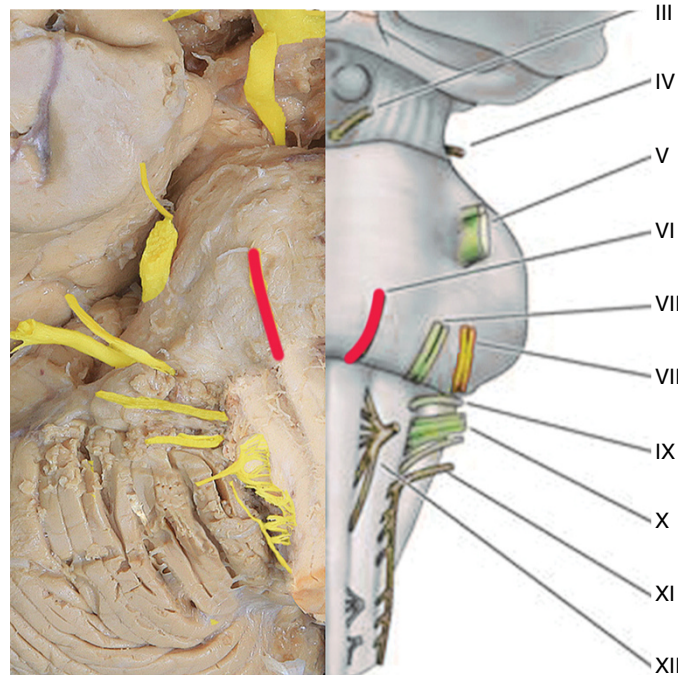

Figure 6.3 Photograph and drawing highlighting the origin of the abducent nerve from the brainstem.

Within the cavernous sinus, the abducent nerve is found lateral to the internal carotid artery and medial to the ophthalmic nerve (Figure 6.5). It enters the orbit through the superior orbital fissure (see Figure 6.4) and then lies against and innervates the lateral rectus muscle (Figures 6.6 and 6.7). In the cavernous sinus, the nerve is joined by some sympathetic fibers from the plexus on the internal carotid artery.

The lateral rectus muscle's only function is to abduct the eye. Thus, any reduced activity in this muscle results in an eye that is more adducted than it should be, and one that does not move smoothly with the other eye when looking toward the side of the affected lateral rectus muscle.

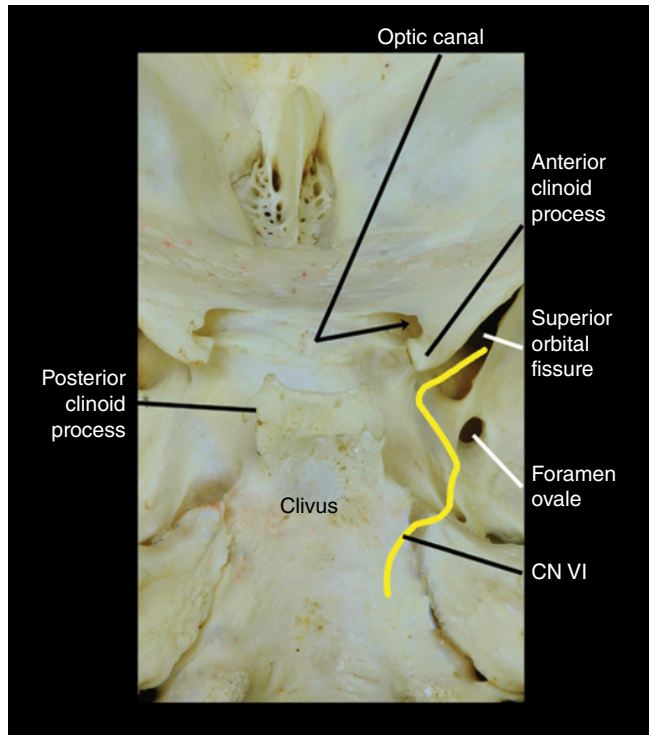

Figure 6.4 Schematic illustration showing the path of the abducent nerve passing from the brainstem to the orbit.

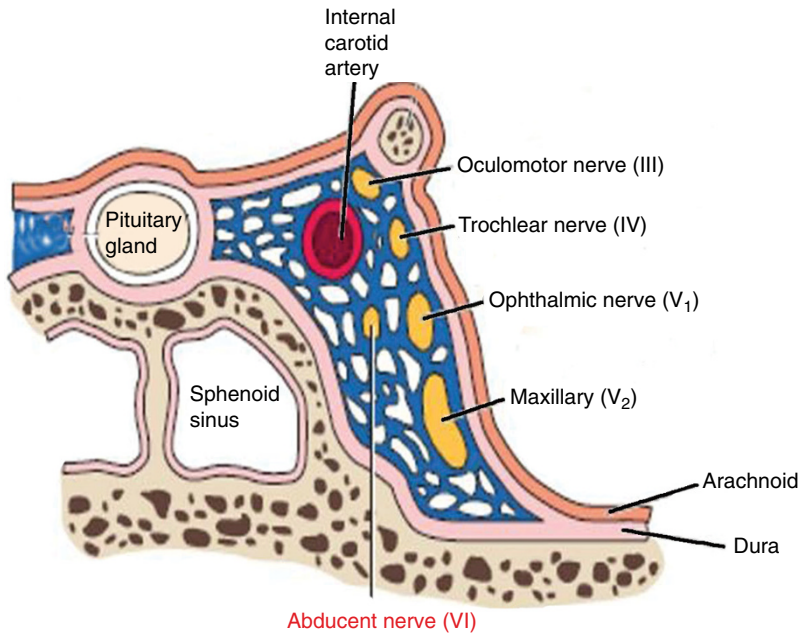

Figure 6.5 Coronal cross-sectional view of the cavernous sinus highlighting the position of the abducent nerve vis-à-vis the other cranial nerves and blood vessels located within the sinus.

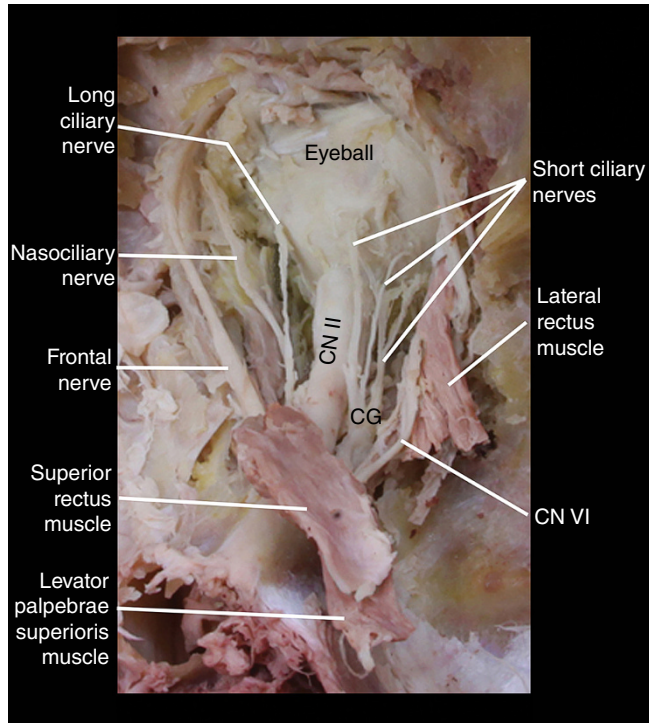

Figure 6.6 Superior view showing the abducent nerve entering the orbit (roof of orbit removed) and innervating the lateral rectus muscle. Note that the superior rectus and levator palpebrae muscles are cut and reflected and that the lateral rectus muscle is cut. Note also how the abducent nerve enters the medial surface of the muscle. CG, ciliary ganglion.

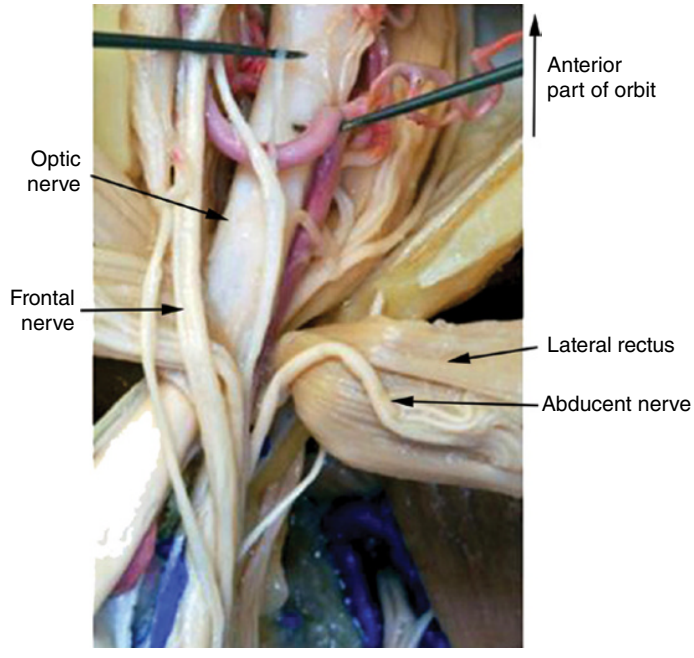

Figure 6.7 A closer superior view than that shown in Figure 6.6 in which the abducent nerve is shown entering and innervating the lateral rectus muscle. Courtesy of Dr. Wonil Joo, Catholic University of Korea, South Korea.

Judy wrote this to an Internet forum:

> I am a 27-year-old female. Three weeks ago I began having "jumping eyes" which got progressively worse into "crossed eyes/double vision." Three days ago my eyes crossed and have been that way since. I have already received my diagnosis (went to eye doctor today) of VIth nerve palsy. He was concerned that I have no other symptoms and I am younger than most patients diagnosed with this. Also he commented that the usual onset is only a couple days and its full blown double vision…mine, has taken three weeks to full double vision.
>
> I will be having an MRI Friday and a blood workup though I have never had diabetes, high blood pressure, or high cholesterol. If the MRI shows nothing and the blood workup shows nothing that may have caused it I will be having an MRA [magnetic resonance arteriogram; an MR scan that looks at the blood vessels in the brain] (I guess looking at the arteries in my head not just structure?). The doctor was excellent today because from everything I am reading about this condition he diagnosed me correctly and is doing all the necessary testing.
>
> I am posting because I find my case interesting and was wondering if anyone had any opinion (not necessarily suggestions as if the doctor should test for something else). I do have a patch but the strain is only relieved for about fifteen minutes so it's "patch on, patch off" (can't you hear Mr. Maigi from Karate Kid?!). Are there any other suggestions for temporary relief? I am getting a kink in my neck because I am turning my head to look to the left (it's my left eye affected so can't look straight or to the left AT ALL). Aside from walking around with my eyes shut, anyone have anything? Warm tea bags on my eyes? Cool cucumber slices? I can't drive, can't do my job properly, and am beginning to have a constant headache from the strain. And this may last 3 to 6 months?!?!?! GULP!

The abducent nerve can be absent congenitally (Duane syndrome) with the lateral rectus innervated by a branch of the oculomotor nerve. This syndrome is the cause of about 1% of all cases of strabismus (crossed eye; this results because both the lateral and medial rectus are now innervated by the same nerve and often inappropriately activated together).

A colorful description of an autopsy case of unilateral absence of the abducent nerve was provided by Generali in 1842:

> When finding myself on the morning of April 4, 1842, in the anatomy room I saw half a head from which the brain had been removed. Interested as I was in repeating my observations and in varying the manner of teaching, the case led me to reveal a rare anomaly …. That fragment of cadaver belonged to an old lady of about 90 years of age, blind for some time and almost completely deaf. It was the left half of the head; I searched along the basilar canal under its silvery rug, beneath the posterior clinoid process for

the nerve of the sixth pair, ordinarily situated there in the dural sheath, in order to be able to follow it along its course; and not having found it, I supposed that it might have been torn in the process of removing the cerebral mass; nevertheless, I insisted upon discovering the opening through which that nerve trunk ordinarily passes, and I was struck by surprise and curiosity when I realized there was no trace of the canal I sought. …

With hammer blows I reduced the orbital vault to fragments thus uncovering the neuromuscular apparatus contained in that cavity; and occupying myself in examining the lateral rectus muscle, or abductor of the ocular bulb, I revealed that that muscle received two small nerve fibers which penetrated it on the corresponding part internally (on the ocular side); these branches were immediately derived from the nerve of the third pair or oculomotor nerve (Generali, 1842).

CLINICAL ASPECTS

Signs and symptoms

Sixth nerve palsy often involves other nerves or neurological structures and it is sometimes difficult to determine if palsy only involves this nerve. Common causes of presumed, isolated unilateral abducent nerve palsy include trauma, vascular deficiency (primarily related to diabetes), lumbar puncture (spinal tap; the associated loss of CSF [cerebrospinal fluid] induces a slight drooping of the brain), stretching (pinching of the nerve), tumors, and multiple sclerosis (MS). The recovery rates are about 30–60%, with lower rates for bilateral palsy.

Below is a case of abducent nerve palsy that occurred after an inadvertent release of CSF during an attempt to induce spinal anesthesia (the dura mater of the spinal cord should not have been penetrated in this procedure). The vast majority of lumbar puncture patients do not suffer abducent nerve damage although headache is a common post procedure symptom. However, some lumbar puncture patients do, in fact, suffer abducent nerve palsy, which occurs with the reduction in CSF pressure. As in the presented case, these patients typically recover, usually in a few weeks.

A woman aged 42 was to receive an extradural analgesic for surgery to remove her gall bladder, but inadvertently the dura was pierced by a large gauge needle, with the patient lying on her right side. There was a rapid loss of about five ml of CSF through this large bore needle. The next day the patient complained of nausea, pain in the back of the neck and headache, aggravated upon sitting up. Three days later double vision was noted. The next day the left lateral rectus muscle was completely paralyzed. It took three months for complete recovery (Bryce-Smith and MacIntosh, 1951).

Below, we present a case in which dental anesthesia in a previously undiagnosed MS patient may have caused a transient, abducent nerve palsy.

A 30-year-old man presented with a sudden occurrence of diplopia on left lateral gaze the day after extraction of the mandibular right second and third molars because of cavities. He did not complain of head or eye ache, nausea, dysphagia (swallowing difficulty), or speech problems, nor did he indicate paresthesia or weakness in his limbs. On neurologic examination, there was a restriction on lateral gaze of the left eye. The rest of his neurologic examination was normal.

Based on MRI scans, MS was then diagnosed. He was treated for five consecutive days with 1000 mg/day intravenous methylprednisolone, followed by 40 mg/day oral prednisolone for 15 days, which was tapered 8 mg every 3 days [these are steroids that are used to minimize inflammation]. There was a partial improvement of left abducent paralysis at the fifth day of intravenous corticosteroid therapy. The improvement was remarkable at the sixth day of oral corticosteroid therapy, and he was completely cured at 20 days (Kocner, 2009).

The authors interpreted their results as indicating that the two events, onset of MS attack and lateral rectus palsy were linked (i.e., the attack of MS resulted in the lateral rectus palsy) and that both were likely triggered by the dental anesthesia.

What is intriguing about this case report is that there are no prior observations in the literature relating the onset or an attack of MS following the usage of local mandibular nerve anesthesia. Thus, we are left to ponder whether mandibular block anesthesia may precipitate an MS attack.

As in the aforementioned case, MS is the assumed cause in 4–9% of unilateral sixth nerve palsies. In the majority of cases, however, a detailed history and neurological examination reveal other symptoms or signs of brainstem dysfunction when MS is the cause of a sixth nerve palsy. Thus, true isolated sixth nerve palsy is very uncommonly the first sign of MS.

Bilateral palsy, although more common with the sixth nerve than with other cranial nerves, is still relatively uncommon. Many of these cases involve abnormalities of the subarachnoid space such as elevation or depression of CSF pressure, meningitis, or neoplasm. Papilledema (see Chapter 2; Figure 2.7) is often present in these cases.

H. Steele and colleagues published a case of bilateral abducent nerve palsy in 2007 that was due to cancer (Figure 6.8):

A 59-year-old man presented with a three-week history of double vision, which was worse on looking to the left (Figure 6.8). The patient also had non-insulin dependent diabetes mellitus, hypertension and hypercholesterolaemia [high cholesterol levels]. For the previous six months he had been experiencing daily left-sided frontal headaches.

An initial CT scan found nothing abnormal. Based on his vascular risk factors, a microvascular sixth nerve palsy was the preliminary diagnosis, but there were atypical features – headache, a stuttering onset to the diplopia, and the partial nature of the lateral rectus palsy – and so further investigation was necessary. His glasses were fitted with a prism that corrected the diplopia for three months, although his headaches persisted. The patient then felt that his diplopia worsened and the prism no longer helped. He began wearing an eye patch. On this examination he had bilateral partial lateral rectus palsies but no other new findings. A CT head scan now showed patchy destruction of the skull base. So rather than a vasculopathic cause, this patient's abducent nerve palsy was due to a metastasis [cancer spread] to the base of the skull.

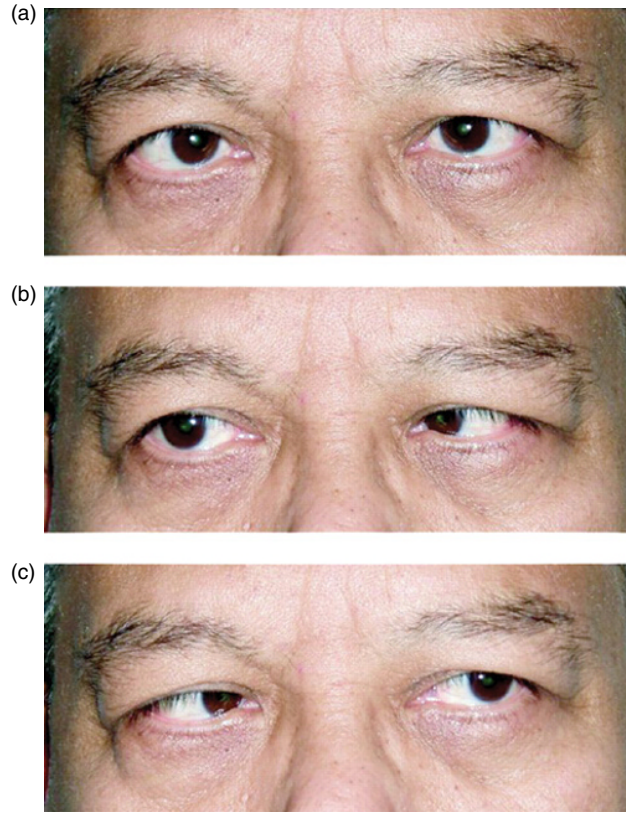

Figure 6.8 Eye movement in a patient with bilateral abducent nerve palsy. In (a), the patient is asked to look straight, in (b) the patient is asked to look to the right, and in (c) the patient is asked to look to the left. Reprinted with permission from Steele *et al*. (2007).

Lateral rectus palsy can occur as a result of a pathological process affecting the abducent nerve in the subarachnoid space as it exits the brainstem. The nerve can be compressed by arteriosclerotic vessels, posterior cranial fossa masses, or malformations. Traumatic injury can be direct from surgery or indirect by blunt trauma. In addition, the nerve can be compressed by a primary or

metastatic tumor or, rarely, there can be a primary tumor of the nerve sheath (schwannnoma).

The sixth nerve as well as other ocular nerves can be involved in abnormalities in the cavernous sinus or the superior orbital fissure. Primary and metastatic tumors, infectious and inflammatory processes, ischemic lesions, and aneurysms can occur in these areas and cause a sixth nerve palsy. Unlike the oculomotor nerve, direct pressure from an aneurysm is a very uncommon cause of isolated sixth nerve palsy. Tests to evaluate the likelihood of an aneurysm are not necessary in this situation. If a distant aneurysm has ruptured, however, it can cause subarachnoid hemorrhage or increased intracranial pressure, which can secondarily cause a sixth nerve palsy.

Although diabetes would not typically be the likely cause of a patient with bilateral, as opposed to unilateral sixth palsy, Gupta and colleagues described such a case in 2009:

> A 70-year-old woman complained of horizontal diplopia. She had mild headaches and a prior sinus infection. Her past medical history included diabetes mellitus, obesity (450 lbs), high blood pressure and high cholesterol levels, asthma and rheumatoid arthritis. Lab work and MRI did not provide any evidence of brain or brainstem abnormalities and thus her physicians doubted brainstem abnormalities were the cause of her diplopia. Thus, the authors concluded that this patient had the unusual condition of bilateral abducent nerve paralysis due to microvascular ischemia associated with her diabetes. Three months after onset, this patient had complete recovery (Gupta, Bhatti, and Rucker, 2009).

Treatment

Spontaneous recovery occurs in most cases of acquired sixth nerve palsy when a specific cause is not found. If a cause is found (e.g., tumor, MS) treatment is based on this underlying cause. Symptomatic treatment with an eye patch or prism lenses diminishes double vision during recovery.

In a patient with lateral rectus weakness or palsy associated with abducent nerve dysfunction, the intramuscular injection of botulinum toxin (Botox) in the medial rectus muscle of the same eye can be used to prevent or minimize medial rectus muscle contracture and allow more normal eye movements. This toxin (originally known as a "sausage poison" or "fatty poison" because the bacterium that produces it was found in contaminated meat products) acts to temporarily inactivate impulse transmission between the nerve and muscle. Thus, it can be used therapeutically to temporarily paralyze muscle. Usually botulinum toxin injection provides higher recovery rates than conservative treatment.

An Internet case of abducent palsy treated with prism lenses is presented below:

> My husband (age 66) suddenly developed double vision four days ago. We were sent to the eye emergency department and they said it was nerve failure to the eye muscle that pulls to the side. Possibly caused by a mini-stroke. He has no other symptoms thankfully. They fitted a prism lens over his glasses and it was very good but worsened over the weekend so we had to go back today. It had gotten quite a bit worse so he now has a stronger prism which is harder to see with but at least it is not double images until he looks much further away. He has to have a full check up with his own doctor later in the week.

If there is persistent double vision after 6 months, eye muscle surgery can be considered.

We are now done with the nerves that control the eye muscles. The next nerve, the facial, has many functions, including controlling all of your muscles of facial expression.

REFERENCES

Bryce-Smith R, MacIntosh RR (1951) Sixth nerve palsy after lumbar puncture and spinal analgesia. *British Medical Journal* **1**: 276–7.

Cary E (1914) Gunshot wound. *Texas State Journal of Medicine* 239–41.

Generali, G (1842) Considerazioni anatomiche, fisiologiche e patologiche intorno il nervo Gran simpatico. Annali universali di medicina compilati dal dottore A. *Omodei* **104**: 60.

Gupta PK, Bhatti MT, Rucker JC (2009) A sweet case of bilateral sixth nerve palsies. *Survey Ophthalmology* **54**: 305–10.

Kocner B (2009) Isolated abducent nerve palsy following mandibular block articane anesthesia: a first manifestation of multiple sclerosis: a case report. *Quintessence International* **40**: 251–6.

Steele H, Aram J, Wilhelm T, Hickman SJ, Ginsberg L (2007) A difficult case: not a microvascular sixth nerve palsy. *Practical Neurology* **7**: 400–4.

7 The Facial Nerve

Figure 7.1 Drawing from 1869 showing a patient with bilateral facial weakness. Reprinted from Wright (1869).

ANATOMY/FUNCTION SUMMARY

The facial nerve has the most complicated anatomy of all the cranial nerves, probably because it is composed of two separate elements that many have argued should really be considered separate cranial nerves. These two separate elements have many somatic and autonomic functions, including innervating all of the muscles of facial expression and causing tearing of the eye and salivation from the salivary glands beneath the tongue.

The beautiful image in Figure 7.1 shows a patient with bilateral facial nerve palsy who was described by Dr. Wright in 1869.

> W.E., aged 65 years, enjoyed good health up to the year 1863, when, early in May, he was seized with repeated and profuse bleedings from the nose. They were successfully checked by plugging. The plugs were removed at the end of sixteen days in a putrid state. Shortly after the epistaxis [nosebleed] he began to complain of acute headache, which continued without cessation for a period of nine weeks. The patient, about this time, first

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came under my own notice. He appeared to be in a feeble and shattered state of health, and suffered much pain in the region of both ears, which speedily became, almost simultaneously, the seats of large abscesses. These discharged very copious quantities of pus, and became the source of profuse and offensive earache, which continued fully five years then gradually ceased. About three months after he began to be out of health, the patient fancied, one morning at breakfast, that he had partially lost the use of his face, for he could not easily control the efforts necessary for the mastication of his food. This was very noticeable on examination, since there was, in fact, palsy of a portion of the left side of the face. The mouth existed in this wry state for about a week, when, the opposite side became affected. The lips now gradually became completely palsied; afterwards the eyelids; and, last of all, the muscles of the nostrils. There is no paralysis of the tongue, nor is the taste sensibly impaired. The sense of smell would be perfect were it not that, on attempting to inspire through the nostrils, the nostrils collapse with the instantaneousness and accuracy of valves. In order to complete the act of mastication, the patient is compelled to surround the lower jaw with his thumb and index finger, in order that, by pressing his cheeks against the gums, he may prevent the accumulation of food in the sulcus which is formed by them and the buccinator muscles.

The tactile sensibility of the face is perfect in every part, and, according to the patient's own statement, sometimes unpleasantly excessive. When questioned about the salivary secretion, he states that he never spits; he could not if he desired. The eyes shed an abundance of tears, which, not finding their way into the nostrils, trickle over upon the cheeks, and leave the sinus membrane [cornea] dry. The doubly palsied visage once seen is never to be forgotten. It has been compared to a "mask"; but a mask has always some kind of expression; this, however, has none. It is absolutely soulless, and, even in the greatest merriment, so awfully dismal that the mirth would produce the same effect upon the bystander if it proceeded from a lifeless object. The eyelids look "like a broken bow"; and the red everted membrane of the lower one is bathed in tears which are welling over upon the face. The globe of the eye is forcibly retracted beneath the overhanging brow. From the maxillary bones hang the flabby cheeks, in conversation flapping to and fro like vacant sails. The upper lip is pendulous and bulky; the lower one falls and doubles upon itself, thus allowing the free escape of fluids introduced into the mouth. From his inability to articulate with accuracy the labial consonants b, p, f, m, v, and those combinations which require, for their accurate formation, the explosive action of the buccinators, the patient finds great inconvenience in sustaining a continued conversation. The difficulty, however, is to some extent overcome by supporting the lower lip in apposition with the upper, inflating the cheeks and suddenly compressing them with the tips of the fingers. It is both curious and interesting to witness the constant use which a person, suffering from this affection, is ever making of his fingers in aid of the muscles of the face (Wright, 1869).

This wonderfully descriptive passage shows how the loss of one's facial muscles affects many aspects of one's life, including interacting with others and eating. This view was similarly expressed by Mavrikakis in 2008, when he stated, "Normal facial function plays a critical role in a person's physical, psychological and emotional makeup."

ANATOMY/FUNCTION

The VIIth cranial nerve, the facial, is the nerve that supplies the muscles of facial expression (Figure 7.2). A somewhat independent part of the nerve that is considered by some authorities to be a separate cranial nerve is called the intermediate nerve (nervus intermedius); it was given this name because the nerve is located "intermediate" between the facial nerve proper and the VIIIth cranial nerve as they exit the brainstem (Figure 7.3). The intermediate nerve contains parasympathetic fibers within it that, upon stimulation, result in salivary gland secretion and tearing, and also has some general sensory taste fibers.

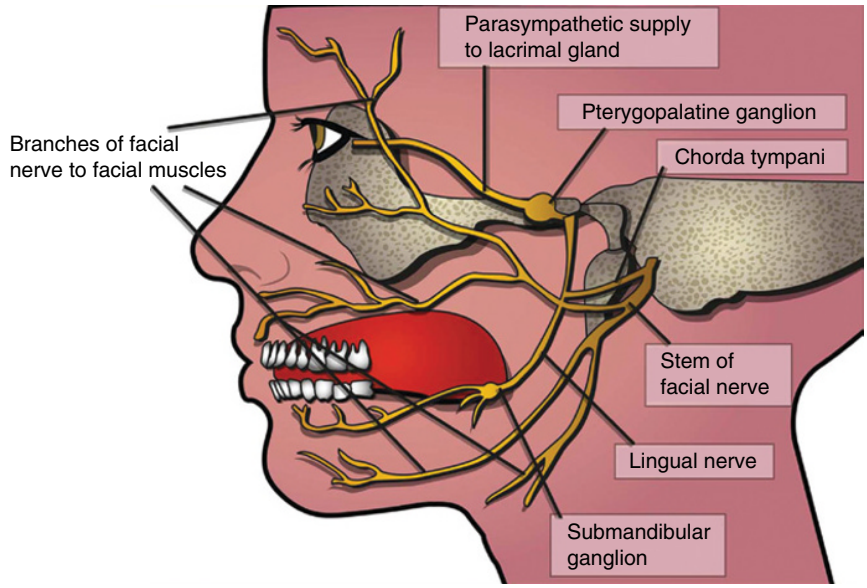

Figure 7.2 Schematic illustration of the anatomy of the branches of the facial nerve.

The facial nerve (proper) emerges as a fairly large fiber bundle at the caudal border of the pons, in front of the VIIIth cranial nerve (Figure 7.3). The fibers of the intermediate nerve typically emerge from the brainstem as a single root, although there can be more than one, and form a small bundle between the facial and the VIIIth nerve; the intermediate nerve then travels with these two nerves in their course to the opening of the internal auditory canal (IAC)

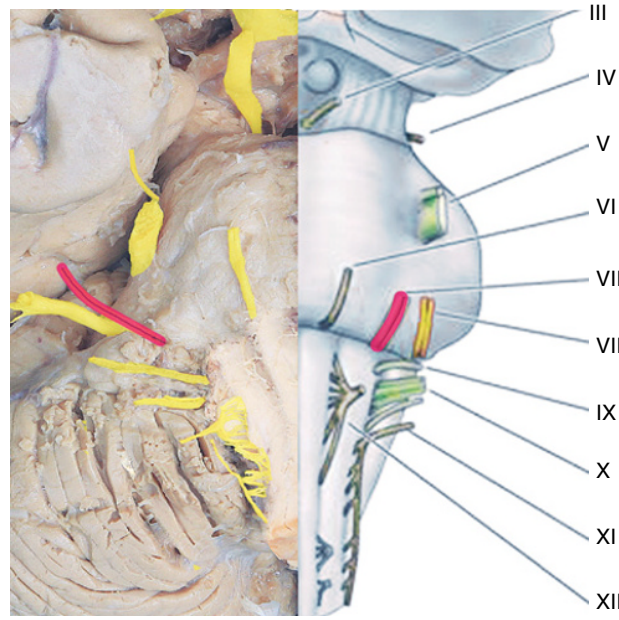

Figure 7.3 Brainstem photograph and illustration highlighting the origin of the facial nerve from the brainstem (note the differentiation of the nerve into two elements; the lateral element is the intermediate nerve).

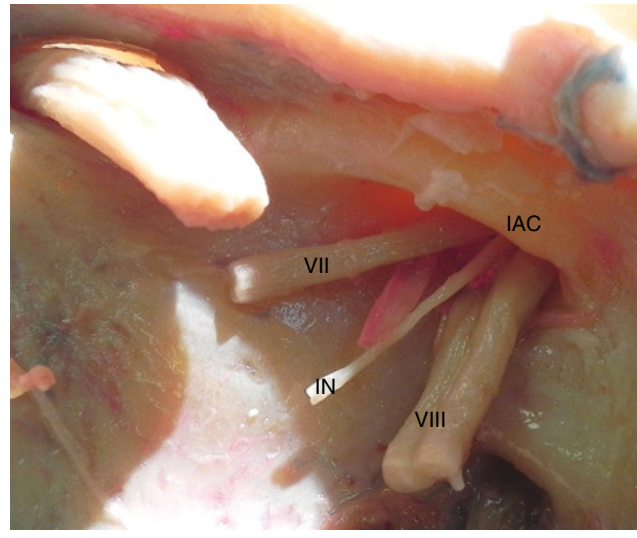

Figure 7.4 The intermediate (IN), facial (VII), and vestibulocochlear (VIII) nerves entering the internal auditory canal (IAC). Courtesy of Dr. R. S. Tubbs.

(Figures 7.4, and 7.5). From the opening of the IAC, the facial and intermediate nerves continue in their bony channel (facial canal; fallopian canal; Figure 7.5), which is within the petrous part of the temporal bone (Figures I.33 and 7.5).

The intermediate nerve has many names, that is, nervus intermedius, intermediary nerve, portio intermedia, Wrisberg's nerve, and Sapolini's nerve. It is considered to be responsible for the sensations of taste from the anterior two-thirds of the tongue, floor of the mouth, palate, and general sensory information from a portion of the skin of the external ear (auricle), and to carry the parasympathetic fibers (motor) associated with the facial nerve. Cell bodies of the sensory neurons are located in the geniculate ganglion within the facial canal (Figures 7.5 and 7.6), whereas the cell bodies of the parasympathetic fibers are in the brainstem.

Although the intermediate nerve is generally considered part of the facial nerve complex, there have been repeated calls for it to be considered its own cranial nerve since 1881, when Giuseppe Sapolini, physician to Italian King Victor Emmanuel, labeled it the XIIIth cranial nerve.

Sometimes, the sensory fibers associated with the facial (intermediate) nerve may cause a condition similar to trigeminal neuralgia (see more in the Clinical section later in this chapter). In 1909, Drs. Clarke and Taylor published a report titled "True tic douloureux of the sensory filaments of the facial nerve" in *The Journal of the American Medical Association*.

Patient – Mrs. E.T., aged 28. Aside from the history of morphinism [using too much morphine], contracted since the neuralgia began, the family and personal history previous to present illness are negative.

Present Illness – In February, 1907, the patient experienced paroxysmal, intermittent pain without known cause, just in front of the left ear. The pain occurred for half an hour almost weekly. Two months afterward the pain in front of the ear was of daily occurrence of a typical neuralgic character, sometimes lasting for two and three hours. In the following October, eight months after the onset, the pain had increased constantly so that there was not only a stabbing pain in front of the ear, but also a steady pain in the depths of the ear, on the anterior wall of the external meatus. At times there was a moderate degree of neuralgic pain in all three distributions of the trigeminal nerve and in the occipital region. The latter distribution of pain in the trigeminal and occipito-cervical nerves decreased in five or six months, was intermittently present during the following year, but was never so severe as in front of the ear and in the anterior wall of the external meatus. The patient was taking about twelve grains of morphine daily when I first saw her. Hygienic and electrical treatment very soon removed all the neuralgic pain except that in the region of the ear. All ear, eye and throat and general medical examinations proving negative, the conclusion was unavoidable that the lesion was a true tic douloureux of the geniculate system of the facial nerve, and that the proper remedy was a physiologic extirpation [surgical removal] of the ganglion, which I recommended. Later I learned that Dr. Starr had practically come to the same conclusion and recommendation.

The operation was performed at the New York Hospital by Dr. Taylor, April 23, 1909.

Postoperative History – Immediately after the operation all pain ceased. The patient had some ataxia [unsteadiness], which steadily improved. The hearing, slightly impaired at first, owing to slight damage of the acoustic nerve, was reported normal by an otologist one week after operation. The division of the facial nerve resulted in a complete peripheral palsy which we trust will undergo spontaneous recovery in time; if not, a faciohypoglossal nerve anastomosis [connection] may be undertaken. A slight redness of the external auditory meatus at the junction of the anterior wall with the tympanic membrane, observable before operation, has since disappeared. All sensory examinations of the face and external ear proved negative three days after operation. The former area of pain seemed to the patient to be a little less sensitive in the tests. Since the operation patient has reduced her morphine from twenty-five grains to about six or eight grains daily. A steady withdrawal is in progress.

To summarize: We have here a true tic douloureux of the sensory filaments of the facial nerve, apparently cured by a physiological extirpation of the geniculate ganglion.

Note – October 10, 1909: Examination of the patient today, a little more than five months since the operation, shows the following: The patient has had no pain in the ear; hearing is, nearly if not, quite normal and the conjunctival dryness on account of the facial palsy is much less troublesome. The normal muscle tone of the paralyzed face is present and slight but distinct voluntary contraction in the face is observable at the superior and inferior angle of the mouth and in the zygomatic and buccinator muscles. The ataxia is no longer present.

In 1909 when the Clarke and Taylor report was published, it is clear that the greatly reduced activity in the facial muscles (see the following text) was an acceptable outcome of the surgery because of the reduction in pain. Also, at that time medication options were limited.

The general motor fibers of the facial nerve are axons from the cells of the motor facial nucleus in the brainstem (Figure I.12). Fibers from the motor cortex generate impulses initiating voluntary movements of the facial muscles, which reach the facial muscles via the facial nucleus in the pons. In addition, the facial nucleus may be activated by impulses from subcortical regions, which presumably play a role in the emotional innervation of the facial muscles (reflect for a moment how effortless it is to smile without thinking about it, for example, as a response to someone else's smile [emotional smile] but yet is difficult to produce a true smile voluntarily). Furthermore, afferent impulses entering some of the other cranial nerves may elicit reflexes in which the efferent link of the reflex is formed by the facial nerve (e.g., the blink reflex; see Chapter 5).

In humans, the facial nerve contains about 7000 fibers. Three-quarters of these are myelinated and most of them are relatively thick, 7–10 μm. It is likely that the fibers from the facial nucleus in the brainstem of one side pass only to the facial muscles of that side.

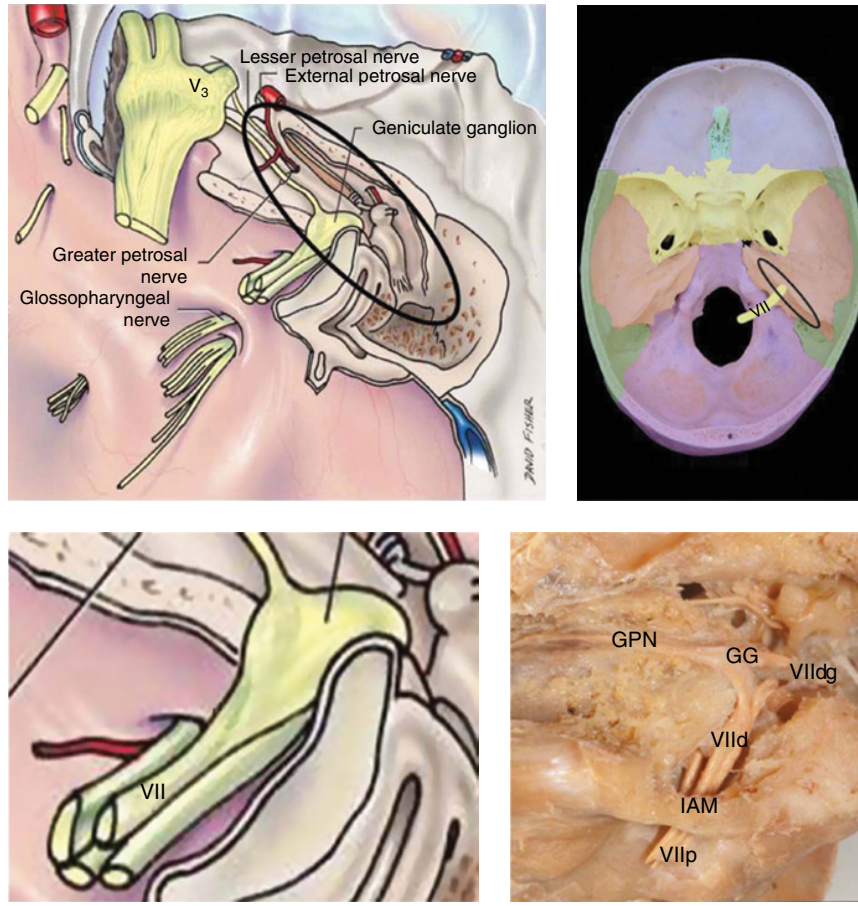

Figure 7.5 Upper left: a drawing of the junction between the right anterior and middle cranial fossae with the bone overlying the petrous portion of the temporal bone "cut away" to show the intrinsic structures including the internal auditory canal (IAC) and the geniculate ganglion. Upper right: a superior view of the cranial fossae showing the location from which the drawing on the left is derived (black oval); CN VII is drawn in on the image. Lower left: a drawing of the nerves entering the IAC (from the image directly above with CN VII labeled). (The drawing shows nerve VII including the intermediate nerve; the other nerves entering the IAC are all components of CN VIII; see Chapter 8.) Lower right: an actual dissection of the area circled in the above images with most of the petrous portion of the temporal bone removed. Abbreviations: VIIp, CN VII proximal to IAC; IAM, internal auditory meatus (canal); VIId, CN VII distal to IAC; GPN, greater petrosal nerve; GG, geniculate ganglion, VIIdg, CN VII distal to the geniculate ganglion. The image on the upper left is reprinted from Tubbs *et al*. (2009). The lower right image is modified with permission from Liu, Arnold, and Robinson (2012). Courtesy of Dr. M. Robinson; photographer, C. Jeffery.

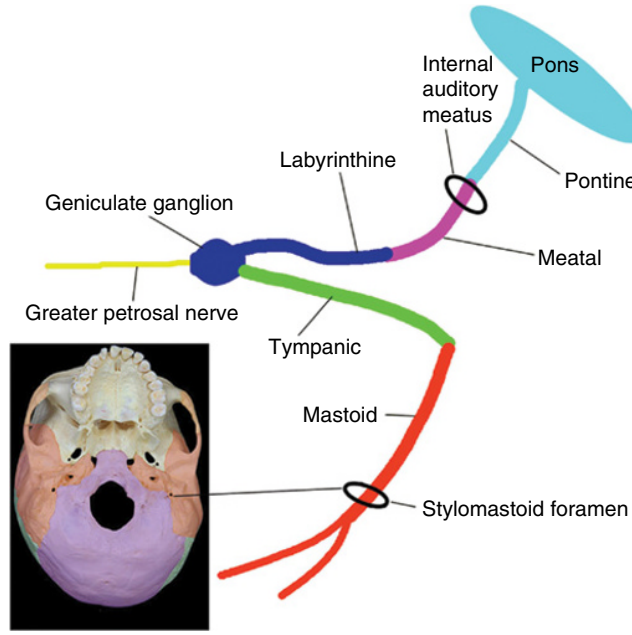

Figure 7.6 Illustration showing the parts of the facial nerve, with the inset showing the stylomastoid foramen for orientation.

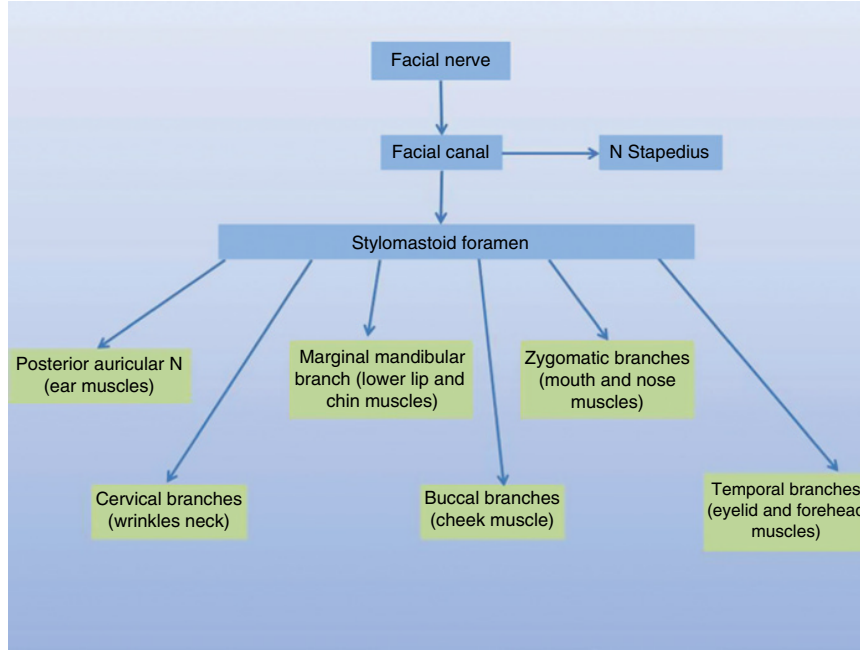

Figure 7.7 Flowchart showing the muscular branches of the facial nerve.

The initial part of the facial nerve between the brainstem and the internal auditory meatus (opening of the IAC) is called the pontine part (Figure 7.6). The meatal part of the facial nerve enters the canal, which at this point is directed laterally (Figure 7.6); as the nerve passes adjacent to the inner ear, it becomes the labyrinthine part, which continues to the geniculate ganglion (Figures 7.5 and 7.6) where, at this so-called facial "knee" (geniculum), it makes a sharp bend in a posterior direction. The geniculate ganglion is located at this bend and this ganglion contains the cell bodies of the afferent fibers of the facial nerve (mainly those of the intermediate nerve). From the geniculum, the tympanic part of the nerve travels horizontally in a posterior direction. The canal with the nerve then makes a second bend and its final course is directed downward (mastoid portion) to the stylomastoid foramen (Figures I.32 and 7.6), where the facial nerve leaves the skull. The majority of the fibers of the intermediate nerve leave the IAC before the main nerve exits the skull (see the following text).

In the first part of its course external to the skull, the facial nerve is embedded in the parotid gland within which it forms a plexus (Figures 7.7 and 7.8) from which the nerves to the muscles of facial expression emerge. Before the facial nerve divides into its five terminal branches, it gives off a posterior auricular branch that ascends behind the auricle and innervates the extrinsic muscles of the ear and the occipital muscle. In animals that can do more than wiggle their ears as some people can, these muscles are very important for locating the source of a sound.

Surprisingly, wiggling of the ears can be a medical problem because it can occur involuntarily in response to stress or other psychological problems. In 1988, Dr. Keshavan presented a report that appeared in the *American Journal of Psychiatry* that described 10 patients who had a wiggling ear tic. The second patient is described below:

> Mr. B, a 46-year-old recently widowed shopkeeper, presented with "shaking" which had begun three months earlier, after his wife's death. He complained of a "heaviness" in his head, tenseness, sadness, self-pity, suicidal ideas, and sleep disturbances. His ears moved irregularly once or twice a second; the tics increased when he talked about his deceased wife and could be reduced at will briefly, at the cost of mounting inner tension. The results of a physical examination and other investigations, including an EEG [electroencephalogram], were normal. Both his depressive symptoms and ear movements gradually subsided over one year with psychotherapy and antidepressants (Keshavan, 1988).

Dr. Keshavan concluded that he could not explain why life problems manifested in tics of these "unobtrusive organs" in these patients.

Another early branch of the extracranial part of the facial nerve innervates the posterior belly of the digastric muscle and the stylohyoid muscles, which are accessory chewing muscles located under the tongue. Some motor fibers

emerge from the tympanic part of the nerve (Figure 7.6) and enter the middle ear cavity to innervate the stapedius muscle (Figure 7.9), which acts to reduce the movements of the last in the chain of the three middle ear bones, the stapes, and thus functions to dampen loud noises.

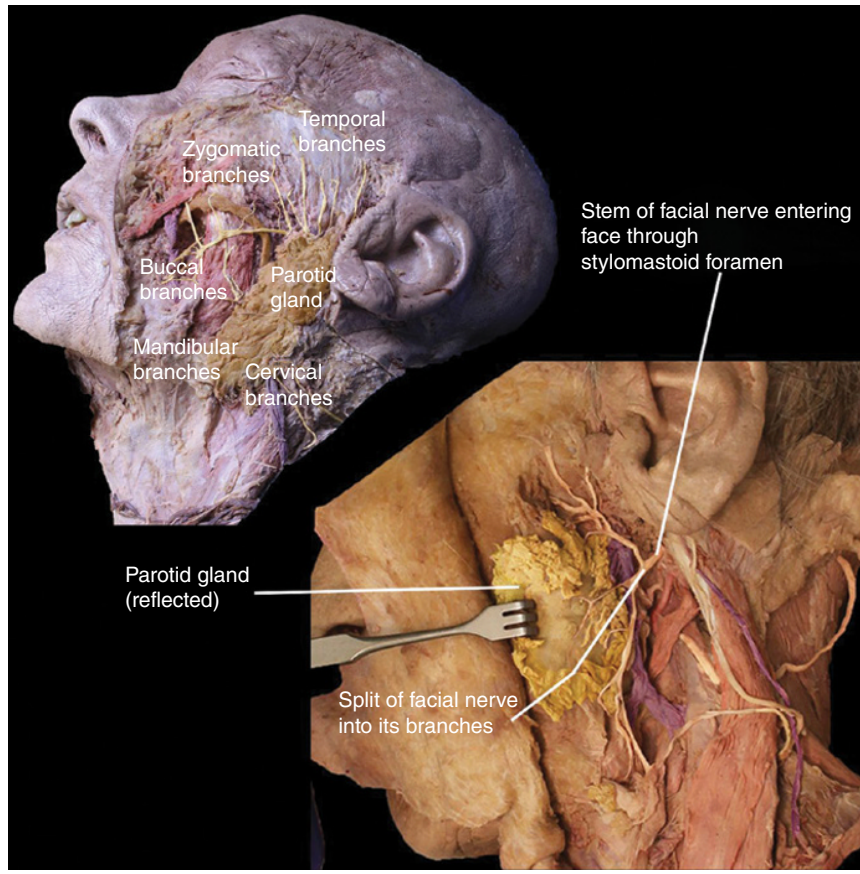

Figure 7.8 Upper left: dissection of the lateral aspect of the face showing the parotid gland and major branches of the facial nerve. Lower right: deeper dissection showing the stem of the facial nerve as it emerges from the stylomastoid foramen and splits into its many branches within the parotid gland, which is reflected. The lower image is provided with the courtesy of Drs. M. Robinson and L. Liu, the University of Sydney, Australia.

The upper terminal branches of the facial nerve run from the parotid plexus anteriorly across the zygomatic arch to the frontalis, orbicularis oculi, and corrugator muscles (Figure 7.10). Other branches course horizontally to the zygomatic, orbicularis oris, and other muscles surrounding the mouth, including the buccinator muscle. A lower cervical branch supplies the platysma, which is a very superficial muscle, not shown in Figure 7.10, that tenses the skin of the neck and can "pop out" and become quite prominent when we grimace. Classically, there are five terminal branches of the facial nerve: temporal, zygomatic, buccal, marginal mandibular, and cervical (Figure 7.8).

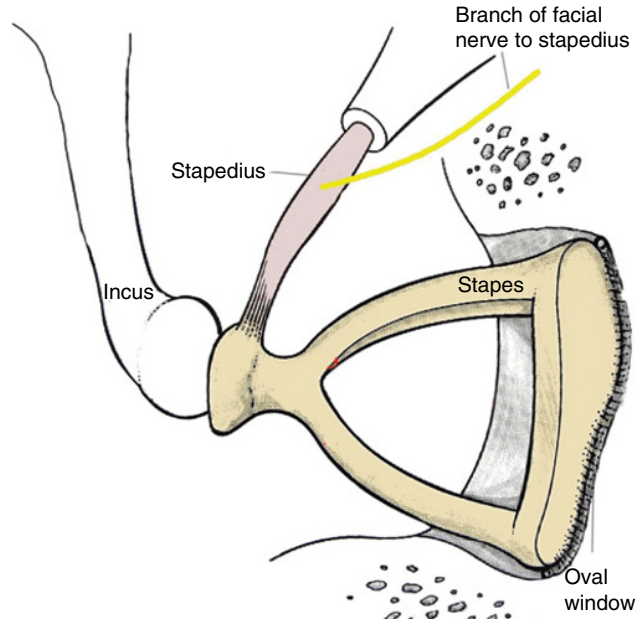

Figure 7.9 Illustration showing the stapedial branch of the facial nerve innervating the stapedius muscle. This muscle dampens the movements of the stapes in response to loud sounds so that the vibrations transmitted to the oval window are reduced. The stapes is about 0.1 in. in length and is located within the middle ear cavity.

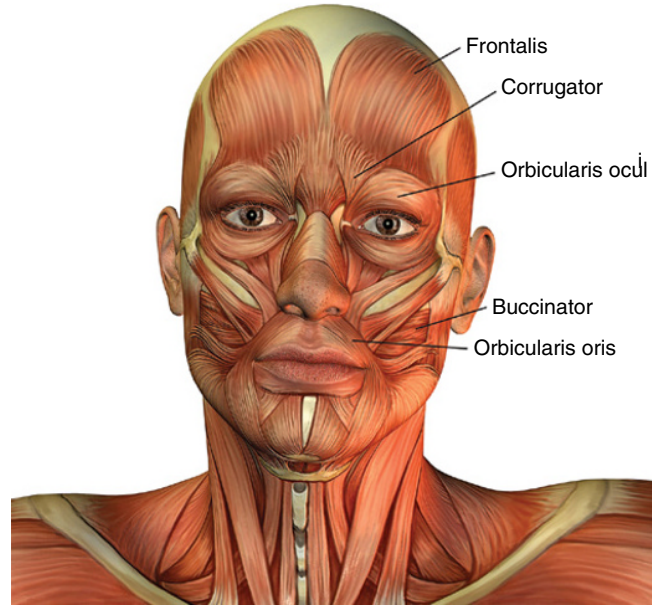

Figure 7.10 Muscles of facial expression. Original image used with permission of Dreamstime.com.

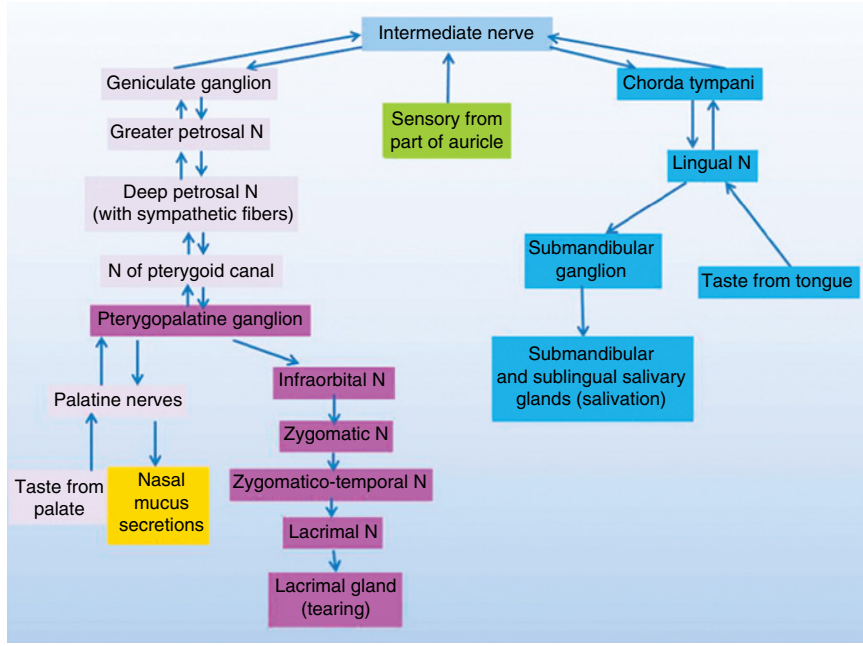

Figure 7.11 Flowchart showing the branches and functions of the intermediate nerve.

As shown by the flowcharts in Figures 7.7 and 7.11, it is much easier to learn the branches of the facial nerve if the intermediate nerve is considered separately from the facial nerve proper. The earlier paragraphs have reviewed the branches of the facial nerve proper. The fibers of the intermediate nerve are distributed primarily by two branches that leave the nerve in the facial canal. The greater petrosal nerve leaves the intermediate nerve at the geniculate ganglion (Figures 7.5, 7.6, and 7.11), and through a small opening, the hiatus of the facial canal, it gets to the anterior surface of the petrous part of the temporal bone. It then runs forward and passes below the trigeminal ganglion and lateral to the internal carotid artery as it traverses just above the foramen lacerum (Figures I.34 and 7.12). (The foramen lacerum is an opening only in prepared skulls. In life, a thick connective tissue layer covers the opening of the foramen lacerum, and nothing with the exception of small vessels penetrates the actual foramen.) The greater petrosal nerve then joins the deep petrosal nerve (from the sympathetic plexus surrounding the internal carotid artery) to form the nerve of the pterygoid canal (Vidian nerve; Figure 7.13). The Vidian nerve is named for a famous anatomist of the 16th century. Current terminology refers to the nerve as "the nerve of the pterygoid canal." Through the pterygoid canal (Figure 7.12), this nerve passes to the pterygopalatine (sphenopalatine) fossa and ends in the pterygopalatine (sphenopalatine) ganglion (Figures 7.2 and 7.13). In this way, parasympathetic fibers from the intermediate nerve and sympathetic fibers surrounding the internal carotid nerve reach the pterygopalatine ganglion. Postganglionic fibers from this ganglion then

stimulate tears to be produced by the lacrimal gland (via the zygomatic nerve and its connections with the lacrimal nerve (see Chapter 5; Figure 7.11). Other postganglionic fibers from the ganglion carry secretory impulses to mucous glands in the nasal cavity (Figure 7.11). Taste fibers from the palate run centrally in the greater petrosal nerve. Thus, if the greater petrosal nerve was destroyed in a person, tears would not be produced, the nasal cavity would be very dry, and taste would be lost from the palate. (We know this is very complicated and hard to follow on a single read through. Just read the text carefully and look at the images and it should make sense. If you can get a real skull to examine, it will be easier to follow than using just text because the path followed by these branches involves three dimensions and you can put pipe cleaners in the foramina/canals and see where they terminate.)

The other branch from the intermediate nerve, the chorda tympani (Figures 7.2, 7.14, and 7.15), leaves the nerve in the IAC just below the nerve to the stapedius. It enters and traverses the middle ear cavity adjacent to the tympanic membrane (Figure 7.15), and leaves it and the skull to enter the infratemporal fossa to join the posterior aspect of the lingual nerve (see Chapter 5; Figures 5.17, 5.18, and 7.2). In this way, preganglionic parasympathetic fibers to the submandibular and sublingual salivary glands reach the lingual nerve. Thus, the facial nerve provides the stimulation that results in salivation from the salivary glands that are located under the tongue. The afferent taste fibers from the anterior two-thirds of the tongue run in a central direction via the lingual nerve and the chorda tympani. These fibers have their cell bodies in the geniculate ganglion (Figures 7.5, 7.6, 7.11, and 7.14). In contrast, taste fibers from the posterior one-third of the tongue travel in the glossopharyngeal nerve (CN IX; Chapter 9). Thus, if the chorda tympani is destroyed, the person would lose taste from the anterior two-thirds of the tongue and would not salivate from the glands under the tongue, but would still feel general sensation from the anterior two-thirds of the tongue if the lingual nerve remained undamaged, because general sensations are transmitted via CN V.

There are some general sensory branches in the intermediate nerve that are thought to join the main branch of the facial nerve distal to the geniculate ganglion and provide sensation to a part of the auricle. These fibers are associated with the Ramsey–Hunt syndrome (see the Clinical Aspects section).

As described earlier, preganglionic parasympathetic fibers from the intermediate nerve pass in part in the greater petrosal nerve to the pterygopalatine ganglion and in part in the chorda tympani to reach the lingual nerve and eventually to the submandibular ganglion. Secretion of saliva and tears from reflex or emotional stimuli is initiated by fibers that activate the cells of the salivary nucleus in the brain stem. However, we wish to emphasize that there is a definite connection between our conscious self (within the brain cortex) and that part of the autonomic system that is mundanely beyond our control and regulates the first step of digestion, salivation. Indeed, the stimulus to

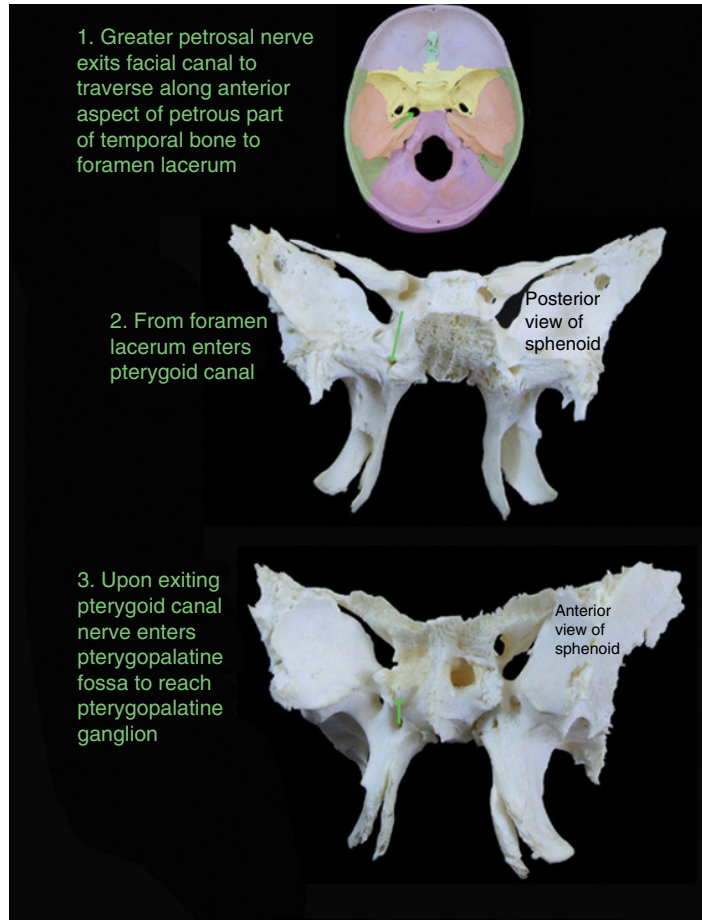

Figure 7.12 The path of the greater petrosal nerve is shown in green. The top image (1) shows a superior view of the cranial base (cranial fossae) in which the path of the nerve is shown as it exits the petrous portion of the temporal bone and crosses over the foramen lacerum to reach the pterygoid canal. The middle image (2) shows a posterior view of the sphenoid bone (yellow in top figure) and the nerve (green) entering the pterygoid canal. The lower image (3) shows an anterior view of the sphenoid bone and the nerve exiting the canal to enter the pterygopalatine fossa.

salivate can be visual, olfactory, or even auditory. For example, you walk into your grandmother's kitchen and you begin salivating at the smell of garlic, olive oil, or bacon. Somehow the conscious recognition of the meaning of those odors triggers the parasympathetic response to salivate. Salivation is our way of unequivocally stating that something good is about to enter our mouths.

Recently it has been demonstrated that the facial nerve sensory ganglion (classically the "geniculate ganglion") actually consists of two components, a geniculate ganglion and a meatal ganglion. In most people, the geniculate ganglion component contains the majority of cells, but in about 10% of people the meatal component is greater.

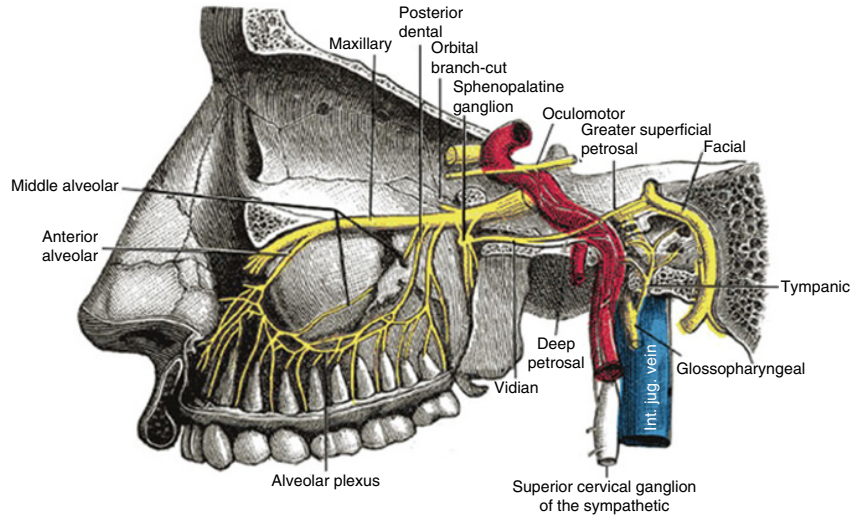

Figure 7.13 This illustration is based on one in the 1918 edition of *Gray's Anatomy of the Human Body*. Note the location and nerves leading to the sphenopalatine (pterygopalatine) ganglion. Also in this illustration, the greater petrosal nerve (greater superficial petrosal nerve) is shown joining with the deep petrosal nerve to form the Vidian nerve (nerve of the pterygoid canal). This nerve brings sympathetic and parasympathetic inputs to the ganglion for distribution.

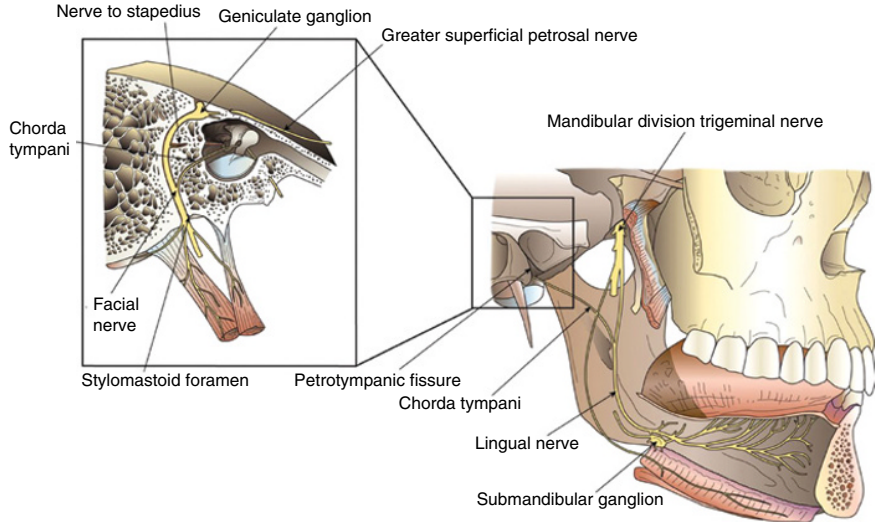

Figure 7.14 Schematic illustration of the course of the chorda tympani from the facial nerve to the lingual nerve and tongue. Inset shows an oblique vertical slice through the petrous portion of the temporal bone. The anterior two-thirds of the tongue are drawn in a lighter shade than the posterior one-third to indicate the area innervated by the chorda tympani nerve. Reprinted with permission from McManus, Dawes, and Stringer (2011).

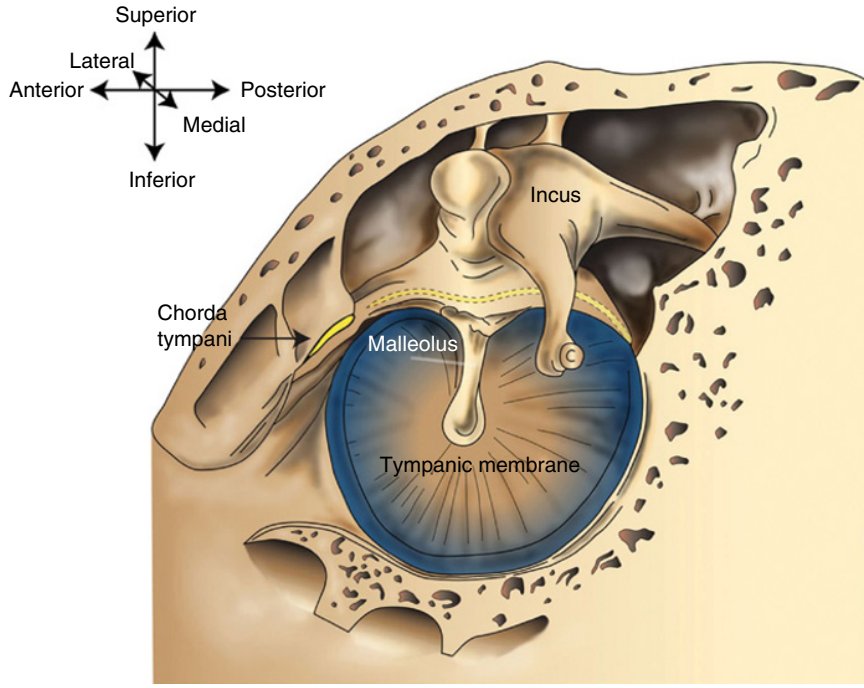

Figure 7.15 Illustration of the right middle ear, viewed from the tympanic membrane laterally. The chorda tympani traverses across the tympanic membrane from posterior to anterior. Reprinted with permission from McManus, Dawes, and Stringer (2011).

During the middle part of the 20th century, surgical transection of the intermediate nerve was a common and apparently successful procedure for atypical facial pain. A very interesting case was published by a very well-regarded neurosurgeon, Dr. Ernest Sachs, Jr., in 1968.

This 43-year old woman was first seen in 1951 because of right-sided face and head pain. The pain was not like tic douloureux. It started in the right maxillary area, spread to the entire right face and ear, with unilateral tearing and nasal discharge. It lasted a few hours to as long as 24 hours and occurred during the day or night. She was free from pain for a month or so, and then had "clusters" of severe attacks, each lasting 4–8 hours. She had numerous hospital admissions for these attacks, but attempts to relieve her pain were unsuccessful. In 1952, the right facial pain had become associated with a severe lancinating pain in the right ear.

It was postulated that the ear and facial pain might be due to a tic douloureux-like phenomenon in the nervus intermedius. At operation, stimulation of the nervus intermedius reproduced the pain in the ear and right face; it was therefore sectioned. During this maneuver, as the VIIth nerve was being retracted while cutting the nervus intermedius, the patient inadvertently moved because of pain and, to our dismay, the VIIth

nerve was torn. However, when the VIIIth nerve was now touched, she again had ear and face pain. We were so surprised by this finding that the maneuver was repeated to make sure that she was perceiving this pain via the VIIIth nerve. After much thought and discussion and with the patient's permission, the VIIIth nerve was sectioned. After this the patient was deaf on the right side but the pain was gone (Sachs, 1968).

Dr. Sachs was perplexed by this case, as we are, and hypothesized that the VIIIth nerve may carry some pain fibers from the intermediate nerve. We are also perplexed by the rather widespread nature of the patient's pain relative to the limited general sensory distribution of the fibers of the intermediate nerve (thought to be confined to just the auricle). There are some similarities between this case and the case from 1909 presented above, although that patient's pain was not considered to be similar to tic douloureux. Regardless, during the almost 60-year time span between the two reports, little progress had been made in finding ways to relieve the pain presumed to be caused by abnormal impulses in this nerve other than to completely cut it.

CLINICAL ASPECTS

General signs and symptoms

The primary function of the facial nerve complex is to mediate movements of the muscles of facial expression. Its role in the pathways for taste and in the innervation of the lacrimal (tearing) and salivary glands and of the skin of the auricle is seemingly secondary, but losing either function could still be rather devastating. The motor function of the nerve is examined by testing the activities of the facial muscles in acts such as closing the eyelids, smiling, frowning, blowing out a candle, whistling, etc. On inspection, a lesion in the facial nerve will be revealed as an asymmetry between the two halves of the face. Similarly, the examiner may observe atrophy, contracture, twitching, and involuntary movements. The sense of taste is tested by applying substances of different tastes, for example, salt, sugar, quinine, citric acid, on the tongue. Interestingly, changes in the secretory functions of salivation and tearing, which may be tested by obtaining reflex secretions from the lacrimal and salivary glands, are often unnoticed by patients who have these deficits.

Problems of the facial intermediate nerve may be associated with conditions affecting any of its functional aspects. The site of the lesion can often be determined by the signs and symptoms that appear in the individual patient. Indeed, before the development of cross-sectional imaging techniques such as CT and MRI, diagnosis of a patient's complaints was made exclusively following a thorough history and physical examination. Clearly, the experience and knowledge of the individual clinician was an important factor for

diagnosis. Because of the complexity of the paths taken by this nerve, it is easy to understand why different physicians could make different diagnoses. Today that detective-like process is augmented by the use of high-resolution CT and MRI, which can help to determine the locations of lesions associated with the nerve. The experience and knowledge of the clinician, combined with that of the neuroradiologist, aids in the accurate localization of facial nerve abnormalities.

Facial nerve palsy is the most commonly occurring cranial nerve paralysis. If only some of the branches are involved, for example, in diseases of the parotid gland or wounds in this region, the paralysis will be restricted to particular facial muscles. Far more commonly, the entire nerve distal to the geniculate ganglion is affected and there is widespread loss of motor function, but this still may not be complete. The affected facial muscles will lose their tone and may gradually atrophy. The normal wrinkles and creases in the face, due to the attachment of muscle fibers in the skin, will become less apparent. The affected side of the face has a smooth, empty expression. Although this condition is typically very upsetting to the patient, in 1853 the German neurologist, Moritz Heinrich Romberg, said in his textbook, *Manual of the Nervous Diseases of Man*, that there was no better cosmetic for older women than bilateral facial palsy (this was widely quoted), an observation that did not escape the Botox industry of today! As mentioned previously, the neuromuscular poison botulinum, commercially marketed as Botox, is frequently used today to eliminate wrinkles. The rationale for this treatment is simply to relax the facial muscles under the control of the facial nerve. Too much Botox, unfortunately, completely eliminates all muscle tone; hence, the clever joke by the late comedian Joan Rivers, a well-known proponent of Botox, "Am I smiling, I can't tell?" Excessive use of Botox can leave a person with the inability to express any sign of facial emotions.

In typical idiopathic (without an identifiable cause) facial palsy (Bell palsy), the angle of the mouth on the affected side droops. The patient is unable to draw the angle of the mouth laterally (when trying to show teeth) and the eye cannot be closed. The patient cannot frown, whistle, or smile and speech suffers. Because of the paralysis of the orbicularis oculi muscle, the patient cannot close the eyes, and the cornea of the eye can become dry with resultant formation of a corneal ulcer.

The same signs may appear in nuclear facial palsy, in which the facial nucleus in the brainstem is affected. Fascicular twitching of the facial muscles may also be seen in such instances. Depending on the localization of the lesion within the facial nucleus, the paralysis or paresis may be limited to certain muscle groups.

A supranuclear (cortical) facial palsy is seen in lesions of the fibers from the portion of the motor cortex that sends fibers to the facial nucleus in the brainstem. In these lesions, the upper facial muscles (e.g., frontalis) are not significantly affected because both cerebral hemispheres supply fibers that innervate these muscles bilaterally. The patient is thus able to close an eye and wrinkle the forehead on the paretic side of the face. Furthermore, facial reflexes and emotional facial expressions are preserved so that there is no muscle atrophy.

A peculiar phenomenon that is apparent in supranuclear palsies is dissociation between voluntary and emotional facial innervations. In spite of the inability to show teeth when requested, the patient may be able to smile spontaneously at a joke because there are intact connections between the centers in the brain that control emotions and the facial nuclei in the brainstem.

Loss of taste in the anterior two-thirds of the tongue in facial palsy suggests an interruption of the sensory fibers of the ipsilateral intermediate nerve. Such a loss of taste in this distribution may occur in combination with loss of facial motor function in any lesion that involves these nerves between their exit from the pons (and within the pons) and the emergence of the chorda tympani (Figures 7.2 and 7.6).

Loss of taste without motor symptoms will occur if the chorda tympani is affected in the middle ear cavity or further peripherally in its course, and may also follow lesions of the lingual nerve (in the latter case, anesthesia of the tongue will also be apparent from the disruption of CN V fibers; Chapter 5).

Disturbances in the secretion of saliva will occur in the same lesions that produce loss of taste because the secretory fibers follow the same route as the taste fibers. The secretion of tears, however, will be affected only in lesions located before the geniculate ganglion (because the parasympathetic neurons to the lacrimal gland run in the greater petrosal nerve; Figures 7.5, 7.6, and 7.11). Although tearing is not usually affected in most cases of facial paralysis, a late complication of Bell palsy (see the following section) is referred to as "crocodile tears." In this condition, patients tear up when they eat or think about food due to presumed aberrant regeneration (synkinesis) of facial nerve fibers to the lacrimal gland (Figure 7.16).

Figure 7.16 A phenomenon known as crocodile tears sometimes occurs as a sequela of Bell palsy. In this condition, thinking about food results in tearing. Reprinted with permission from Yiddishwit.com. Courtesy of Johanna Kovitz.

If a facial nerve palsy involves the nerve proximal to the tympanic branch, paralysis of the stapedius muscle occurs. This results in hyperacusis, excessive loudness of sound.

Bell palsy

Bell (Bell's) palsy is a well-known, usually temporary paralysis of the facial nerve. The annual incidence is 20–30 per 100,000. William Gowers (1842–1915) in his 1886 textbook on nervous diseases described Bell palsy thoroughly. Gowers noted that in more than half the cases, exposure to cold initiates the condition. Generally, he found that a draft of cold air had blown on the side of the face and head, as in sitting in a railway carriage opposite an open window. Although the belief in an association between a cold draft and the development of Bell palsy still persists (today, typically from an open car window), there are no data substantiating this relationship.

Some patients with Bell palsy have had a viral illness just prior to the onset of their symptoms. Numbness or pain around the ear is present in about 50% of cases. As with trigeminal neuralgia, Bell palsy is slightly more prevalent in women (60%) and if the stapedius muscle is involved, the patients will complain of sounds being too loud.

In patients with Bell palsy, great care is required to protect the exposed cornea, which is subject to trauma and ulcerations from incomplete eye closure. Therefore, eye patching, particularly at night, and administration of artificial tears is required.

The overall prognosis in Bell palsy is good – 80–85% of patients recover completely – but the remainder may have synkinesis, residual weakness, tearing, or contracture. Synkinesis is a common permanent sequela, resulting from misdirection or regeneration of axons into muscles or glands that the fibers did not originally innervate, as in crocodile tears (Figure 7.16). More commonly than crocodile tears, synkinesis appears as a simultaneous movement of different muscles that normally do not contract together such as subtle eye closure with smiling, or lip or chin twitching with blinking. This can be annoying but is only rarely disabling.

In the Introduction chapter, we presented a photograph of Mary King (Figure I.7), a reporter for a Columbia, South Carolina, TV station (WIS), who developed the condition, which was described on the station's website. Part of that description is presented below:

> I was sitting on an airplane in Charlotte when I first noticed I couldn't rub my lips together. After realizing the whole right side of my face was motionless, I notified a flight attendant.
>
> The pilot took the plane back to the gate where I was met by a medic team. My dad met me at the airport and rushed me to the hospital where we met my mom. My fears that I might be having a stroke were replaced by two words, Bell's Palsy.
>
> I learned that deep inside my brain, my VIIth cranial nerve was inflamed. Doctors cannot pinpoint what causes the inflammation, but say

it can be brought on by a variety of factors including stress, lack of sleep, a weakened immune system and an array of viruses.

"The facial nerve becomes inflamed and then it stops functioning," said Dr. Hammett. "Without signals from the nerve all of the muscles go weak or are paralyzed on one side of the face."

By day seven of my attack, my symptoms had not changed much. I still could not blink or close my right eye, and I had to sleep with an eye-patch to keep it shut. Doctors say this is necessary because if the eye dries out it can damage the cornea.

While I'm not a doctor, I know that Dr. Hammett is completely right. Hope is truly key to recovery. While going through Bell's Palsy, it can be depressing to look in a mirror or to want to be in public. With no idea when your face may recover, if ever, it can be hard to look at the bright side of things.

I think it was when I went to pick up my wedding gown with my mom that I had a breakthrough. All I wanted to do was smile, but I felt so embarrassed to even look in the mirror as I tried on the gown. I began to explain to the women at the store that I had Bell's Palsy and I couldn't smile, and one of the ladies replied, "You are smiling, you're smiling with your eyes." Perspective is everything.

When I woke up on day 15, I could crack a smile for the first time. Now, I don't think I ever want to stop smiling! It was more than two weeks of hope, medication, family and friends, patience, many prayers and the Good Lord that finally turned my unintentional frown upside down.

A similar case of Bell palsy was published in *The Daily Mail* on September 18, 2011, written by the British novelist, Isabel Wolff. The headline was:

I feared I'd look like Frankenstein forever: How this novelist tried to beat Bell's Palsy

In early July I'd just got home after taking my children to school when I felt a crackling sensation across my right cheek, as though there were caterpillars crawling across my skin. I then felt a contracture in my lips.

I looked in the mirror, saw that half my face had dropped, and thought that I must have had a stroke. I ran to my GP who asked me to wrinkle my forehead. I couldn't. She then told me to puff out my cheeks and to squeeze shut both eyes. This was beyond me. "You've got a Bell's," she said.

She then wrote a prescription for the medication that, she said, "should get you back to normal within two to three months."

The word "should" alarmed me. What if I were to stay like this – my right eye wide open and unblinking, my cheek and jaw frozen and slumped? Not only did I look hideous, I couldn't speak properly, or eat properly. I couldn't drink without dribbling. Unable to keep my lips together, I drooled. Worst of all, I couldn't smile, producing only a horrible, lop-sided leer. When I saw myself, I wanted to cry.

Bell's Palsy is a frightening condition because you don't believe that you'll ever look like yourself again

Bell's Palsy is a rare condition, affecting one person in 5000 and has no known specific causes, though it's thought that viruses might play a part.

I believe that my own case was triggered by a bout of shingles (the reactivation of the chicken pox virus) along my right jaw a few weeks before.

Now, unable to close my eye, I had to put drops in every night and wear a patch. I also had a constant pain behind my right ear.

Unable to smile attractively, I stopped trying to, which lowered my already depressed mood. I became introverted and avoided seeing friends or going to parties. I simply didn't want to face the world.

If I couldn't avoid speaking to someone I'd turn the other cheek, or try to cover the afflicted side with my hair. I also contemplated the irony in the timing of my palsy, since the novel I was writing, *The Very Picture of You*, was about a portrait painter, and so I'd been giving a lot of thought to the human face.

The artists I'd interviewed had all stressed that if they were to alter the angle at the corners of their sitter's eyes or mouth by even a fraction of a millimeter, they would completely change that person's expression.

I became obsessed with my face, constantly peering at it in the mirror, desperate to see any signs of improvement, however minimal.

I was cheered to learn that George Clooney had Bell's when he was at high school – he got called "Frankenstein" – and had clearly made a full recovery, as had Pierce Brosnan.

But it terrified me that another sufferer, the former Canadian Prime Minister Jean Chretien, had very clearly not.

Most encouraging were the YouTube videos in which Bell's sufferers had bravely filmed themselves, week by week, as their condition improved. As indeed, gradually, did mine. After three weeks I began to feel the crackling sensation again as nerves started to reactivate. I found that I could now close my right eye.

"You've got your smile back," my daughter said in mid-August. What I'd also got back, I saw with utter annoyance, were the lines on my brow. I never thought I'd be so happy to see my wrinkles again.

Wolff's piece (only part of which is presented above) reinforces the quote found at the head of the chapter by Mavrikakis about how one's identity is inherently bound in one's face.

Bell palsy has been associated with the presence of herpes simplex virus, suggesting that a reactivation of the virus in the geniculate (meatal) ganglion may be responsible for this condition. Even if true, the reactivation sometimes is believed to be triggered by an event such as fever, upper respiratory infection, influenza, diabetes, pregnancy, menstruation, or tooth extraction.

The nerve paralysis in Bell palsy does not result directly from the virus but from the reactive inflammatory process that occurs, as suggested in Isabelle Wolff's case report. Theoretically, the virus causes nerve inflammation and this inflammation results in nerve swelling. Because the nerve is confined to a tight-fitting bone channel, the swelling in turn constricts the nerve's blood supply and the result is impaired impulse conduction and muscle paralysis. The fact that the administration of steroids often speeds recovery in Bell palsy supports the hypothesis that inflammation contributes to the etiology of Bell palsy. The diagnosis of Bell palsy is one of exclusion (i.e., other causes of facial weakness, such as stroke or tumor, must be ruled out). MRI scans sometimes show inflammation in the facial nerve, but are most helpful in ruling out other causes of facial weakness. Bilateral Bell palsy is rare.

In addition to the herpes simplex virus, a wide variety of other infectious, inflammatory, or systemic diseases are known to cause facial nerve palsy similar to Bell palsy. These include Lyme disease (up to 10% of facial paralyses in endemic areas), Ramsay Hunt syndrome (see the following text), sarcoidosis, Guillain–Barre syndrome, diabetes mellitus, and connective tissue disorders such as Sjogren's disease, leprosy, and rare entities such as the Melkersson–Rosenthal syndrome. Patients who have a stroke or demyelination (from multiple sclerosis) in the pons may also present with acute facial paralysis.

Congenital malformations

Congenital malformations of the facial nerve (present at birth) vary from those that are asymptomatic to those that cause profound facial paralysis. Abnormal variation in the path of the facial nerve may be an isolated anomaly, with the segment of the nerve distal to the geniculate ganglion most often affected, or may be evident as part of a larger congenital temporal bone region abnormality.

Inflammatory disorders of the facial nerve

James Ramsay Hunt was an American neurologist (1872–1937) who has three syndromes named after him; the most common one is pertinent to the facial nerve and is also known as herpes zoster oticus. Ramsay Hunt first described this condition in 1907 and referred to it as geniculate neuralgia. It is basically a herpes zoster infection of the area of skin supplied by the general sensory fibers within the intermediate nerve and is often triggered by stress, aging, or immunosuppression (Figure 7.17). In some instances of Ramsay Hunt syndrome, unilateral facial paralysis, secondary to herpes zoster, may precede or occur with the typical herpetic vesicles in the external auditory canal. The facial weakness may be more severe than in Bell palsy with less likelihood of complete recovery.

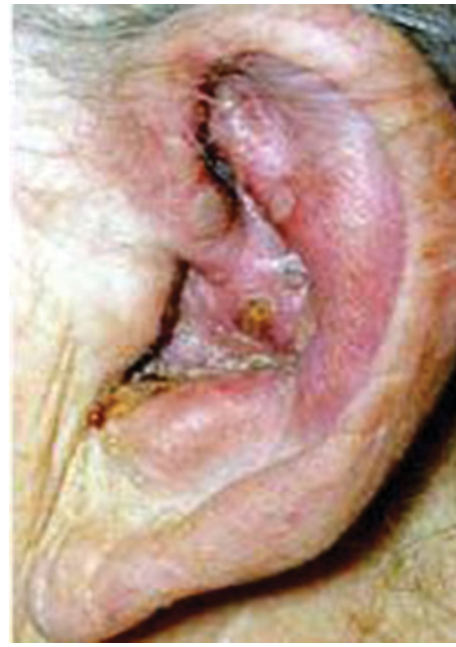

Figure 7.17 Photograph of the ear of a patient with Ramsey Hunt syndrome. The sores are typical of herpes zoster lesions.

A bilateral case of Ramsay Hunt syndrome in a diabetic patient was described in *BMC Ear, Nose and Throat Disorders* in 2004.

> A diabetic male patient presented with a history of pain in his left ear for the last eight days (Figure 7.18). Two–three days after onset of ear pain, the patient developed facial weakness on the left side along with vesicular eruptions on the left conchae and in the left external auditory meatus. After another 2–3 days the patient had a similar episode on the right side. On the day he presented he showed bilateral facial weakness, impaired taste sensation, dryness of eyes along with decreased hearing on both sides but no history of ear discharge or vertigo. There was a history of stressful events in the past six months before the onset of the rash (Syal *et al.*, 2004).

The patient in this case showed a sign that is often present in Bell palsy, the Bell phenomenon (Figure 7.18). This sign is characterized by an upward movement of the eye when an attempt is made to close the eyelids. The upward movement of the eye is actually normal and occurs in all of us. The phenomenon becomes noticeable to examiners only when the orbicularis oculi muscle becomes weakened and does not completely close the eyelid as in, for example, facial palsy (Figure 7.18).

The facial nerve may also be secondarily involved in inflammatory disorders of the temporal bone. About 5% of patients who have middle ear infections and 1% of patients who have cholesteatoma (skin cysts in ear) may present with facial nerve paralysis. Malignant otitis externa (external ear infections) may also be associated with facial palsy.

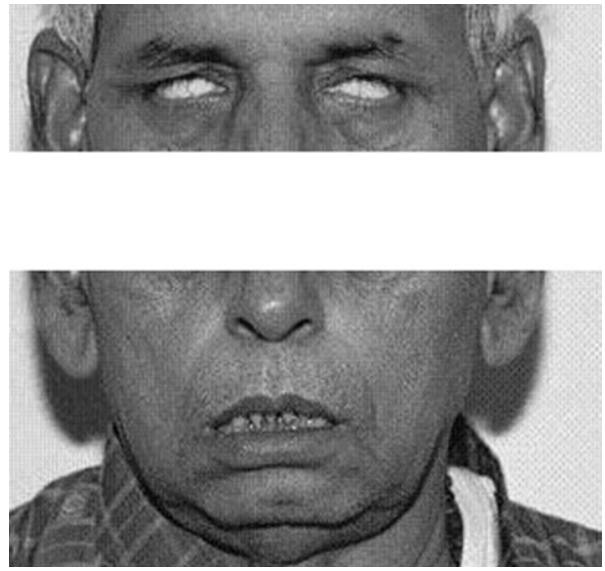

Figure 7.18 The Bell phenomenon. This sign is characterized by an upward movement of the eye when an attempt is made to close the eyelids. The space in the image is there to protect patient identify. Reprinted with permission from Syal, Tyagi, and Goyal (2004).

Vascular disorders of the facial nerve

Hemifacial spasm is characterized by unilateral, involuntary twitching or spasms of some or all of the muscles that are innervated by the facial nerve. It is believed that neurovascular contact at the root exit zone of the facial nerve accounts for hemifacial spasm (similar to the view that trigeminal neuralgia is caused by contact at this zone for nerve V). Contact with an adjacent vascular structure in this region presumably results in the production of abnormal facial nerve impulses. The extent of contact required to produce such an effect is unclear. Hemifacial spasm may not be observed in some patients despite the presence of significant nerve compression due to a vessel. Also, hemifacial spasm has been reported to result from contact of a vessel with the distal facial nerve (not at the root entry zone). As with trigeminal neuralgia, there is a very high success rate with microvascular decompression surgery in simple cases (80–90% success rate).

Two cases of hemifacial spasm of the facial nerve that were on a British Internet forum are printed below (in England, surgeons are referred to as Mister rather than as Doctor):

> I am a 54-year-old man living in North London, who was diagnosed with HFS [hemifacial spasm] about five years ago. I had botox treatment for about four years, the first couple of years with satisfactory result, but gradually the injections were becoming less effective. I had my first consultation with Mr. K at the National Hospital for Neurology and Neurosurgery, Queens Square, London in Feb 2010 when he explained to me in great detail about the chances of success and all the risks involved

with microvascular decompression (MVD) surgery. At this stage I was prepared to risk losing hearing in my left ear in exchange for getting rid of the spasms. But Mr. K also mentioned the possibility of developing Bell's palsy which I thought was worse than twitching, and that it is a permanent condition. After doing more research I realized that Bell's palsy is only temporary, I contacted Mr. K again in Oct 2011 to arrange the operation. I was operated on Tues 3rd Jan 2012, discharged on Sun 8 Jan 2012 to continue with my recovery. I thought I was immediately spasm free when I woke up, but in fact it seems to be worst the day after. Mr. K's assistant told me that the nerve may take some time to heal and it may be a few weeks before we know if the operation is successful. I was not too bothered as I have read the experiences of the members of the HFS association. I am just grateful for the skill of Mr. K leaving me with my full hearing intact and no uncontrollable discomforts other than dizziness for the first three days. Today is the eighth day post-surgery and I am off all painkillers already. The staples were removed yesterday and the incision wound feels better. I shall certainly let you know when I am finally spasm free. I will be most happy to answer questions from anybody if it helps.

Case 2 is below:

I had microvascular decompression surgery in the USA in July 2010, the outcome is that the spasms remain. I have lost my hearing on my right side and am considering a crossover hearing aid because one sided hearing is quite horrible. I have tried botox three times so far and noticed no difference at all. I now have tinnitus [ringing in ears] poor balance and generally am being driven crazy. Do think it through before having this very risky surgery.

In the first case, it appears that the decompression surgery was at least partially successful, whereas the second patient is clearly upset over the lack of relief.

Joseph Jules François Félix Babinski (1857–1932) was a French neurologist who was born in Poland. He is most known for his 1896 description of the Babinski sign, an abnormal foot reflex indicating CNS damage, but he also described a paradoxical synkinesis in hemifacial spasm, known as "the other Babinski sign." It is characterized by eye closure and frontalis muscle contracture at the same time; thus, the eyebrow rises during eye closure.

Neoplasms of the facial nerve

Tumors of the facial nerve usually present with progressive facial paresis or paralysis. Facial paralysis that does not develop in a pattern typical of Bell palsy (e.g., gradual onset, progression for more than 3 weeks, persistence for longer than 6 months) must be evaluated for the presence of a tumor. The facial nerve may be afflicted by primary neoplasms of the nerve, tumors of the temporal bone, or by metastatic tumors from distant neoplasms.

Trauma

Fractures of the temporal bone may be associated with facial paralysis in up to 50% of cases. Immediate facial paralysis usually indicates severe nerve injury (transection), whereas delayed paresis or paralysis may result from a hematoma (blood clot) interfering with nerve function.

A significant proportion of traumatic facial nerve injuries occur during childbirth. Typically, the injury is associated with the use of forceps during delivery. The baby shows pulling of the mouth to the normal side when crying, facial droop, and difficulty in fully closing the eye on the affected side. This usually resolves spontaneously within a few weeks (Figure 7.19).

Figure 7.19 Infant with right-sided facial paralysis due to injury during birth. Note the absence of a smile on his right side.

This association between the use of forceps during delivery and the subsequent development of a facial nerve palsy in newborns was first identified by a French physician, Hector Landouzy (1812–1864), who titled his 1839 doctoral thesis, *Essai sur l'hémiplégie faciale chez les enfants nouveau-né* (Essay on Facial Hemiplegia in Newborns). In it, he describes a case in which the infant was delivered by one of his teachers:

> During the child's cries, the left corner of the mouth is highly deviant, higher and further away from the center than that of the right side; the mouth is oblique from right to left and bottom to top; the left eye is entirely closed, the right side eyelids are mostly open and completely immobile, even during the varied movement produced by the child's cries. It seems, during these violent contractions, that one side of the face is being pulled by the other.

Facial nerve palsy caused by forceps has a current incidence of about 8.8 cases per 1000 births. This condition can also occur in vaginal births without the use of instrumentation due to the pressure of the mother's vertebral column on the area of the stylomastoid foramen (see the Introduction chapter).

The facial nerve becomes anatomically relevant to plastic surgeons where the nerve enters the parotid gland and then divides into the five major motor branches. As the five branches exit the gland, the nerves are located very superficially and are subject to injury during cosmetic or restorative surgery. Damage to two of these branches is relatively common with significant ramifications: the temporal branches have a long course, with few terminal branches, and have no connections with other facial nerve branches. The frontalis muscle often derives its sole innervation from one solitary nerve branch (Figure 7.10). Paralysis of the frontalis results in flattening of the skin on the forehead and an inability to wrinkle the forehead or elevate the eyebrow.

The marginal mandibular (or just mandibular) branch of the facial nerve innervates the muscles of the lower lip (Figure 7.10). A person with injury to this nerve presents a very conspicuous deformity when opening the mouth. The conspicuous nature of this deformity can be extremely disturbing to the patient (Figure 7.20).

Surgery to repair traumatic facial nerve injury is aimed toward achieving facial symmetry when the muscles are relaxed, as well as during voluntary and involuntary muscle movement. Corrective surgery can lead to complete recovery in many cases of traumatic facial paralysis.

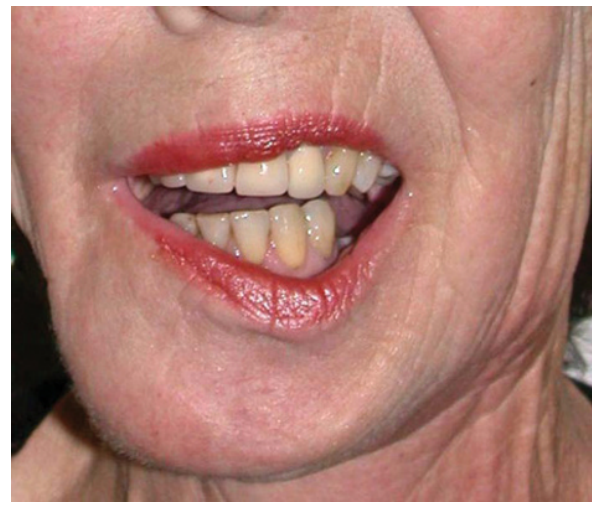

Figure 7.20 A woman with injury to the right marginal mandibular branch of her facial nerve. Note how while trying to smile her right lower lip remains in a neutral position as a result of the nerve injury. Reprinted with permission from Kolokythas (2010).

We now move on to the nerve of hearing and balance, the vestibulocochlear nerve, which used to be known as the auditory nerve.

REFERENCES

Keshavan MS (1988) The ear wigglers: tics of the ear in 10 patients. *American Journal of Psychiatry* **145**: 1462–3.

Kolokythas A (2010) Long-term surgical complications in the oral cancer patient: a comprehensive review. Part I. *Journal of Oral and Maxillofacial Research*. http//dx.doi.ng/10.5037/jomr.2010.1301.

Liu L, Arnold R, Robinson M (2012) Dissection and exposure of the whole course of deep nerves in human head specimens after dissection. *International Journal of Otolaryngology* **2012**: 1–7. Article ID 418650, doi: 10.1155/2012/418650.

Mavrikakis I (2008) Facial nerve palsy: anatomy, etiology, evaluation, and management. *Orbit* **27**: 466–74.

McManus LJ, Dawes PJ, Stringer MD (2011) Clinical anatomy of the chorda tympani: a systematic review. *The Journal of Laryngology and Otology* **125**: 1101–8.

Sachs Jr. E (1968) The role of the nervus intermedius in facial neuralgia. *Journal of Neurosurgery* **28**: 54–60.

Syal R, Tyagi I, Goyal A (2004) Bilateral Ramsay Hunt syndrome in a diabetic patient. *BMC Ear, Nose and Throat Disorders* **4**: 3.

Tubbs, R.S., Menedez, J., Loukas, M. *et al.* (2009) The petrosal nerves. *Clinical Anatomy* **22**: 537–44.

Wright FW (1869) Notes on a case of double facial palsy. *British Medical Journal* **1**: 184–5.

8 The Vestibulocochlear (Acoustic) Nerve

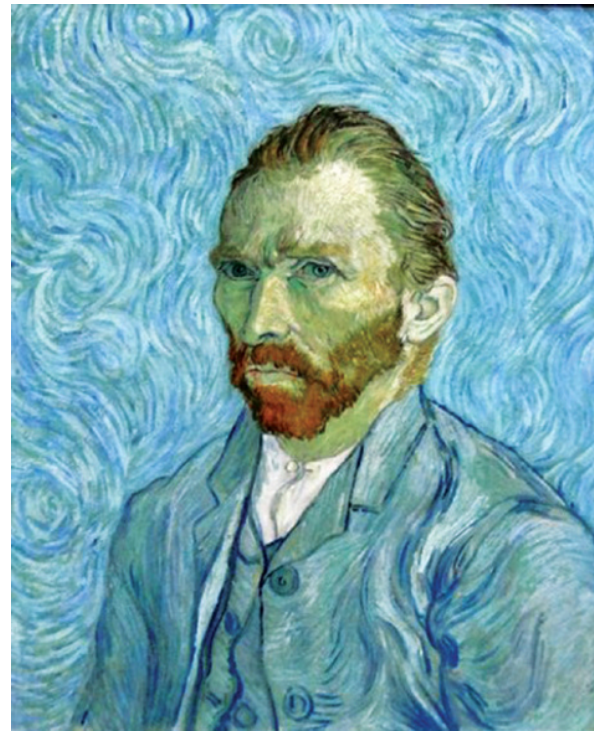

Figure 8.1 Vincent Van Gogh, *Self Portrait, 1889* – the year before he died. Although he was not diagnosed in life, Van Gogh may well have suffered vertigo due to Ménière's disease. This depiction of the swirling vortex, spinning, turning, and moving world is familiar to many patients suffering from this vestibular disturbance.

ANATOMY/FUNCTION SUMMARY

The VIIIth cranial nerve is actually composed of two functionally different components, the *vestibular nerve* and the *cochlear nerve* (Figure 8.2); it is thus preferentially referred to as the vestibulocochlear nerve – the nerve of equilibrium and hearing (at one time it was referred to as the auditory nerve, which is why the mnemonic for learning these nerves mentioned in the Introduction chapter uses the letter "A"). Each component primarily conducts impulses

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centrally from the organs of equilibrium and hearing within the inner ear. Both components of the VIIIth nerve also leave the brainstem together on the lateral surface of the medulla, just beneath the caudal border of the pons, the vestibular portion being ventral to the cochlear portion (Figures 8.3 and 8.4).

Ménière's disease is a disorder of the inner ear that can cause hearing loss, vertigo, and ringing in the ear (tinnitus). It is not generally believed to be a cranial nerve disorder per se, but its symptoms can be very similar to those in abnormalities of the VIIIth cranial nerve. The Dutch artist, Vincent Van Gogh, was thought to have had this disease and some of his paintings reflect this illness (Figure 8.1).

Below is an Internet case of presumed Ménière's disease affecting the CN VIII that appears to have been successfully treated by a chiropractor:

> I will try to keep a long story short, but acquired all Ménière's symptoms shortly after wrenching my neck a bit. After MRIs, steroids, ENTs [ear, nose, and throat physicians], and neurosurgeons, suggestions of hearing aids, I finally sought the help of a chiropractor. Many seem to balk at this idea, but I feel obligated to let those that suffer know that his manipulation cured me. He explained that any minor neck wrenching, e.g., slipping on ice, etc., can cause misalignment. In my case, the 3rd, 4th(?) vertebrae was out of place, pressing on the nerve that controls hearing and balance and causing hearing loss in my right ear, tinnitus, and horrible vertigo. I know how very frightening and debilitating this is, and feel compelled to let others know that my doctor eliminated all symptoms in a week's time, but had me follow a routine for a few months to strengthen my neck. I have been totally symptom free for well over a year. Can this be the case with all sufferers? I don't know, but I was angry with all of the other doctors that never even breathed the word chiropractor to me. Labels are often put on conditions and then procedures and medications created for the conditions, when sometimes the answer is just so much easier. Just as not all doctors are created equally, neither are all chiropractors, but I found a very good one, new school, and incorporates natural well being.

Of course, this case represents a classic example of anecdotal evidence versus the scientific method. The authors are happy to learn that the patient now feels completely cured; however, a single successful treatment does not a cure make! It is difficult to generalize the patient's positive response to chiropractic treatment to other patients with Ménière's disease. In fact, based on the onset of the patient's symptoms and his description of them, this patient may have had benign paroxysmal positional vertigo rather than Ménière's disease (it is unclear whether the patient was actually ever diagnosed with Ménière's disease by a medical professional or whether this was perhaps an example of incorrect self-diagnosis; a situation very common today due to the proliferation of medical information available on the Internet). Nevertheless, the coincidence of such a manipulation with alleviation of symptoms is how

significant correlations provide the impetus for further investigation that can lead to a discovery that produces effective treatment.

ANATOMY/FUNCTION

From the lateral surface of the brain stem the vestibulocochlear nerve (together with the facial and intermediate nerves) enters the internal auditory canal (IAC) and can be followed as a large fiber bundle before splitting into its divisions (Figures 8.2, 8.3, 8.4, and 8.5).

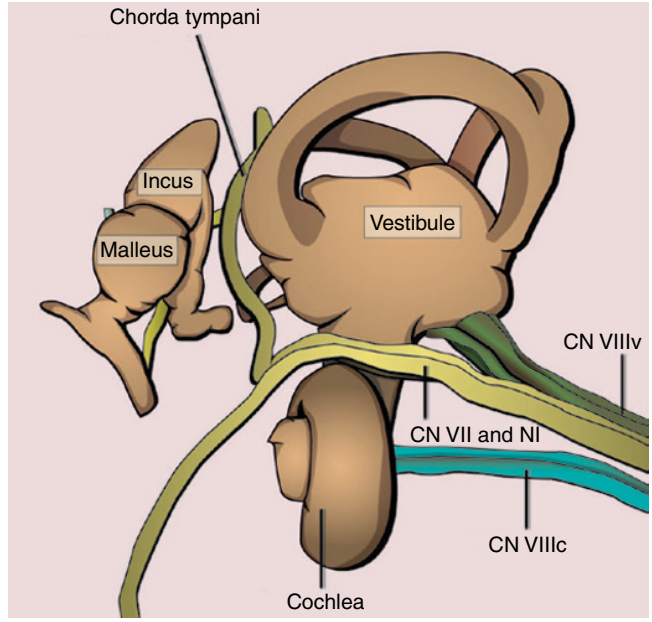

Figure 8.2 Schematic illustration of the distal portion of CN VIII (also showing some of CN VII). VIIIv is the vestibular portion of the CN VIII, whereas VIIIc is the cochlear portion. NI is the intermediate nerve (see Chapter 7).

Vestibular nerve

The fibers of the vestibular nerve are processes (dendrites and axons) of the ganglion cells located in the *vestibular (Scarpa) ganglion* within the IAC (Figure 8.5). The central processes (axons) of these comprise the vestibular nerve. The peripheral ones (dendrites) travel as several smaller bundles to the crista ampullaris of the three semicircular ducts (these ducts are lined by membranes that are within the bony semicircular canals), the maculae of the utricle, and the saccule within the vestibule (Figures 8.2 and 8.5).

The central processes (axons) of the vestibular ganglion cells enter the brainstem and most of them divide into an ascending branch and a descending branch that terminate in the four vestibular nuclei (Figure 8.6).

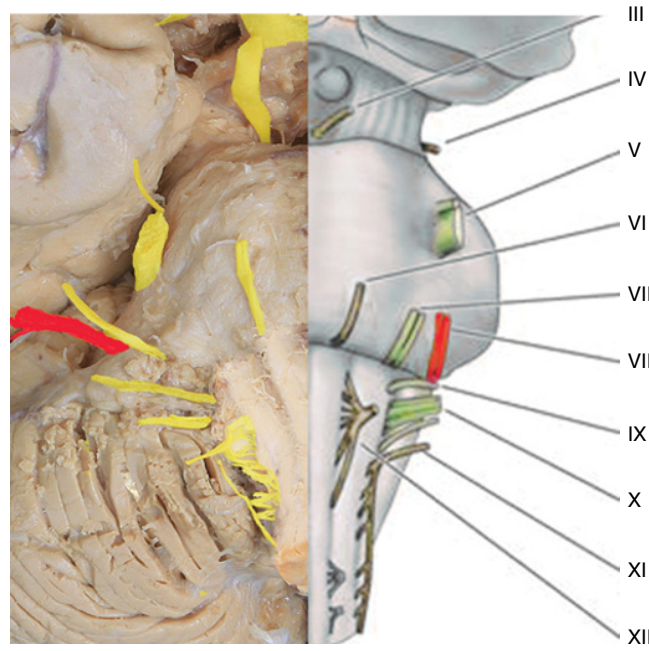

Figure 8.3 Dissection (left) and drawing (right) showing origin of cranial nerves III to XII from the brainstem, highlighting the origin of CN VIII.

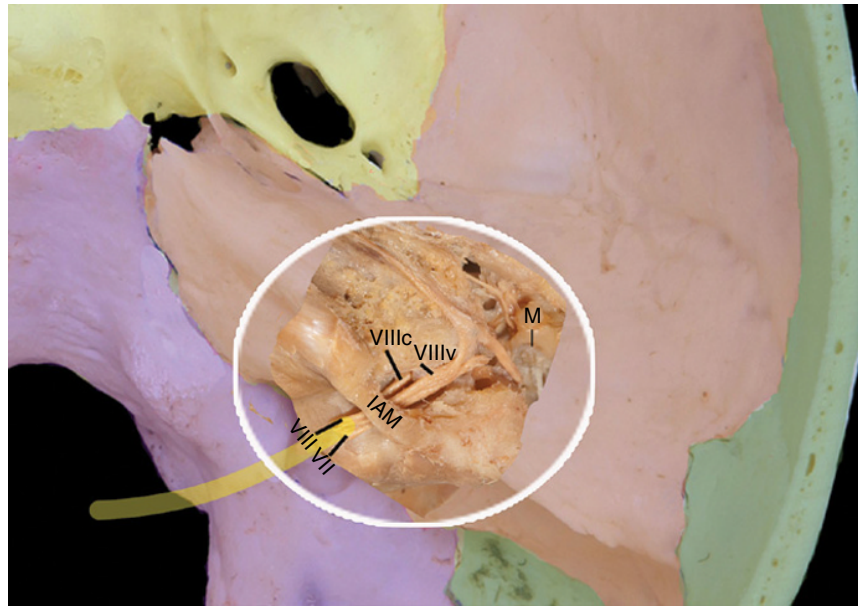

Figure 8.4 Cadaver dissection (white circle) inserted on to photograph of the petrous portion of the temporal bone (see Figure I.33) showing the path of CN VIII from the brainstem through the subarachnoid space into the IAC. Abbreviations: I, incus; IAM, internal auditory meatus (canal); M, malleus; VIIIc, cochlear portion of nerve; VIIIv, vestibular portion of nerve. The dissection inset is used with permission from Liu, Arnold, and Robinson (2012). Courtesy of Dr. M. Robinson; photographer, C. Jeffery.

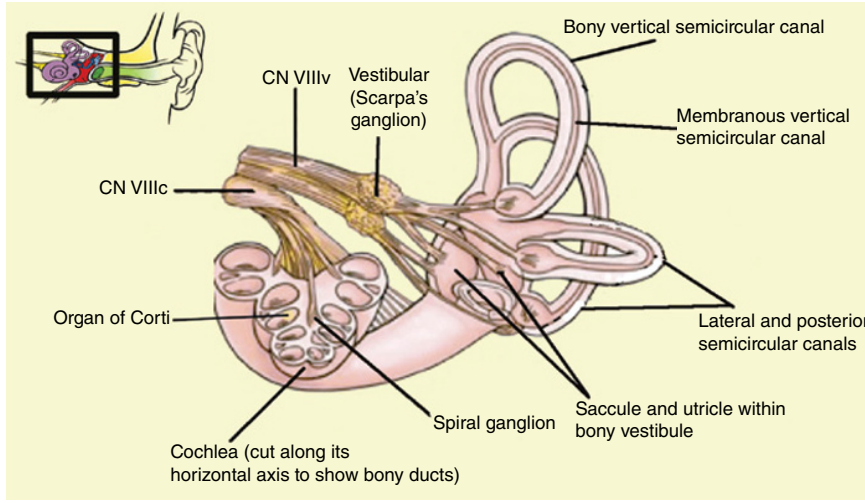

Figure 8.5 Drawing of the vestibular and cochlear apparatuses. The expanded ends of the semicircular canals (ampulla) contain the sensory organs of the canals (crista ampullaris; not labeled in this illustration) whereas the sensory organs of the utricle and saccule are within these two structures. Note that within the bony labyrinth is a much smaller membranous labyrinth that contains endolymph. The organ of corti is found within the cochlea. VIIIc is the cochlear portion of the VIIIth nerve and VIIIv is the vestibular portion. Inset showing location of the vestibular and cochlear apparati in the head is courtesy of Wikimedia (http://commons.wikimedia.org/wiki/File:Anatomy_of_Human_Ear_with_Cochlear_Frequency_ Mapping.svg). See also Figure 8.7.

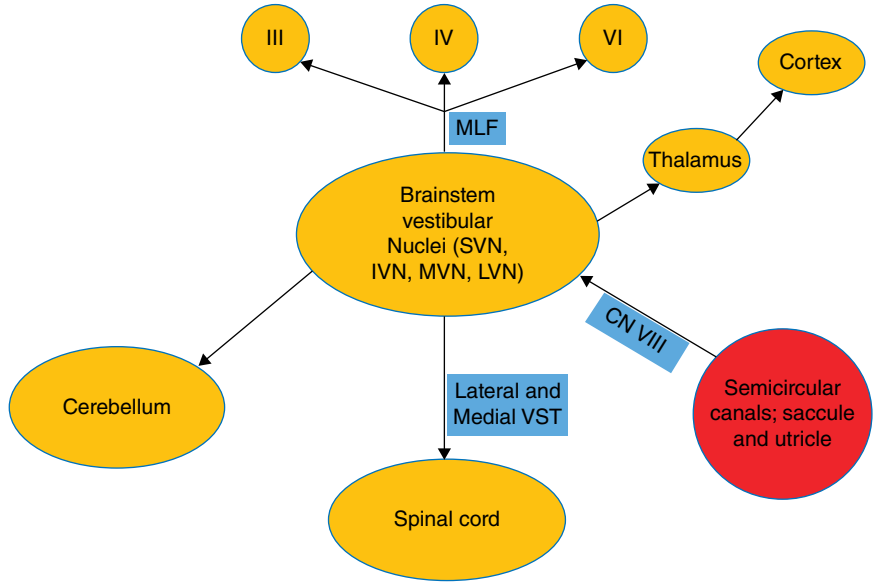

Figure 8.6 Central vestibular pathways. The afferent neurons from the vestibular apparatus project via fibers in CN VIII to the four vestibular nuclei (superior, inferior, medial, and lateral nuclei) located in the rostral medulla and the caudal pons. The MLF (medial longitudinal fasciculus) is a fiber bundle that conducts this information to the cranial nerve nuclei of the oculomotor, trochlear, and abducent nerves. Information from the vestibular nuclei also projects to the spinal cord via the medial and lateral vestibulospinal tracts (VST) (important for balance and posture), to the cerebellum (also for balance and posture), and to the cerebral cortex via the thalamus (for awareness of head position).

The efferent fibers from the vestibular nuclei are so arranged as to be able to influence chiefly three other regions of the CNS: the cerebellum, the spinal cord, and the nuclei of the extraocular muscles of the eye (Figure 8.6). Furthermore, impulses from the vestibular apparatus reach the cerebral cortex. The impulses to the cerebellum and spinal cord affect posture, gait, and balance whereas those to the extraocular muscles enable fixation of the eyeball as your head turns (see Chapters 3, 4, and 6).

The vestibular nerve conducts impulses from the cristae of the semicircular ducts and from the maculae of the utricule and saccule (Figures 8.2 and 8.5). The stimuli are generated by currents in the endolymphatic fluid that is within the semicircular ducts, macula, and utricle, which arise from movements of the head.

The following case was presented to the local medical society in 1869 to show the effects of vestibular nerve dysfunction:

> M.D., age 35, carpenter, was sent to me on July 10th, by Dr. Greenough. A fine, healthy looking man, with the following history. About two years ago had for some time a catarrh [cold] of the pharynx, during which he hawked up much viscid mucus; this, he says, was not preceded by any acute inflammation. As this passed off, he began to have a slight buzzing in left ear, which he scarcely noticed and which has continued. About one year ago, without known cause, began to have frequent attacks of vertigo, nausea and vomiting, and a continued, dull, heavy feeling in head. The vertigo was so severe that it often obliged him to lie down and occasionally caused him to fall. The vomiting was usually in the morning. On account of these symptoms he has often obliged to give up work, and lost his appetite, although when he could take food he digested it well, without any symptoms of dyspepsia [upset stomach]. Not particularly subject to cold in the head. No cough or sore throat; never any pain or tenderness in the ears; never noticed any diminution in his hearing; noises in the ear are increased by a cold in the head. Pulse and skin natural; bowels regular. Has taken a large quantity of medicine without relief (Green, 1869).

Cochlear nerve

The cell bodies of the afferent fibers of the cochlear nerve are cells that comprise the *spiral ganglion* (Figure 8.5). This is situated in the long spiral canal of the cochlea (Figures 8.2 and 8.7). The dendrites of the ganglion cells arise around sensitive hair cells within the cochlea (organ of Corti), which respond to the vibrations caused by sound waves (in the endolymphatic fluid in the cochlear duct; Figures 8.5 and 8.8), and the axons join and form smaller bundles that run toward the base of the cochlea. Through a series of small holes, they enter the IAC where they fuse to form the cochlear nerve (Figure 8.2).

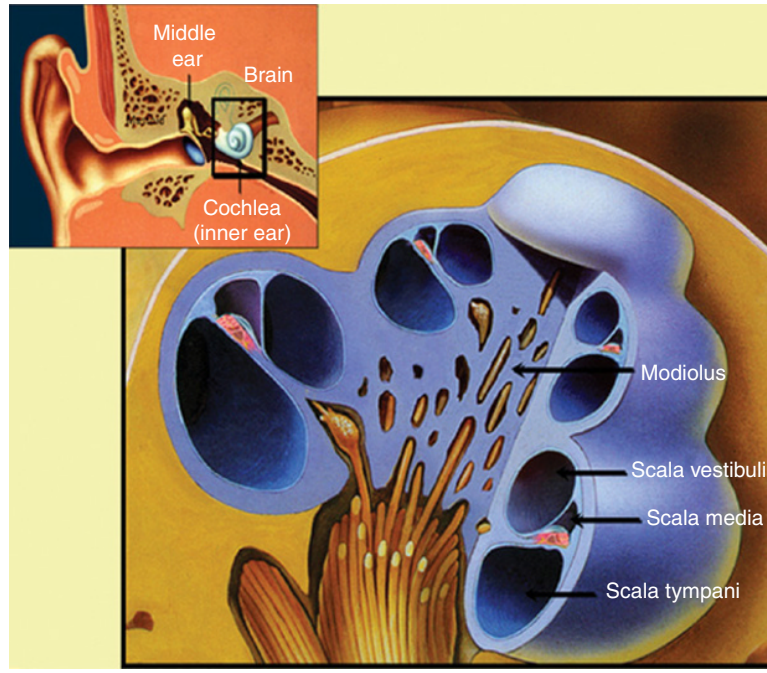

Figure 8.7 A sectional drawing of the cochlea showing the spiral ganglion. The other labeled structures are the modiolus, which is the central bony element in the cochlea, and the scalae vestbuli, media (cochlear duct), and tympani, which are canals within the cochlea. The inset in the upper left shows the cochlea situated in the temporal bone. Courtesy of Graham Clark Foundation.

The fibers of the cochlear nerve enter the medulla and terminate in the *dorsal and ventral cochlear nuclei* (Figures I.12 and 8.8). The cells in these nuclei give off axons that transmit the impulses centrally. The pathways mediating conscious perception of sound ascend in the brainstem and have relay stations there. From the latter nucleus, the last link in the pathway runs as fibers to the (primary) acoustic cortical area in the temporal lobe. The connections are both crossed and uncrossed, meaning that the impulses from one cochlea project to both sides of the brain.

For each fiber of the cochlear nerve, the excitatory response is sharply tuned on one characteristic frequency. Because each fiber responds to a specific frequency, the complex of cochlear nerve fibers spanning low-to-high frequencies at variable intensities enables a total spectral analysis of the stimulating sound. Thus, one's ability to separate complex sound into its component parts is already partially accomplished at the lowest level of the auditory system.

These differently tuned fibers within the nerve each synapse in discrete regions of the cochlear nuclei and this orderly representation also occurs within the cortical acoustic area (tonotopic localization).

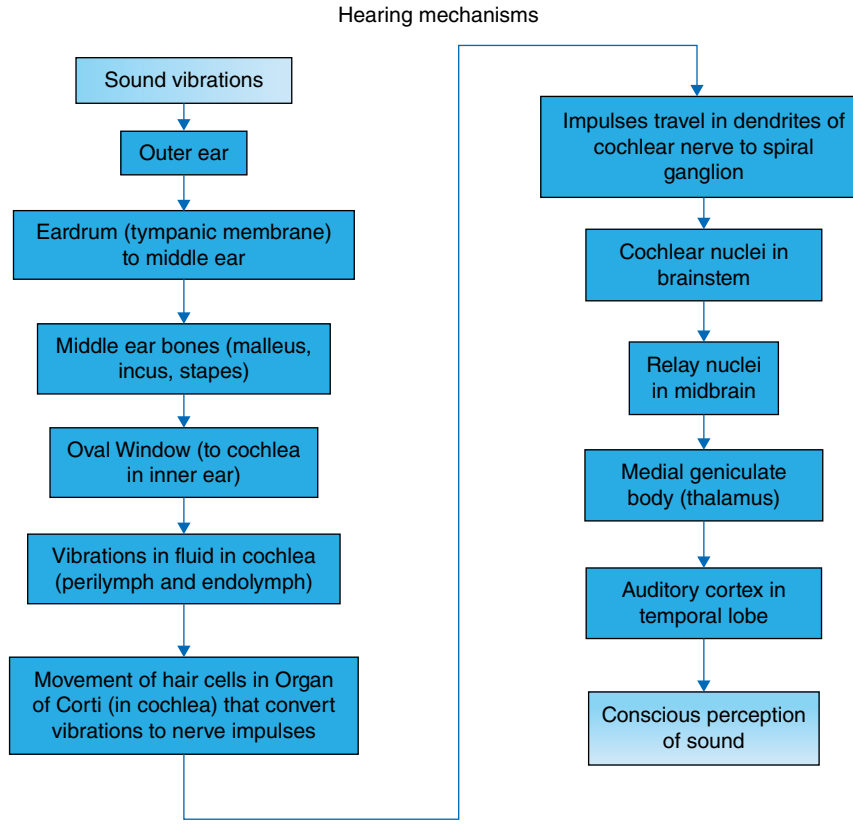

Figure 8.8 Flowchart depicting the mechanism of hearing.

CLINICAL ASPECTS

Nontraumatic conditions

Although the vestibular and cochlear portions of the VIIIth nerve are quite separate anatomically and functionally, lesions of the combined nerve often affect both vestibular and auditory modalities. Furthermore, it is quite difficult clinically to separate pathological conditions that affect just the nerve rather than (or combined with) the vestibular and hearing apparatuses within the inner ear. We will not discuss here the detailed anatomy of the cochlea or semicircular canals, but instead will briefly discuss some basic tests to assess the clinical status of the vestibular and acoustic systems, including the integrity of the VIIIth nerve. We will then discuss clinical issues that primarily are thought to involve the nerve rather than the inner ear mechanisms.

When we move our heads the fluid (endolymph) within the semicircular canals momentarily lags behind the skull movement. Differential movement of fluid between the semicircular canals of the two sides increases the activity in one vestibular nerve and decreases it in the other, leading to a perception of movement and reflex movements of the eyes (vestibular–ocular reflex;

VOR). Most vestibular nerve or system lesions are destructive, decreasing input from the damaged side. Therefore, the tonic firing of impulses from the damaged side is no longer consistent with that of the undamaged side and the patient perceives head movement when there is none. This results in abnormal eye movements (nystagmus) as the brain tries to maintain a stable visual image.

A clinician can test the VOR by rapidly moving the patient's head slightly to one side and then the other while the patient tries to fix the eyes on the examiner's nose. If the patient cannot maintain fixation with head turning to the right, for example, this would indicate a problem with the right vestibular system. Another test sometimes used to evaluate the VOR is the caloric reflex test (Figure 8.9). By irrigating each ear with cold and warm water (relative to body temperature), a differential is created in the neural output of the two sides that results in eye deviation toward the ear if cold water is used and away from the ear if warm water is used. In a patient who is awake, nystagmus then develops in the opposite direction. In a comatose patient with intact brainstem reflexes, the eyes will deviate, but there will be no nystagmus.

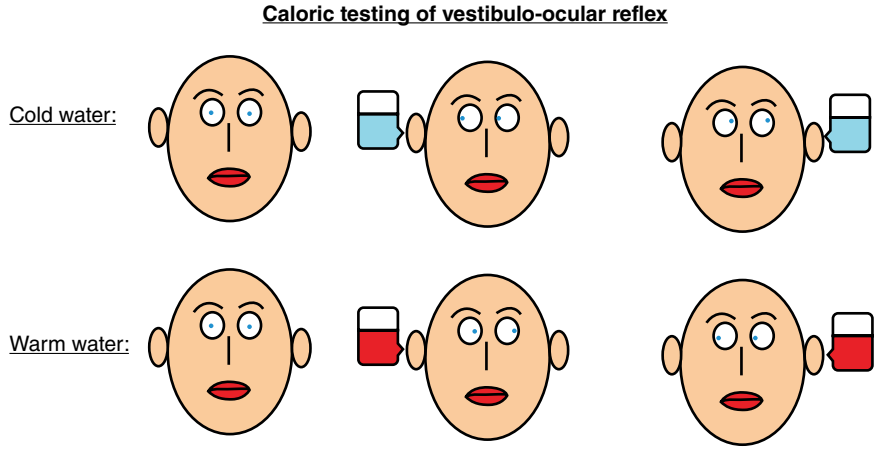

Figure 8.9 Caloric testing of the vestibular ocular reflex in a comatose patient with intact brainstem. Courtesy of Wikilectures.

Testing the acoustic nerve is simpler than testing the vestibular nerve. A quick test of hearing is to ask a patient to compare the sound of rustling fingers in the two ears. There are more sophisticated audiometric tests that can pinpoint whether the hearing loss is due to lesions of the inner ear or the acoustic nerve. Each of us presumably was screened for hearing loss in school.

There are two terms that are most associated with dysfunction in the vestibular and auditory systems, respectively. (1) Vertigo is the illusive perception of motion. Patients describe it as a sensation that the world is spinning about them or they are spinning in the world. A close approximation would be that which we experience on a merry-go-round, except that the reality of the experience is more intense. Vertigo is only one type of dizziness, as discussed

further later. (2) Tinnitus is the perception of sound by a patient when there is no external sound. It is typically referred to as "ringing in the ears," but can also be perceived as a rustling or roaring sound.

True vertigo can be caused by various tumors including acoustic neuromas, meningiomas, arachnoid cysts, epidermoids, lipomas, and vascular malformations, which can compress CN VIII as it leaves the brain stem. Typical symptoms of such tumors besides vertigo are unilateral loss of hearing, tinnitus, and imbalance.

"Dizziness" is a layman's term that is associated with a possible problem in the vestibular system, but can have many other causes. Dizziness can include a wide variety of symptoms such as vertigo, light-headedness, imbalance, lack of coordination, and disorientation. These symptoms can be caused by central or peripheral vestibular problems, but can also be related to many other causes, including decreased blood supply to the brain from cardiac causes or low blood pressure, cerebellar dysfunction, anxiety, or cognitive issues.

As mentioned earlier, an acoustic neuroma may cause dysfunction of CN VIII. Although referred to as "acoustic neuroma" because the patient presentation is most commonly unilateral hearing loss, this noncancerous tumor strangely almost always arises from the vestibular portion of the nerve (Figure 8.10). It is therefore more correctly known as a vestibular schwannoma. The clinical incidence is 10–15 per million/year. In many cases, the tumor is small and remains unchanged in size for many years following diagnosis. This presents the patient and clinician with a difficult decision over

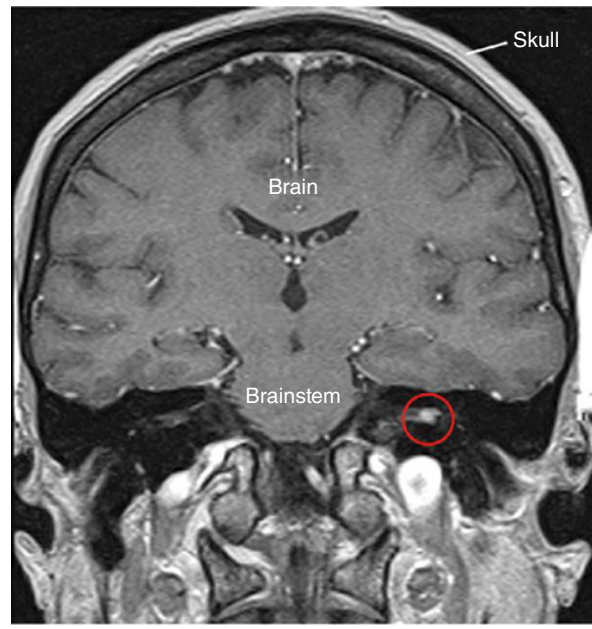

Figure 8.10 A coronal MRI image of a patient with a left acoustic neuroma (vestibular schwannoma) (circled). Courtesy of Dr. Edward Weber.

whether or not to remove the tumor surgically because of the risks associated with such surgery (e.g., potential loss of function of facial nerve and loss of hearing).

Charles Ballance, in 1984, may have been the first surgeon to remove a vestibular schwannoma. In his surgical report he described how difficult it was to get his finger around the tumor in order to remove it. The patient lived for many years after surgery, albeit with facial and trigeminal nerve palsies.

Below is a recent Internet case of a vestibular schwannoma:

> I have a left-sided schwannoma and have severe ear ringing and occasional lip and facial tingling. My doctor did an in depth balance and hearing test and because there was no hearing loss they will watch the tumor and may recommend me for gamma knife surgery. I won't elect gamma right away…afraid of facial nerve destruction/drooping.
>
> I am lucky enough to live in Connecticut where we have Yale New Haven Hospital – I have seen the neurosurgeon and the base skull surgeon. And I have mailed my MRIs to a wonderful neurosurgeon out in Missouri. All said the same thing. But the doctor in Yale, a neurosurgeon, was not 100% convinced it was a simple schwannoma because he sees speckled features so he is recommending removal for biopsy. I am 49. I am in good health. He thinks he will save my face nerves but could not promise anything on the hearing – he said usually that is affected at the least and gone because you have to sever the nerve to completely remove the tumor. If you leave any of it to try and save hearing, you can have a regrowth. He said if I was older or in poor health, he might try the gamma – but that will usually end up with a re-growth.
>
> My vision is also beginning to be effected. Words jump out of paragraphs as I read and are blurring together.
>
> Of course the tinnitus is driving me crazy on some days. Some days it is so mild it is barely noticeable.

This patient has many of the typical issues associated with a vestibular schwannoma and the visual disturbances probably result from problems with nystagmus. Furthermore, note that some days it is barely noticeable, a common but unexplained phenomena in neurologic conditions.

Vestibular neuritis is an acute inflammatory condition that affects the eighth nerve itself and is thought to result from a viral infection or reactivation of herpes simplex virus. Symptoms include vertigo, nausea, vomiting, and imbalance. Most patients recover well without treatment, although there are some reports that oral steroids may accelerate the recovery. Symptomatic medications for vertigo and nausea are useful for the first few days, but they may slow the process of compensation. Vestibular rehabilitation can aid recovery.

Below is a case with prolonged symptoms of vestibular neuritis:

Patient: 32 years of age, single, white female, physician in psychiatry training.

Jan. 8, 1990: Patient experienced sudden and severe dizziness and motion intolerance, and intense nausea and vomiting and was unable to get out of bed.

Jan. 11, 1990: Patient managed to call a taxi and to get to the Emergency Medical Department, Wake Forest University Medical Center. After obtaining a medical history, physical examination, blood and urine samples, and a chest X-ray, the patient was initially treated with vigorous intravenous rehydration and anti-vomiting agents.

Physical examination: Unremarkable, except patient is very fatigued, pale, quite nauseated, and complaining of dizziness. Patient has no fever or rigors. Patient's other systems are normal.

Laboratory data: All clinical laboratory data were within normal range. Pregnancy test was negative. Bacterial or viral agents were not found.

Jan. 13, 1990: Vomiting stopped and nausea almost subsided, but vertigo persisted. An otolaryngology consult was obtained and patient was examined by otologist. Routine otolaryngologic examination showed normal features except patient had nystagmus. Patient was very unstable in the upright position, and was unable to complete stepping test because of a fall to the left after one or two steps. Based on the history and the complete otolaryngologic examinations, the patient seemed to be suffering from acute onset of vestibular neuritis. Prescribed Valium.

Vestibular evaluation: Caloric test revealed minimal response with ice in left ear. Asymmetric responses were seen with a rotatory test (patient rotated), and direction fixed right beating positional nystagmus was seen in all positions.

Jan. 14, 1990: Nausea almost subsided and vertigo somewhat subsided, but unsteady gait persisted. Dosage of Valium was reduced, Antivert started.

Hearing evaluation: Hearing in both ears was within normal limits with a slight high frequency hearing loss.

Jan. 16, 1990: Still unsteady gait, but vertigo was resolved. Continue Antivert.

Jan. 18, 1990: Patient was improving and was tolerating unsteadiness well. Continue Antivert.

Jan. 18, 1990: Patient was discharged to home. Continue Antivert as needed.

Jan 25, 1990: Patient visited outpatient otolaryngology clinic. Most of symptoms were resolved, except unsteady gait. Continue Antivert, as needed.

Feb. 2, 1990: Patient's gait was steady enough to return to normal work on Feb. 5, 1990. Caloric response of the affected ear had returned to near normal.

Mar. 2, 1990: Patient was doing very well. Unsteadiness had subsided. However, patient reported that she was unable to ride a bicycle. The left ear caloric response was near normal.

July 20, 1990: Patient's vestibular disorders (vestibular neuritis) were completely resolved, including normal caloric response from the left ear. Patient was able to resume bicycling at a slow speed. No return appointment was set up (Ryu, 1993).

Trauma

Skull trauma can cause direct injury to CN VIII. Below is a case from World War I in which an explosion-related temporal bone fracture likely injured the nerve. The former soldier described was asking for a pension based on his injury:

> Lieutenant C.C.N., R.F.A., aged 33, appeared before Aural Board for assessment of a pension on March 9, 1920. He stated on April 18, 1916, while in Mesopotamia, he was struck on the head at the base of the right mastoid process by a piece of shell casing which he indicated as being about 4 in. by 3 in. in size. He said that he found he was deaf in this ear when the bandages were removed ten days later, and that he has been so ever since. Later, in answers to questions, he said that he was unconscious for two or three minutes after being hit, and that then he was so giddy that he was unable to get up, and that he continued to have severe attacks of giddiness for some time but that these had stopped by the time he arrived in England in June, 1916. His Board papers show that he complained of tinnitus and of giddiness on exertion when before a Board at Poona on June 2, 1916.
>
> On examination no scar can be found behind the right ear and the eardrum is intact with no evidence of any old perforation. On the left side the eardrum is normal, the air and bone-conduction are normal; on the right both air and bone-conduction show some shortening with the normal relation one to another. The sound of a tuning fork placed on the mid-line of the head is lateralized to the left side. When the noise-machine is inserted in the left ear and set going he raises the voice distinctly, but with the right ear there is no response. Though he hears the fork in the right ear he has practically no hearing in this ear; with the noise-machine going in the left ear he does not respond to the voice. On syringing the left ear with cold water a very strong normal reaction was obtained, but though the right ear was syringed with water of the same temperature for three times as long no response was noted (Layton, 1920).

The published case description did not elaborate whether the soldier was awarded the pension or not.

It has been recognized since the 1940s that traumatic brain injury (TBI) can cause dizziness, vertigo, and disequilibrium. TBI is believed to affect the vestibular system via direct damage to vestibular end organs or the vestibular nerve although the precise mechanism underlying the relationship between TBI and vestibular disorders is unexplained.

A World War I case that was published in 1931 describes a patient who suffered a concussion during the war.

White, male, age 35. Diagnosis: Neurosis, traumatic, constitutional; deafness, almost complete, right due to traumatic lesion of right auditory nerve.

In October of 1918, while on the front in the Meuse-Argonne sector, patient was rendered unconscious following the explosion of a shell and was taken from the scene of action and placed in a field hospital. At the same time he sustained superficial wounds on the left thigh and leg and was gassed, but no skull wound was sustained. Upon regaining consciousness after a period of 24 hours or longer he complained of deafness in the right ear, head noises, and complete paralysis of the right side of the face. He was hospitalized continuously from this time on and was sent to this country as a casualty. While deafness was almost complete from the date of the injury, and while he suffered from slight constant vertigo, actual paroxysms of severe vertigo did not develop until December, 1924. At that time he experienced his first attacks of marked dizziness and he developed seizures accompanied by muscular rigidity with unconsciousness; for several days following each attack he would be in a dazed state. For the past four years and at the present time, in addition to complaining of deafness, periods of vertigo both with and without unconsciousness, tinnitus, and facial paralysis, he suffers from periodic headache, becomes easily depressed, is reclusive and frequently cries (Baird, 1931).

These two cases show that damage to the vestibular system and likely nerve damage from head injury can occur both with and without accompanying brain injury.

TBI has been an especially serious issue for the soldiers who were part of the Iraq and Afghanistan campaigns primarily because of roadside bombs (improvised explosive devices). Mild TBI was reported by at least 20% of the US soldiers.

Below is a specific case that was reported on National Public Radio and on their website (http://www.npr.org/templates/story/story.php?storyId=106321923):

Sgt. Albert Couture's road to recovery begins behind a horse stable on the Tennessee side of Fort Campbell. He leads a mare named Jazz to a green pasture. Horseback riding hopefully will help Couture regain some of the balance he lost after confrontations with improvised explosives in Iraq on his last deployment.

Couture did not leave Iraq with visible injuries, but small concussions can catch up with a soldier, even years later.

"You can do most of your daily job, but some things make you very anxious, make you dizzy, make you nauseous," an army medical technician said.

For Couture, TBI showed up in the form of headaches and dizziness.

"I didn't think anything was wrong with me," he said. "I figured I just had a bad head."

But dizziness slowly became emotional instability after returning home. Couture said he became an angry person – or, at least, he was told he had become angry.

"I don't really remember," Couture said, explaining that he eventually put his fist through a glass door.

The horse riding and other therapy at Fort Campbell will help Couture's recovery. More than 75% of those treated by the Army do recover.

The Army continues to investigate methods to diagnose and treat TBI, and therefore has great interest in the VIIIth cranial nerve.

Our next nerve, the glossopharyngeal, has a strange combination of functions having to do with eating and swallowing.

REFERENCES

Baird JH (1931) Traumatic affections of the auditory nerve. *The Medical Bulletin of the Veterans Administration* **7**: 1032–6.

Green JO (1869) Obstinate vertigo, nausea and vomiting dependent on disease of the ear. *The Boston Medical and Surgical Journal* **79**: 388–90.

Layton TB (1920) Case in which a blow on the mastoid process caused partial destruction of the auditory nerve with destruction of the vestibular nerve. *Proceedings of the Royal Society of Medicine* **13**(Otology Section): 102–4.

Liu L, Arnold R, Robinson M (2012) Dissection and exposure of the whole course of deep nerves in human head specimens after dissection. *International Journal of Otolaryngology* **2012**: 1–7, Article ID 418650, doi: 10.1155/2012/418650.

Ryu JH (1993) Vestibular neuritis: an overview using a classical case. *Acta Oto-laryngologica (Supplement)* **503**: 25–50.

9 The Glossopharyngeal Nerve

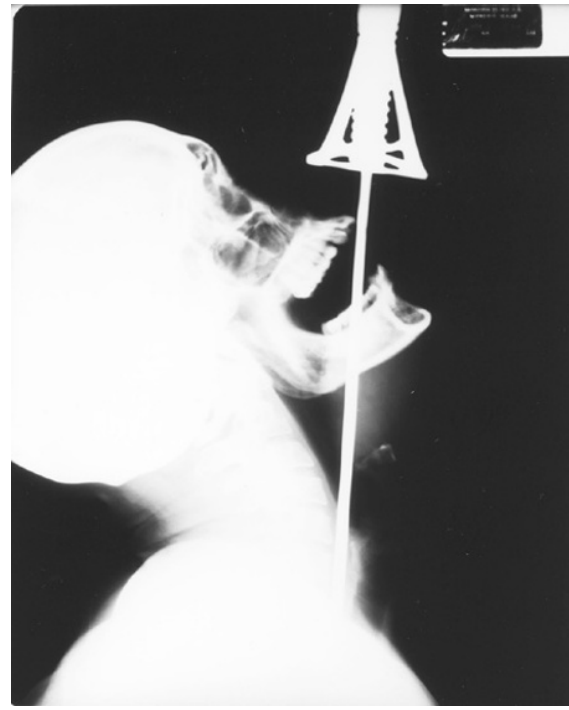

Figure 9.1 Radiograph of Mr. Brad Byers "swallowing" a sword. Courtesy of Brad Byers (http://www.bradbyers.com/).

ANATOMY/FUNCTION SUMMARY

As its name implies, the glossopharyngeal nerve supplies, first and foremost, the tongue and the pharynx. It is sensory (both taste and general sensation) to the posterior one-third portion of the tongue and motor to some of the muscles of the pharynx. It also supplies parasympathetic innervation to the largest salivary gland, the parotid (Figure 9.2).

In 1926, the well-regarded neurologist Charles Dana said the following about the glossopharyngeal nerve:

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
First Edition. Joel A. Vilensky, Wendy M. Robertson and Carlos A. Suárez-Quian.
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> To a kindly and imaginative mind, somewhat imbued with neural anatomy, the glossopharyngeal nerve makes a sympathetic appeal. It stands alone among the twelve cranial apostles, as a nerve without any very definite or important physiology and without any disease attached to its function. It has no tic or palsy or algia [pain]; it shares with the fifth and tenth nerves in supplying touch, taste and deglutition. But it is not vital to these functions. It could be resected with impunity. It receives only disregard and aloofness from surgeon and clinician (Dana, 1926).

Despite Dr. Dana's observation, clinical conditions associated with the glossopharyngeal nerve can be significant. This nerve is responsible for the gag reflex and in order for a sword swallower to overcome this reflex he must practice suppressing it (Figure 9.1). Below is a case in which the same reflex caused a serious problem for a patient:

A 25-year-old man presented with a history of gagging and swallowing problems. He also complained of right-sided neck pain when swallowing. His CT scan showed a mass in his neck that was firmly attached to his right glossopharyngeal nerve (Figure 9.3). This mass was excised surgically, which gave the patient complete relief of his gagging and swallowing pain (Tay, Swanston, and Lumley, 1994).

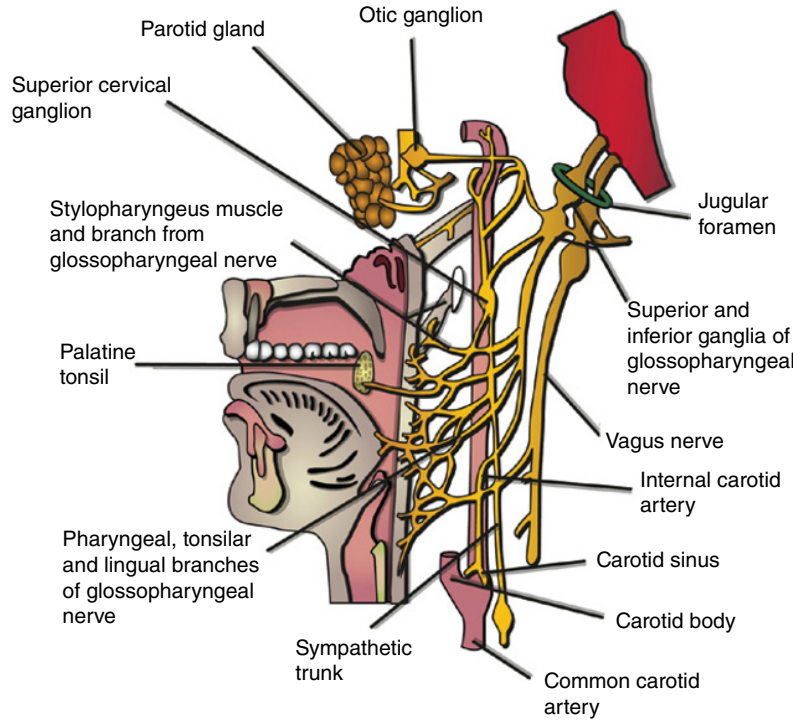

Figure 9.2 Schematic diagram of the glossopharyngeal nerve. This diagram also shows the many connections between the autonomic and somatic nervous systems associated with the glossopharyngeal and vagus (CN X) nerves, which are not generally discussed but which are very prevalent, especially in the head and neck.

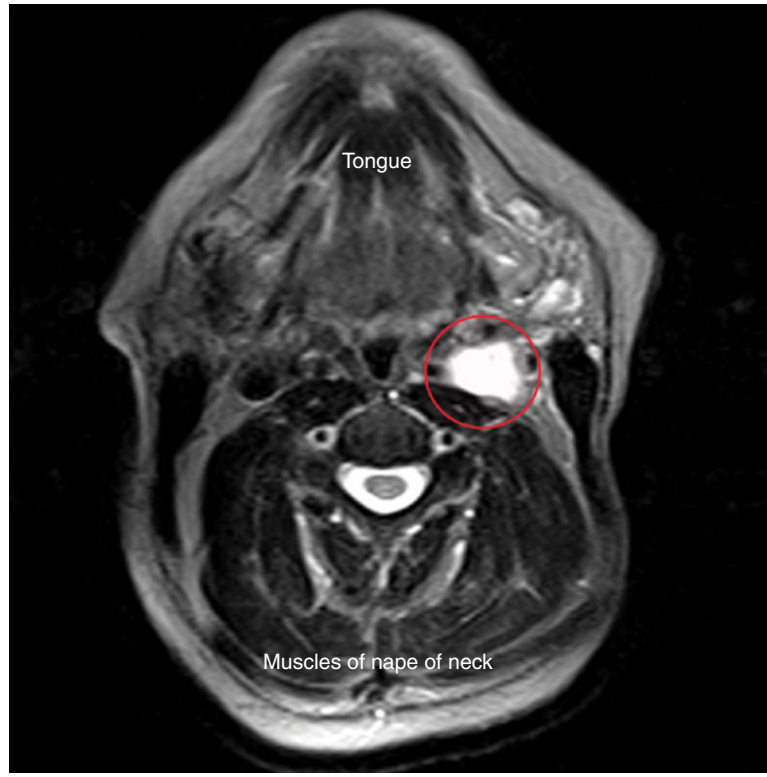

Figure 9.3 Axial section CT image of the upper neck of a patient in which a tumor (circled) encloses the glossopharyngeal nerve (this is not the CT scan of the patient in the case but a patient with an identical tumor on his left side; the published CT was not as clear as this one because it was done with an old CT scanner). Courtesy of Dr. Edward Weber.

ANATOMY/FUNCTION

The IXth cranial nerve is formed by five–six small fiber bundles that emerge from the medulla oblongata immediately anterior to the vagal fibers (Figure 9.2) and passes to the anteromedial part of the jugular foramen (Figures 9.4, 9.5, I.32, and I.34). It then descends in an arch with its convexity below and behind the base of the tongue, where it splits into its terminal branches. The nerve then lies on the lateral wall of the pharynx, and at the approximate level at the base of the tongue it turns in a medially directed bend across the lateral side of the stylopharyngeus muscle to enter the tongue (Figure 9.6). The glossopharyngeal nerve has two sensory ganglia; the small superior ganglion is identified as a small swelling of the nerve in the jugular foramen, and below that is the somewhat larger inferior (petrosal) ganglion (Figure 9.2).

The name "glossopharyngeus" refers to the tongue and pharynx. The anatomical tongue is just what you think about when you think of the tongue, although it is probably larger than you normally envision it to be (a normal adult tongue weighs 2–3 oz). The pharynx (Greek: throat) is a

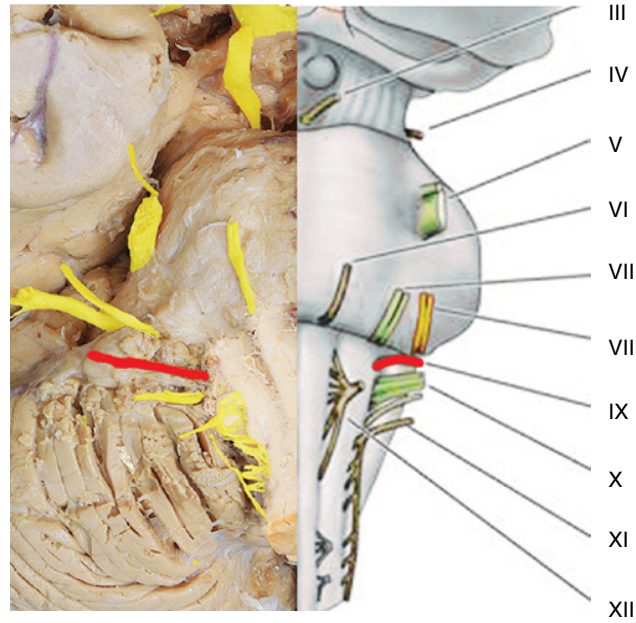

Figure 9.4 Photographic (left) and schematic drawing (right) showing the origin of the cranial nerves from the brainstem with the glossopharyngeal nerve highlighted.

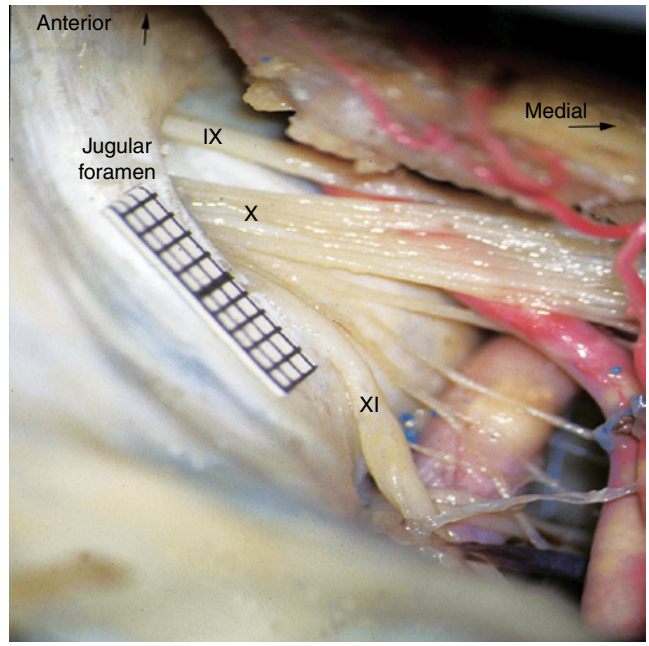

Figure 9.5 High-magnification view of CNs IX, X, and XI exiting the brainstem and entering the jugular foramen. The grid shows 1 mm squares. Courtesy of Dr. P. Mercier. (If orientation is not clear, please compare with Figure 9.4.)

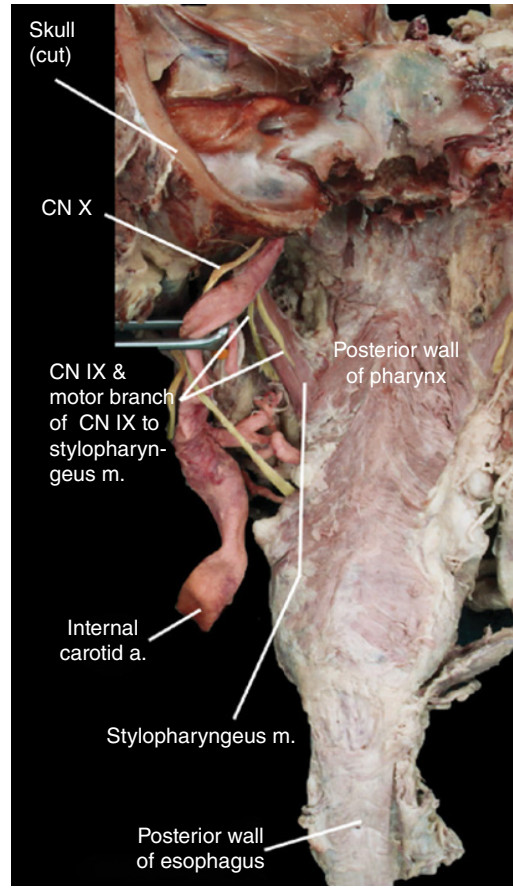

Figure 9.6 Frontally cut skull section that extends inferiorly to include the neck showing the back muscular wall of the pharynx and esophagus, the glossopharyngeal nerve, and the stylopharyngeus muscle. This view is looking at the back of the pharynx with the vertebral column removed (see Figure 9.7).

cylinderical-shaped conduit connecting the oral and nasal cavities (mouth and space behind the nose) to the esophagus and larynx (voicebox) in the neck (Figures 9.2 and 9.7). The pharyngeal chambers serve both respiratory and digestive functions, and also help with phonation, the making of sound. During swallowing, circular constrictor muscles help propel food to the esophagus and longitudinal muscles lift the walls of the pharynx over the food bolus.

The pharynx consists of three divisions (Figure 9.7). The upper portion is the nasal pharynx (nasopharynx), which is the posterior part of the nasal cavity. The nasal pharynx connects to the middle division, the oral pharynx (oropharynx). The oral pharynx starts at the back of the oral cavity and runs down the throat to the epiglottis, a beak-shaped piece of cartilage that covers the larynx to make sure food is directed to the esophagus (Figure 9.7). Recesses in the lateral walls of the oropharynx hold lymphatic tissue known as the palatine tonsils. These are prone to infection and are surgically removed in a tonsillectomy.

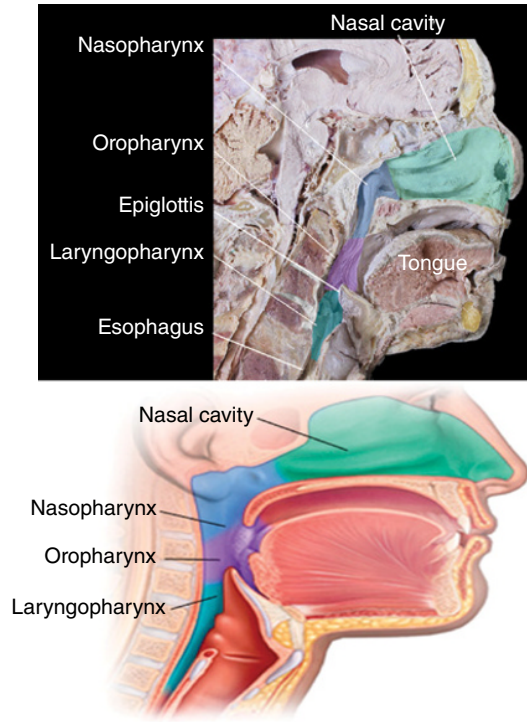

Figure 9.7 Top: sagittal midline section photograph of a cadaver showing the parts of the pharynx. Bottom: illustration showing the same features. Lower illustration reprinted with permission from Mayo Foundation for Medical Education and Research.

The adenoids are additional masses of lymphatic tissue at the base of the skull, the uppermost part of the nasopharynx. Inflammation of the adenoids can cause a nasal voice, snoring, and mouth breathing. These are also often removed during a tonsillectomy.

The continuity between the oral and nasal cavities allows us to breathe via either the nose or the mouth and, when medically required, allows food to be given by a nasogastric tube, from the nose to the stomach. It also explains why food may come out of one's nose when vomiting, or when trying to eat or drink and laugh at the same time.

The most inferior division of the pharynx is the laryngeal pharynx (laryngopharynx), which begins at the epiglottis and ends at the esophagus. Its function is to continue the process of propelling food into the esophagus and also to prevent food from entering the larynx. The sword shown in Figure 9.1 passes through the oral and laryngeal pharynxes to enter the esophagus.

The muscles and mucosa of the pharynx receive their motor, sensory, and autonomic nerve supply through the pharyngeal plexus of nerves (Figure 9.8). This plexus is situated in the fascia surrounding the pharynx and is formed by pharyngeal branches of the glossopharyngeal and vagus nerves, and by sympathetic fibers. The nasopharynx receives sensory innervation primarily from the maxillary nerve (CN V_2).

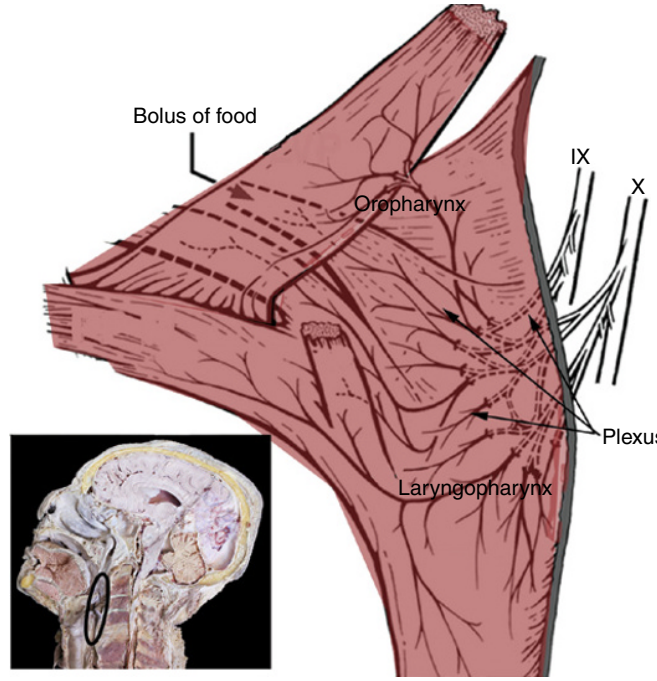

Figure 9.8 The large illustration shows the complex of nerves within the wall of the pharynx that comprise the pharyngeal plexus. The nerves are derived from CNs IX and X, and also include some sympathetic fibers (not shown). The inset shows the anatomical location of the region of the main image.

The pharyngeal plexus can be injured as shown in the case described below:

A 31-year-old healthy woman underwent elective surgical removal of all four third molars under general anesthesia. During the procedure the right side of the mandible was fractured. Immediately after the procedure the patient was aware of right sided soreness in her throat, hoarseness and nasal speech. That evening she had nasal regurgitation of liquids on the right side, difficulty swallowing, and fears of choking. Her speech was nasal and weak. A superficial hemorrhage was then noted on the right side of her nasopharynx. She had drooping of her right palate and deviation of her uvula to the left with breathing. There was decreased sensation to touch on the right side of the soft palate, tonsil and posterior third of her tongue. Three weeks after surgery all her symptoms and signs were improved and after three months of therapy, there was only minimal right-sided weakness. The diagnosis was pharyngeal and palatal dysfunction due to trauma to the pharyngeal plexus (Mermet *et al*., 1990).

The primary functions of the glossopharyngeal nerve are displayed in Figure 9.9. This information, with some additional information on types of fibers and pathway, is shown in the flowchart in Figure 9.10.

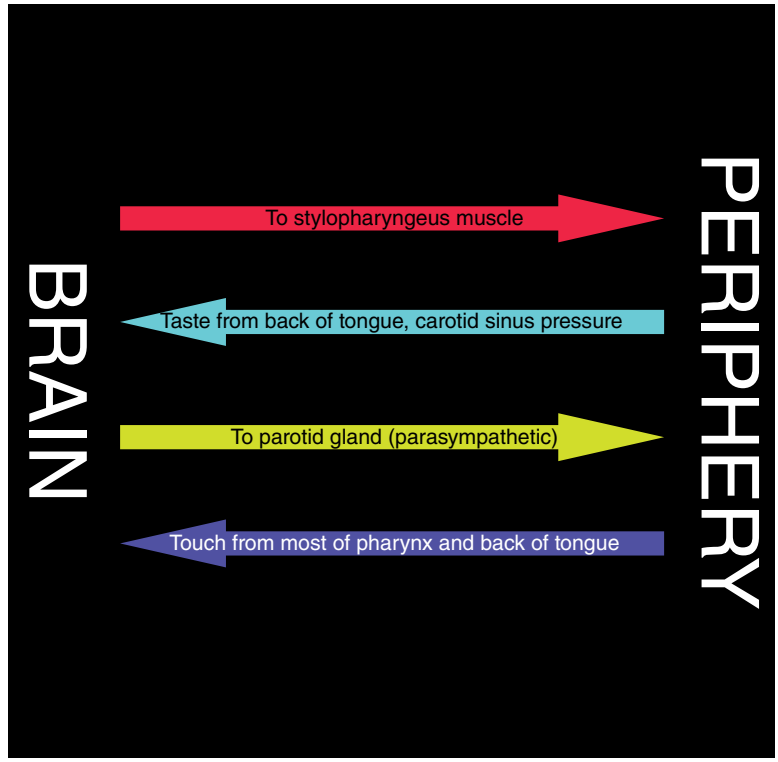

Figure 9.9 The main afferent and efferent functions of the glossopharyngeal nerve.

The glossopharyngeal nerve carries general and special sensory fibers (dark and light blue, respectively, in Figure 9.9) and somatic motor and visceral efferent (parasympathetic) fibers (red and yellow, respectively, in Figure 9.9; see also Figure 9.10). As apparent from Figure 9.9, the glossopharyngeal nerve is responsible for carrying both general sensations such as touch and taste from the back of the tongue (approximately the posterior one-third). You can recall from Chapters 5 and 7 that general sensation from the anterior two-thirds of the tongue is via the lingual branch of the mandibular nerve (CN V) whereas taste from the anterior one-third is via the chorda tympanic branch of the facial nerve (CN VII), which travels with the lingual nerve for much of its course. The tongue has a very complex development and that explains why so many nerves contribute to it (see Figure 12.7 in Chapter 12).

One of the muscles of the pharynx, the stylopharyngeus (Figures 9.6 and 9.10), is separately supplied by a muscular branch of the glossopharyngeal nerve and is the only muscle exclusively supplied by this otherwise primarily sensory nerve.

By means of an anastomosis with the auricular branch of the vagus nerve (Chapter 10), somatic afferent glossopharyngeal fibers take part in the innervation of the auricle of the external ear. This is important because an early symptom of throat and laryngeal cancer can be ear pain. In other words, the brain sometimes is unable to correctly ascertain the origin of

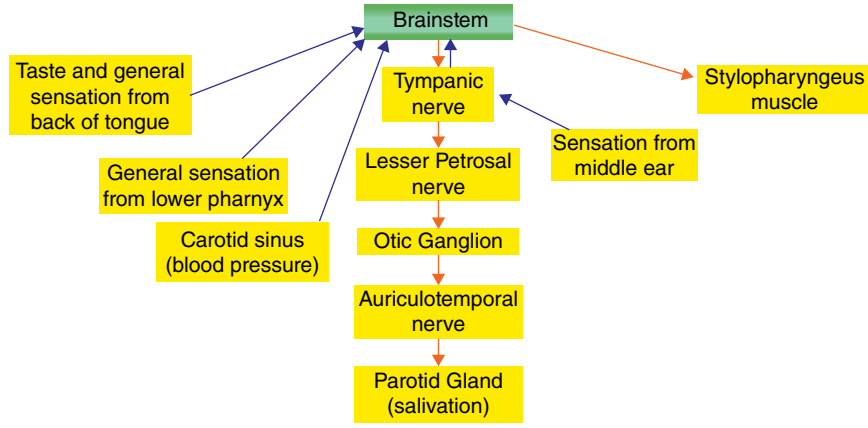

Figure 9.10 Flowchart showing all the functions of the glossopharyngeal nerve. The orange arrows indicate motor pathways (general and visceral) and the blue indicate sensory pathways (general and special).

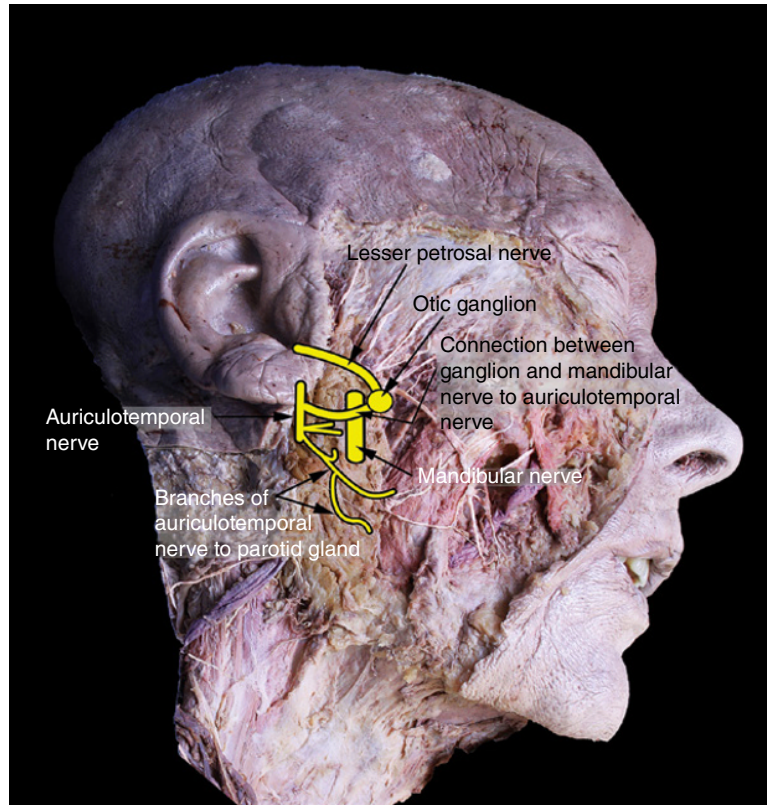

Figure 9.11 Illustrative drawing set upon a cadaver image to show the innervation of the parotid gland. This gland resides along the ramus of the mandible and is the largest of the salivary glands. The pathway from the glossopharyngeal nerve trunk to this gland is very complex and explained here as well as in the text. A branch of the glossopharyngeal nerve, the tympanic nerve, leaves the nerve as it exits the jugular foramen (not shown). This nerve traverses the middle ear cavity and emerges in the cranial cavity as the lesser petrosal nerve. It then exits the cranial cavity near the foramen ovale and enters the infratemporal fossa (Figure I.26). The nerve, which is carrying preganglionic parasympathetic fibers, reaches the otic ganglion and the fibers synapse there. Then the postganglionic fibers join a sensory branch of the mandibular nerve, the auriculotemporal nerve (Figure 5.2), and from this nerve terminal branches enter and innervate the parotid gland.

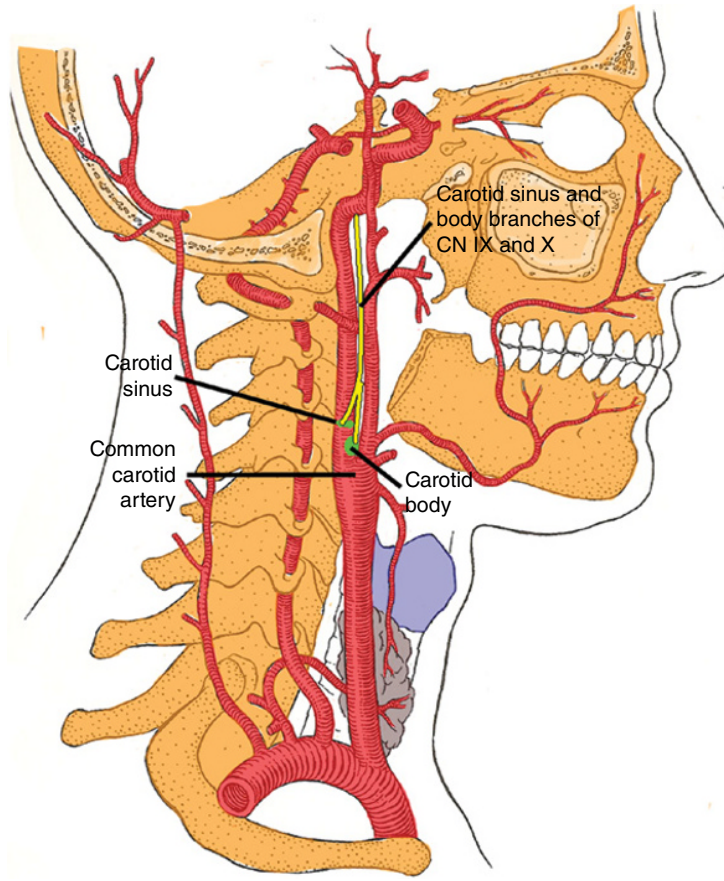

Figure 9.12 Drawing showing the carotid sinus and body at the bifurcation in the neck of the common carotid artery. The branches of the glossopharyngeal and vagus nerves that innervate these structures are also shown.

pain impulses and mistakenly tells you that there is a problem in one body location when it is actually in another. A general term for this phenomenon is referred pain.

The tympanic branch of the glossopharyngeal nerve (Figure 9.2) leaves the inferior (petrosal) ganglion of CN IX and enters the middle ear cavity through a small bony channel. It receives sympathetic fibers from the plexus on the internal carotid artery and enters the cranial cavity. Then the nerve courses as the lesser petrosal nerve (anteriorly on the temporal bone) and again leaves the cranial cavity through a fissure in the temporal bone to end in the parasympathetic otic ganglion, situated just below the foramen ovale (Figure 9.11).

The tympanic nerve and its continuation, the lesser petrosal nerve, carry mainly preganglionic parasympathetic fibers from the inferior salivatory nucleus in the brainstem. In the otic ganglion, the preganglionic fibers establish contact with postganglionic neurons. The axons of these neurons enter

the auriculotemporal nerve (a branch of the mandibular nerve; CN V_3) and supply the parotid gland with secretory fibers (Figures 9.2 and 9.11). And, yes, this route to the innervation of the parotid gland via the glossopharyngeal nerve is very complex and certainly not intuitive. The tympanic nerve, in addition to carrying fibers that supply the parotid gland, also carries sensory fibers that supply the mucous membranes of the tympanic (middle ear) cavity and the Eustachian tube.

Finally, a small branch of the glossopharyngeal nerve, the carotid sinus nerve, leaves the trunk of the main nerve (less frequently, the pharyngeal rami) and runs to the bifurcation of the common carotid artery (Figures 9.2 and 9.12). Here, it innervates the walls of the carotid sinus, a sensor of blood pressure. Frequently, fibers can also be traced to the adjacent carotid body, a sensor of blood chemistry. This nerve commonly has small anastomoses with the vagus nerve.

The fibers to the carotid sinus form the afferent link in the arc of the carotid sinus reflex, which is elicited on stimulation of mechanoreceptors in the sinus for blood pressure.

CLINICAL ASPECTS

Patients with lesions of the glossopharyngeal nerve have loss of taste on the posterior third of the tongue, a decrease in sensation and some muscular control in the pharynx, and loss of some sensation in the auricle; however, these losses are not typically noticed by individuals when the loss is confined to one side. Similarly, reduction in secretion of one parotid gland is easily compensated by increased production of the other salivary glands. Because of these compensations and because of intermingling of fibers of the glossopharyngeal and vagus nerves in the pharyngeal plexus, it is often difficult to clinically diagnose a pure glossopharyngeal nerve lesion. Furthermore, because of their close topographical relations, it is common to find both the IXth and Xth nerves affected simultaneously in lesions of the nerves as well as in lesions of their brainstem nuclei. The most decisive criterion of a lesion of the glossopharyngeal nerve is the absence of the ability to taste on the posterior third of the tongue.

The swallowing mechanism is divided into three phases: oral, pharyngeal, and esophageal. The pharyngeal swallowing reflex is involuntary and is initiated by a food (or liquid) bolus stimulating sensory input from the glossopharyngeal nerve to the brainstem. The muscles that are critical to swallowing contract and relax when impulses from the brainstem send the signal to do so. A unilateral glossopharyngeal nerve lesion can cause difficulty swallowing, decreased general sensation in the posterior third of the tongue, soft palate, and pharynx, and as noted earlier decreased taste in the posterior third of the tongue. On examination, the uvula will deviate toward the contralateral side (being pulled to that side by the muscles on the normal side) and the gag reflex will be diminished when the affected side is stimulated. Bilateral

glossopharyngeal nerve lesions produce bilateral soft palate weakness, causing a nasal voice and nasal regurgitation.

Although purely unilateral lesions of the nerve are not apparently significant (although there is a least one case report that described significant dysphagia [swallowing difficulty]) a case report of a bilateral lesion of the nerve presumably caused by bilateral tonsillectomy in a 30-year-old patient is presented below:

> One month after a bilateral tonsillectomy, a 30-year-old woman was referred to the head and neck surgery clinic for severe dysphagia, numbness, decreased taste sensation at the posterior aspect of the tongue, nasal regurgitation of liquids, nasal voice quality, and a 20-lb weight loss. The patient remained in the hospital one week postoperatively because she was dehydrated and unable to swallow. Ultimately, a percutaneous endoscopic gastrostomy tube was required for supplemental gastric feedings and has remained in use for several years. Our initial examination showed nasal voice, absent bilateral gag reflex, decreased posterior pharyngeal sensation, and a sluggishly mobile palate (Ford and Cruz, 2004).

Injury to the glossopharyngeal nerve is a known risk factor in tonsillectomy because the nerve traverses the fascial bed of the tonsil. In this woman's case, unfortunately, both nerves were apparently damaged in the procedure and did not recover, requiring her to obtain much of her nutrition via a feeding tube.

Tumors can affect the glossopharyngeal nerve as it leaves the brainstem. Nerves IX, X, and XI exit the skull base together through the jugular foramen (Figure 9.5). Infections such as skull base osteomyelitis, fractures, or cancer may thus affect all three nerves, resulting in ipsilateral vocal, palate, and shoulder abnormalities (see Chapter 11).

Based on the regulation of the carotid sinus by the glossopharyngeal nerve, death from overstimulation of the carotid sinus is a theoretical possibility. In this pathway, manual stimulation of the carotid sinus can potentially cause strong glossopharyngeal nerve impulses that lead to death because the heart stops beating. It is possible, but not proven, that this mechanism (carotid sinus reflex death) may contribute to the cause of death in cases of strangulation, hanging, and erotic asphyxiation. Striking the carotid sinus is considered a potentially lethal punch in karate. The carotid sinus reflex can possibly contribute to syncope or death by decreasing blood pressure and heart rate, especially in the aged or in people with carotid sinus supersensitivity.

In surgical removal of the parotid gland for cancer, the nerves carrying the postganglionic parasympathetic impulses from CN IX are cut (from the auriculotemporal nerve; Figure 9.11). Subsequently, the cut ends of these fibers can grow into the neighboring sweat glands of the skin of the face so

that whenever the patient eats or thinks about eating, he sweats profusely. This is called gustatory sweating (Frey syndrome; Figure 9.13). As exemplified by the Internet case below, this is an annoying although not dangerous condition:

> Has anyone had their parotid gland removed? I had mine removed 3 1/2 years ago. They had to cut the nerves that traveled to the salivary glands. In the healing process, the nerves reattached to my sweat glands in my face. Now, when I eat anything spicy, salty, or sour, instead of salivating on that side of my face, I literally bead up with sweat along my cheek. I am told this is called Frey's Syndrome. Unfortunately, I am not finding any relief from it. It is not a dangerous side effect of the surgery, just a very, very, annoying one. Anyone have this problem or have any solutions?
>
> Thanks!

Figure 9.13 A patient with gustatory sweating (Frey syndrome). This 69-year-old patient had her parotid gland removed when she was 18. Salivation was stimulated with sour candy. Note how the tissue paper sticks to the side of the face due to her gustatory sweating. Reprinted with permission from Haker and Mandel (2012).

Glossopharyngeal neuralgia (GN) is a rare disease (0.8/100,000 population) characterized by brief episodes of pain in the base of the tongue and deep pain in the neck. Attacks are often triggered by swallowing, talking, or coughing. Patients often complain of a dry throat. The pain is paroxysmal (comes in "waves"; its character is variously described as lancinating, stabbing, shooting, and like thrusts of a hot iron). The duration varies from a second, or fraction thereof, to nearly a minute, very rarely longer. The distribution is definitive in that it is always within some part of the glossopharyngeal sensory area such as the tonsil, root of the tongue, or pharynx – occasionally the ear lobule. Swallowing, particularly of liquids, talking, chewing, or yawning are given most often as the immediate cause of pain. At times, sneezing, excitement, coughing, exercise, touching, or washing induces the pain, but it often occurs spontaneously.

Approximately 10% of patients with GN experience a decreased heart rate, fainting, seizures, or even cardiac arrest. The latter results from dysfunction/abnormal impulses in the branches of the nerve that supply the carotid sinus.

The cause of GN is generally thought to be similar to that of trigeminal neuralgia; that is, vascular compression on the root entry zone of the nerve (Chapter 5). Accordingly, if medications such as anticonvulsants are not helpful, microvascular decompression (MVD) surgery is a common treatment. If no compression is seen at surgery, the nerve is simply cut. Either procedure typically brings relief and complete unilateral transection is not generally reported to have any lasting significant dysfunction (although there is some inconsistency here). Nevertheless, patients do not have taste or sensation on the posterior aspect of the affected side of their tongue.

Walter Dandy published the below case of surgical correction of GN by nerve section in 1927:

Case 1. History – A strong, healthy man, aged 45, but looking much older, was diagnosed with glossopharyngeal neuralgia. Seldom have we seen a man in greater agony, even in the most severe cases of trigeminal neuralgia. He was then having paroxysms of terrific pain in rapid succession, some induced by swallowing or talking and some even occurring spontaneously. Afraid to swallow or to talk, he sat in terror, with his head hanging forward and directed toward the right in order to allow the saliva to drool from his mouth and away from the affected side. He dared to eat only after his tongue had been cocainized over its base, and particularly, as he so strongly emphasized, over one spot about the size of a dime, near the junction of the tongue with the left tonsil. This "trigger zone," so real to him, did not show anything on examination. For three and one half years he had endured this pain at varying intervals. It had begun in September, 1923, with a severe knifelike thrust at the base of the tongue immediately after taking a drink of cold water; it lasted a few seconds, but for three weeks it occurred several times a day and ended as abruptly as it began. During the attacks, the left ear drum felt as though it were being pushed out and "were ready to burst." In one severe attack just before his operation, the patient felt as if all the teeth in the lower jaw on the affected side were "jumping out of their sockets." His tonsils had been removed in September, 1926, and again in November, 1926, in the vain hope of effecting a cure. During the latter operation, the throat was extensively burned with a cautery. The pain was decidedly worse afterward, and from then until his admission to the Johns Hopkins Hospital in April, 1927, the pains became more and more frequent and severe. He said it seemed to him that a red hot poker was being jabbed through the tongue. At first the attacks were of only two or three seconds' duration, but during the past six months each had lasted about ten seconds. He had the impression that the attacks were more frequent when he talked a great deal, but in his

occupation as a missionary there was little opportunity to get complete rest for any length of time. He had obtained relief for a few days by local application of cocaine.

An intracranial section of the ninth nerve, in the posterior cranial fossa was done. The patient made an uneventful recovery, with immediate and subsequent complete relief from pain of any kind. There was no disturbance of swallowing afterward. He was unable to detect any symptoms due to the loss of function of the ninth nerve. Objectively, however, there was total loss of sensation and of taste over the back of the tongue and pharynx. No motor impairment of any kind could be detected by examination (Dandy, 1927).

This case shows the severity of pain that can be associated with GN.

In 1995, Dr. F. Ferrante and colleagues published a case description of GN that involved heart abnormalities and that was treated with MVD:

A 62-year-old man had a five-year history of episodes of stabbing pain at the level of the glossopalatine arch and the root of the tongue on the left side. These symptoms were accompanied by paresthesias at the same sites, occasional paradoxical dysphagia, and episodes of syncope (fainting) when swallowing. Carbamazepine relieved the pain for about 18 months, but as time went on, it became less effective and failed completely to control an exacerbation of pain 3 months before admission. Painful episodes became more frequent (four or five times a day). During his hospital stay, the patient had an attack of pain at night, during which he had an episode of syncope, preceded by definite bradycardia [slow heart rate] with asystole [the ventricles of the heart stop contracting so that patients experience oxygen deprivation, causing death if prolonged] lasting 15 seconds, with subsequent recovery of consciousness. Left retromastoid craniectomy (entering the cranium from behind the left mastoid process, see Figure I.28) led to identification of an aberrant cerebral artery, which proved to be tortuous, which was tightly attached to cranial nerves IX–XI on the left side. Microvascular decompression was followed by removal of the adhesions and freeing of the artery from these nerves. The only postoperative event was an attack of hypertension immediately after the operation, quickly brought under control by medical therapy. The patient was well on discharge. Six months later, he still had slight paradoxical dysphagia (Ferrante *et al.*, 1995).

An unusual and known cause of GN is Eagle syndrome. In this condition, the styloid process of the skull is abnormally long and is hypothesized to irritate the nerve (Figure 9.14). Surgical shortening of the bone typically alleviates the patient's pain.

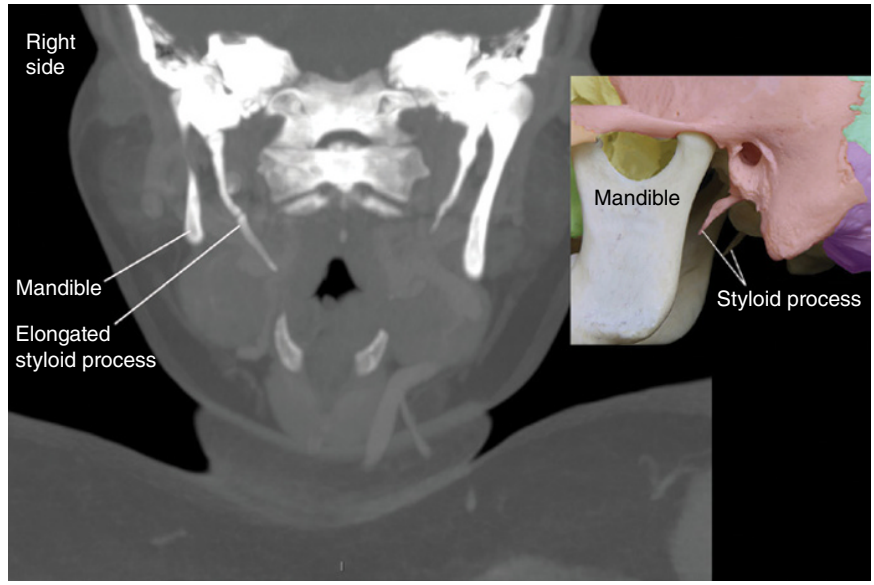

Figure 9.14 The main image shows a coronal view CT scan (it is as if you are looking at the patient's face) of a disproportionately long, right styloid process; note specifically that it extends beyond the lower border of the mandible, which is not normally the case as shown by the inset, which depicts a lateral view of the middle of a normal skull in which leaders point to both normal styloid processes (see Figure I.25). The CT also shows that the patient's left styloid process is similarly enlarged, although to a lesser extent than on the right.

Viral neuritis of the IXth and Xth nerves is increasingly being recognized. Although herpetic infection is a possible cause, the characteristic vesicular skin lesions may not always be obvious when the patient is first seen by a clinician. The symptomatology is similar to that of GN. Below is a case with herpetic eruptions described in 1979 in the British medical journal, *The Lancet*:

> On Nov. 13, 1977, a previously healthy 50-year-old man noticed altered taste followed by pain in the right side of his throat. The pain worsened and on Nov. 17 small irregular white plaques were seen on the right lateral aspect of the pharynx and the right posterior third of the tongue. He also had pain in his right ear. On Nov. 22 the lesions in the pharynx and on the tongue had almost resolved. When seen on Dec. 22 he was well. A laboratory test showed results consistent with a recent infection with herpes (Clark, 1979).

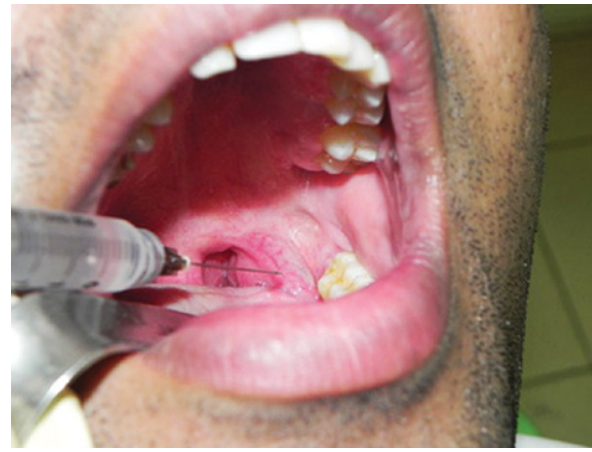

Figure 9.15 Injection to anesthetize the glossopharyngeal nerve. Reprinted with permission from Murthy *et al*. (2011).

Recently, the glossopharyngeal nerve became a target for anesthesia in patients who needed dental procedures and have a uniquely sensitive gag reflex (Figure 9.15). A case of such a patient is presented below:

A 30-year-old patient reported to the department of prosthodontics, for replacement of missing right maxillary first molar. On detailed case analysis, it was discovered that a previous attempt was made to perform the procedure by a dental practitioner, which was abandoned as the patient suffered from severe gagging rendering the procedure impossible.

Glossopharyngeal nerve block (GNB) was planned for this patient to enable comfortable completion of the preparation of the fixed partial prosthesis and recording of good impression. GNB was performed with the operator standing contralateral to the side (Figure 9.15) to be blocked and patient's mouth wide open. The palatopharyngeal fold (posterior tonsillar pillar) was identified and a tongue blade (held with the non-dominant hand) was introduced into the mouth to displace the tongue medially (towards the contralateral side) creating a gutter between the tongue and the teeth. A syringe with 25 gauge needle was inserted into the membrane near the base of the anterior tonsillar pillar and inserted about 0.25 to 0.5 cm and after careful aspiration 3 ml of 2% lignocaine solution with 1:200000 epinephrine.

This enabled successful completion of the procedure (Murthy *et al*., 2011).

As suggested throughout this chapter, CNs IX and X are intimately related in the head and neck. In the next chapter we will review this relationship as well as describe the many additional functions of the long, wandering vagus nerve.

REFERENCES

Clark J (1979) Herpes zoster of right glossopharyngeal nerve. *Lancet* **1**: 38–9.

Dana CL (1926) The story of the glossopharyngeal nerve and four centuries of research concerning the cranial nerves of man. *Archives of Neurology and Psychiatry* **15**: 675–85.

Dandy WE (1927) Glossopharyngeal neuralgia (tic douloureux) its diagnosis and treatment. *Archives of Surgery* **15**: 198–214.

Ferrante, L, Artico M, Nardacci B, Fraioli B, Cosentino F, Fortuna A (1995) Glossopharyngeal neuralgia with cardiac syncope. *Neurosurgery* **36**: 58–63.

Ford LC, Cruz MC (2004) Bilateral glossopharyngeal nerve paralysis after tonsillectomy: case report and anatomic study. *Laryngoscope* **114**: 2196–9.

Haker JM, Mandel, L. (2012) Frey's syndrome: case report. *New York State Dental Journal* **78**: 49–51.

Mermet RW, Zwillenberg D, Maron A, Brill, CB (1990) Unilateral pharyngeal plexus injury following use of an oropharyngeal pack during third molar surgery. *Journal of Oral Maxillofacial Surgery* **48**: 1102–4.

Murthy V, Yuvraj V, Mair PP, *et al.* (2011) Management of exaggerated gagging in prosthodontics patients using glossopharyngeal nerve block. *BMJ Case Reports*. doi: 10.1136/bcr.07.2011.4493.

Tay HL, Swanston AR, Lumley JS (1994) Glossopharyngeal schwannoma presenting as gagging dysphagia. *Postgraduate Medical Journal* **70**: 207–9.

10 The Vagus Nerve

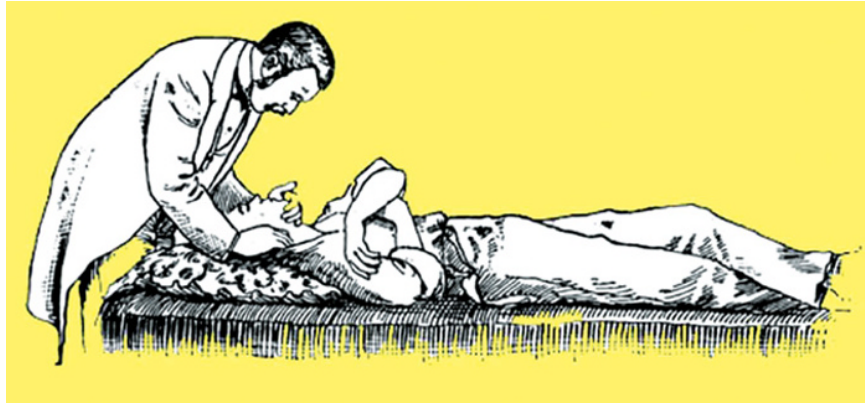

Figure 10.1 Plate 18 from *Osteopathy Complete* by E.D. Barber, D.O., published in 1898. This illustration, *Freeing and Stimulating the Pneumogastric Nerve*, shows a typical osteopathic treatment intended to influence the Xth cranial nerve (pneumogastric/vagus). Regulation of physiological processes was a major goal of early osteopathic treatment for a wide range of disorders. Osteopathic physicians during this period believed that they could modify both the peripheral and central nervous system by manipulative techniques that affected nerve centers throughout the body.

ANATOMY/FUNCTION SUMMARY

The vagus nerve has a very long course and affects speech, digestion, respiration, heart function, and perhaps your body's immune response (Figure 10.2). The nerve travels from the head, through the neck and through the chest to terminate at the lower part of your abdomen, specifically near the left colic flexure (this extent is what is typically stated in textbooks but we will review evidence that the range of vagal innervation may extend to pelvic organs as well). As shown by Figure 10.1, manual stimulation of the nerve was once thought to improve some disease conditions.

The Clinical Anatomy of the Cranial Nerves: The Nerves of "On Old Olympus Towering Top",
First Edition. Joel A. Vilensky, Wendy M. Robertson and Carlos A. Suárez-Quian.
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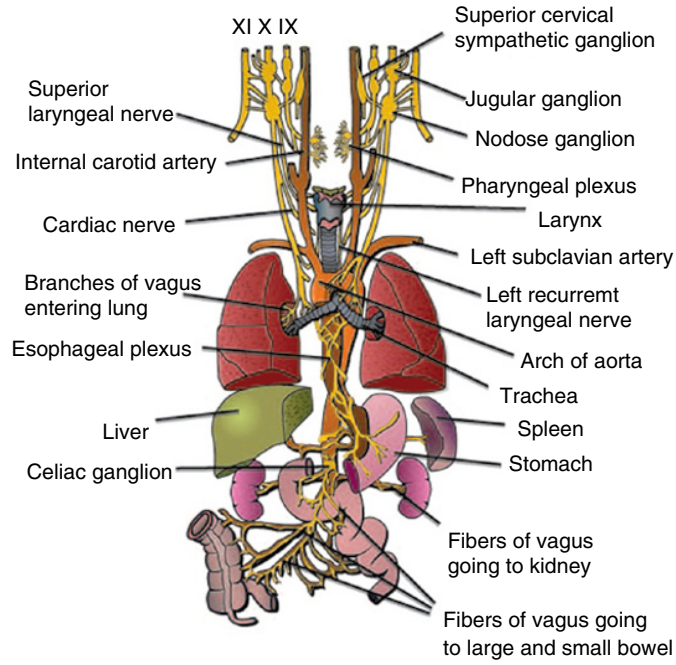

Figure 10.2 Schematic illustration of the long path of the vagus nerve.

Below is a case of presumed vagal nerve dysfunction associated with exposure to cold that was published by Dr. Thomas Hubbard in 1896:

> The gentleman, a druggist, of about forty years of age, returned from a two weeks' lake-trip on August 30, 1895. One week previous, while stopping at Marquette, and after several days' exposure to strong winds yachting on Lake Superior, he had severe neuralgia in the right temporal region. The following morning he awakened with strange and annoying sensations in his throat, and when he attempted to move he found that his right arm was weak, and the head seemed very heavy and inclined to fall over to the left. With assistance from his wife he dressed and went to breakfast. He soon discovered that he could swallow only with difficulty. The bolus of food seemed to stay in the lower pharynx for some time and passed into the gullet slowly. Fluids were in part returned into the mouth. At times he choked quite badly. He observed also that it was difficult for him to raise the right hand toward the mouth.
>
> During the day there was some cough, but it was not severe at first. The patient states that he did not feel as though he had contracted a cold, and rightly, I think, attributed the laryngitis to the irritation of food and drink. His general condition was fairly good, and he continued on his lake-trip, making occasional stops. Several times he had severe attacks of choking, and gradually a mild bronchitis developed. When asleep he snored very badly. By the time he reached home he was anxious and depressed.

It should be added that his habits are excellent, and there is no history indicating a rheumatic diathesis, nor malaria, nor constitutional disease.

I examined him August 30th, and found the following condition: Temperature normal, pulse about 95, stomach and bowels inactive. The urine was normal. Reflexes including pupillary, active. Sensation, both of skin and mucous membrane, was natural. The action of facial muscles and lips was good, and the tongue was protruded vigorously, with a slight inclination to the right. The uvula was drawn over to the left side, and a contraction-dimple was observed on the left, while the right side was drawn smooth. The action of the right pharyngeal muscles was decidedly impaired. The right vocal cord was fixed in the cadaveric position, and the left made compensatory excursion sufficient to produce a fair voice. The mucous membrane over the right arytenoid was infiltrated and looked excoriated or blistered, doubtless from irritating foods. He was coughing quite badly, and on such occasions there was decided inspiratory stridor. Dr. C.L. van Pelt called attention to the fact that the trapezius and sterno-mastoid were paretic. Reaction-tests were not made, but trials of range of motion and strength located the weakness in these muscles. The arm and fore-arm seemed to have normal strength. The head was supported most of the time on the right hand, with the elbow rested. The mind was clear and, as stated, the voice was weak and tremulous, conversation tiring him quickly. The impaired action of the tongue was doubtless due to lack of normal support at the base. During his confinement to the house the pulse varied. At times it was as low as 50, and on excitement would run up to 95, thus suggesting that the cardiac function of the vagus was disturbed.

The treatment consisted of quiet rest, mild cathartics, bromides, and codeine to quiet the spasmodic cough, and the diet was restricted to warm, bland fluids. A mild, detergent gargle was prescribed.

On the second day following, I was summoned in great haste. He had had a desperate attack of choking while taking a little plain soup. For five minutes or more, he struggled violently to catch his breath, which left him much exhausted and frightened. The bromides were increased, and nitrite of amyl was supplied to give him renewed confidence. This attack marked the critical period of his sickness, and from that day he gradually improved. For about two weeks he would throw his head over to the left with each attempt to swallow, thus rendering the palato-glossal and right pharyngeal muscles more tense. The base of the tongue was probably called into action to crowd the bolus into the gullet. He was confined in all about two weeks after he reached home, but the weakness of the throat and shoulder persisted for about a month from the date of his return home. A recent examination shows that all of the paretic symptoms have disappeared. As stated, the right vocal cord seemed to be completely paralyzed in so far as phonation under examination with the laryngoscope could determine, but yet there was probably some motion in ordinary speaking. This is possibly suggestive of independent but limited motor function of the pneumogastric (vagus) (Hubbard, 1896).

This fascinating case underscores the fundamental role that the vagus nerve serves in the regulation of phonation and swallowing, but not all of the symptoms expressed by this patient can be explained by invoking a focal lesion of cranial nerve X. The weakness of the trapezius muscle is consistent with a lesion to the XIth nerve as well, and issues with the tongue bring up the XIIth cranial nerve as also being impaired. The anatomy and function of these nerves will be discussed in subsequent chapters. In this chapter, we will explore how the Xth, the vagus, carries out its functions in the head and neck, as well as in the thorax and gastrointestinal system.

ANATOMY/FUNCTION

The Xth cranial nerve, the vagus nerve, was formerly known as the pneumogastric nerve because it provides innervation to the lungs and the gastrointestinal tract (Figure 10.2). Vagus means wandering in Latin, and this is the name that is used today, referring to its very long course from the brain stem to at least the large intestine. It probably descends lower than that, perhaps all the way to the uterus in women (see the following text).

The vagus is predominantly a visceral (autonomic; parasympathetic) nerve, with its rootlets emerging from the medulla as a series of fiber bundles just dorsal to the inferior olive (Figure 10.3).

Once joined together, the vagus nerve leaves the skull via the jugular foramen (Figure 10.4), where the nerve shows a small swelling, the jugular ganglion. Immediately below the jugular ganglion, the nerve again thickens to form the large, elongated nodose ganglion (Figure 10.5). The efferent (somatic and parasympathetic) vagal fibers proceed without interruption through the ganglia to continue with the sensory fibers as the trunk of the vagus nerve in the neck.

The numerous visceral afferent vagal fibers, which carry sensory information from the thoracic and abdominal viscera, have their cell bodies in the large nodose ganglion, and the jugular ganglion contains the cell bodies of the limited somatic afferent fibers (Figure 10.5). In contrast to every other cranial nerve, there are some peripheral differences in the courses of the branches of the right and left vagus nerves.

After the vagus nerve exits the jugular foramen, it is found close to the accessory (XI) and glossopharyngeal (IX) nerves and the internal jugular vein (which all leave the skull through the jugular foramen; Figure I.32). The vagus nerve descends in the neck, enclosed with the carotid vessels and internal jugular vein in a common sheath of connective tissue. Both vagus nerves enter the thorax, pass posterior to the root of the respective lungs, and form plexuses on the esophagus (Figures 10.2 and 10.6). The right vagal trunk tends to run more posteriorly on the esophagus and the left more anteriorly, a result of the rotation of the gastrointestinal tract during development. The terminal branches pierce the diaphragm with the esophagus to intermingle at the celiac ganglion (Figure 10.7). The celiac ganglion also receives preganglionic

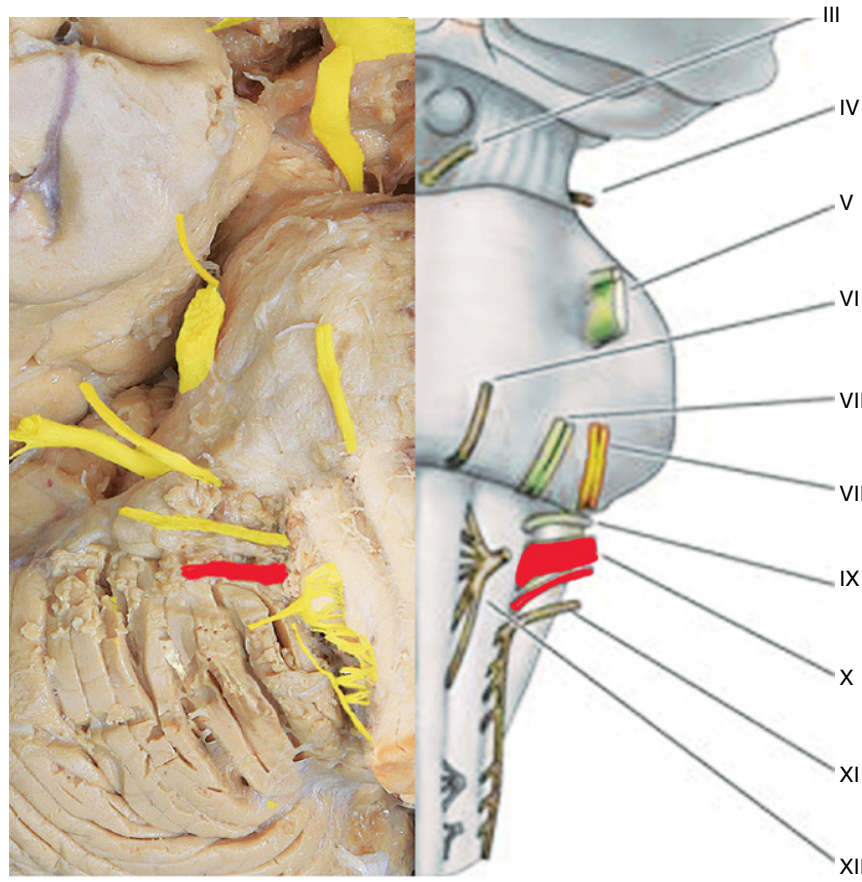

Figure 10.3 Photographic (left) and schematic drawing (right) showing the origin of the cranial nerves from the brainstem, with the vagus nerve highlighted.

sympathetic fibers from the greater splanchnic nerve from the thorax. These latter nerves synapse at the celiac ganglion. From the ganglion, the postganglionic sympathetic nerves and the preganglionic fibers of the two original vagal trunks piggyback on to the blood supply of the gastrointestinal tract, namely the celiac arterial trunk and its derivatives, and are disseminated to all of the gastrointestinal tract and its associated organs as far as the left colic (splenic) flexure (terminal flexure of the large bowel; Figure 10.2). Thus, the vagus supplies parasympathetic innervation to the esophagus, stomach, small intestine, much of the large intestine, liver, spleen, suprarenal glands, kidneys, and to the pancreas. When punched severely in the abdomen, pressure on the celiac ganglion causes the feeling of nausea.

Although, as noted in the earlier paragraph, the distal extent of the vagus' range is classically believed to be the left splenic flexure of the large intestine, there is some evidence that its fibers actually extend to the whole colon. Furthermore, they may even go lower into the pelvis and supply some general sensation to the uterus in women. Drs. Barry Komisaruk and Beverly Whipple of Rutgers University conducted a study on women with transected

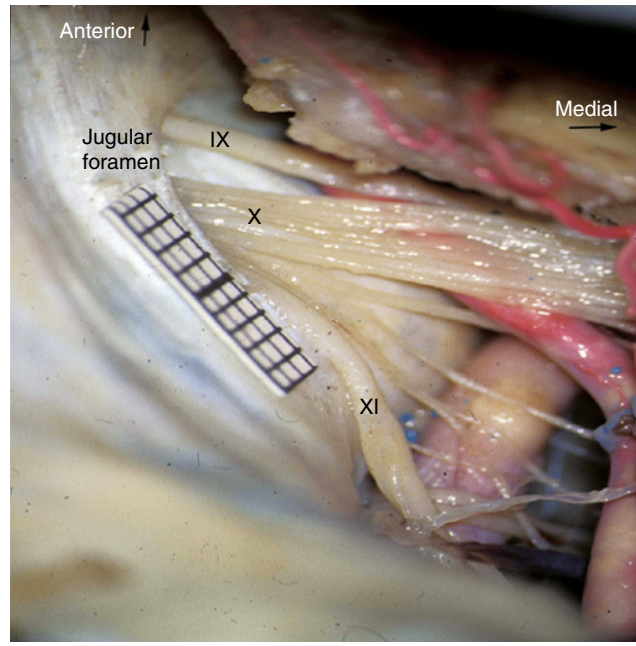

Figure 10.4 High-magnification view of CNs IX, X, and XI exiting the brainstem and entering the jugular foramen. The grid shows 1-mm squares. Courtesy of Dr. P. Mercier. (If orientation is not clear please compare with Figure 10.3).

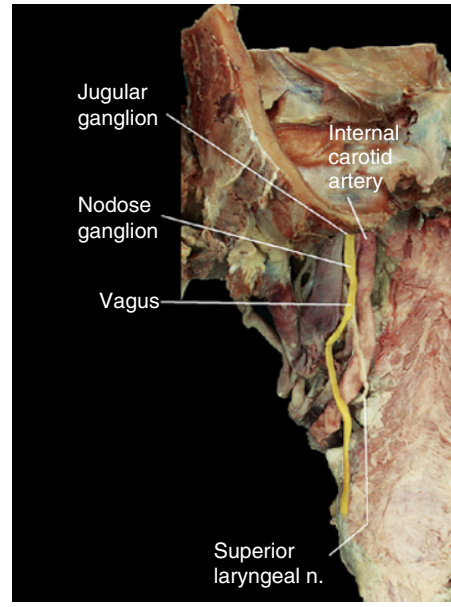

Figure 10.5 The vagus nerve is shown in the neck along with its ganglion and the internal carotid artery.

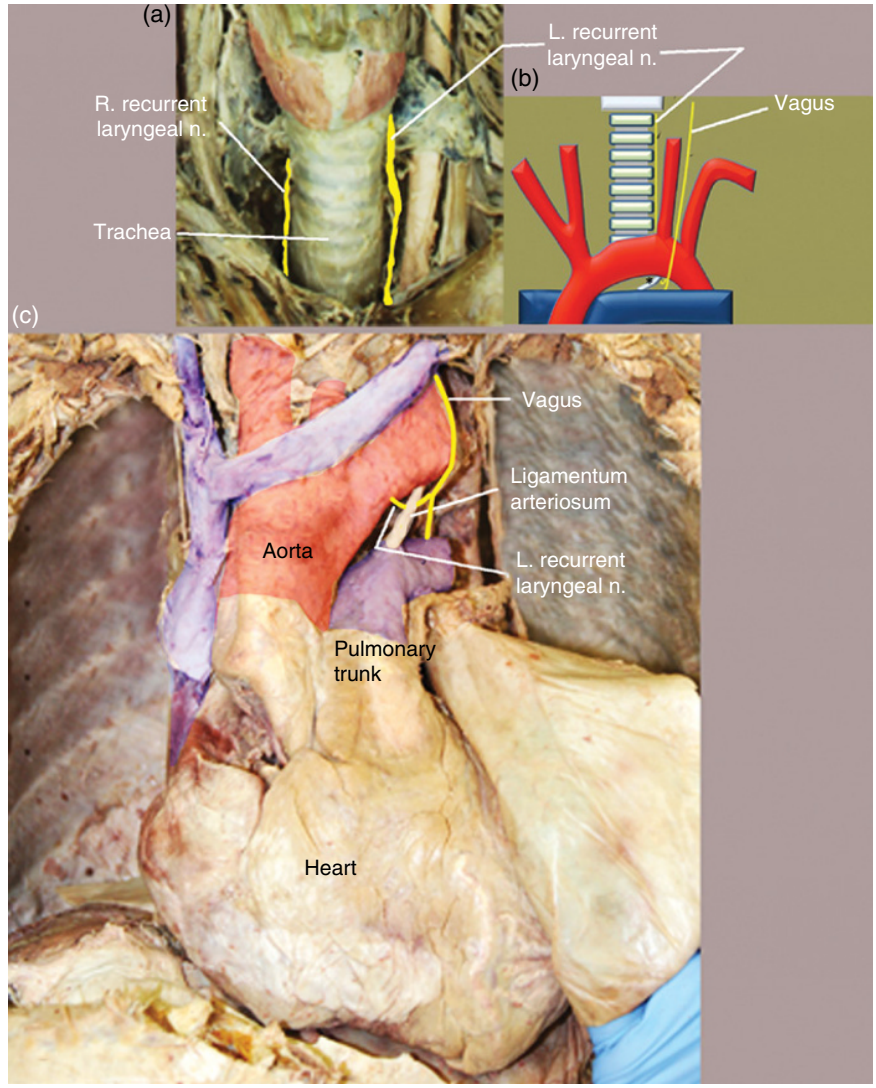

Figure 10.6 Recurrent laryngeal nerve. (a) Cadaver dissection photograph showing both the left and right RLNs along the trachea in the neck. (b) Illustration showing how the left RLN arises from the left vagus nerve and passes around the arch of the aorta. (c) Cadaver photograph showing similar relationships to (b) but also the relationship between the left RLN and the ligamentum arteriosum. Part (b) is reprinted with permission from Van Melle, Meyens, and Budts (2010).

spinal cords in 2004. The women could sense stimulation of the cervix and even achieve orgasm from clitoral stimulation, although it was impossible for their brains to receive information through the expected route from the pelvic somatic nerves (pudendal nerves) because of their transected spinal cords. Brain MRI scans showed that the region corresponding to input from the vagus nerve was active during sexual activity. Because the vagus does not travel within the spinal cord, the authors hypothesized that the women were able to feel sexual stimulation via the vagus.

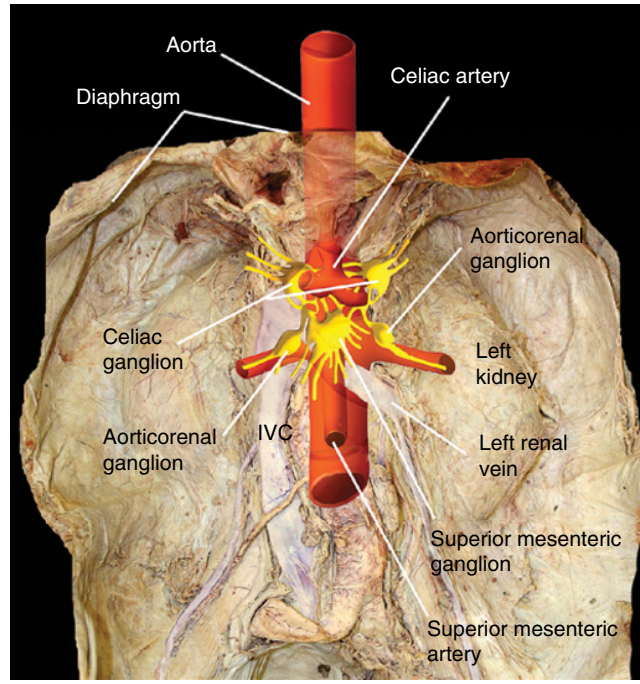

Figure 10.7 Drawing of the aorta with celiac and other abdominal autonomic ganglia superimposed on a cadaver dissection of the posterior (back) abdominal wall (as seen from a front view). IVC, inferior vena cava.

During their courses in the neck and in the chest, the right and left vagus nerves give off many branches. The auricular ramus is a small fiber bundle that emanates from the jugular ganglion, passes through the canals in the mastoid process, and supplies the dorsal wall of the external auditory meatus and part of the auricle (concha). As a result of this connection, throat pain (e.g., due to cancer) is often felt in the ear because the CNS is often unable to differentiate the location of the origin of a stimulant when multiple nerves converge upon a single shared pathway. Unfortunately, patients can thus sometimes be subjected to many ear examinations and treatments prior to finally being diagnosed with laryngeal cancer.

There is a meningeal ramus of the vagus, which re-enters the skull in the jugular foramen and supplies the dura mater in the posterior cranial fossa. This may explain how stimulation of the vagus nerve has been effective in relieving some patients with intractable headache pain.

Other small branches of the vagus establish anastomoses with the glossopharyngeal nerve and with the superior cervical ganglion of the sympathetic trunk (Figure 10.2). As more completely explained in the following chapter, the lower fibers of CN XI are often referred to by some anatomists as the "cranial root" of CN XI whereas other anatomists consider these fibers to be part of the vagus nerve. Here, the "cranial root" of XI is considered an integral part of the vagus nerve.

The vagus nerve near the jugular foramen also gives off pharyngeal rami that branch from the nodose ganglion and take a descending and anterior course on

the pharynx. They take part in the formation of the pharyngeal plexus together with branches from the glossopharyngeal nerve and the cervical sympathetic nerves (Figure 10.2; see also Chapter 9). Somatic efferent fibers from the plexus supply the muscular pharyngeal constrictors, the soft palate, the levator palati muscle, and the muscles of the palatal arches (Figure 9.8). Sensory fibers from the plexus innervate the mucous membranes of the pharynx, the most posterior parts of the tongue, and the upper surface of the epiglottis.

The superior laryngeal nerve leaves the trunk of the vagus nerve just below the nodose ganglion and courses in an inferior and a slightly anterior direction on the lateral side of the pharynx (Figure 10.5). It then subdivides into the external laryngeal nerve, which carries chiefly somatic motor fibers to the cricothyroid muscle (a muscle of the larynx), and a larger internal laryngeal nerve (Figure 10.8). The latter enters the larynx through the thyrohyoid membrane immediately below the greater horn of the hyoid bone and is distributed within the larynx. The internal laryngeal nerve supplies the mucous membrane of the larynx down to the vocal cords, and thus is a sensory nerve for the larynx (Figure 10.8).

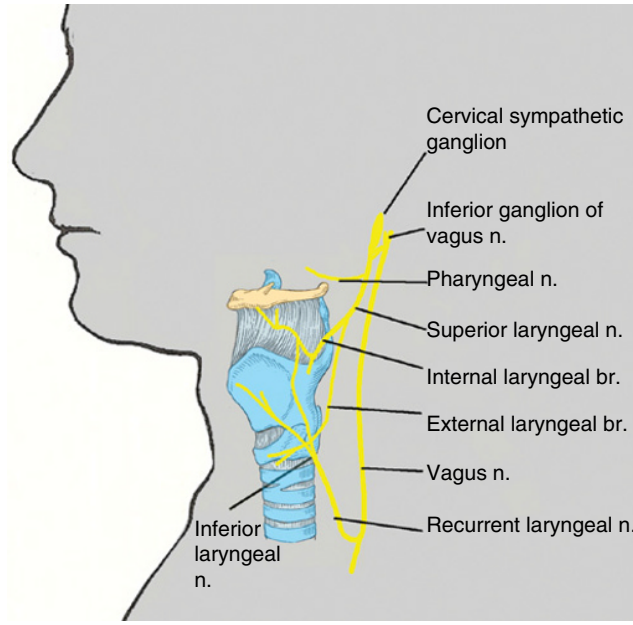

Figure 10.8 Illustration showing the branches of the vagus nerve in the neck.

The recurrent laryngeal branch of the vagus is the primary motor nerve for the larynx and therefore is responsible for speech production (Figures 10.6, 10.8, and 10.9). It leaves the trunk of the vagus nerve at a higher level on the right than on the left, because the right nerve makes a "U-turn" around the subclavian artery, whereas the left recurrent laryngeal nerve (RLN) makes a similar U-turn, but around the arch of the aorta (Figure 10.6). Both nerves then ascend (that is why they are referred to as "recurrent") in the sulcus between the trachea and the esophagus (Figures 10.6, 10.8, and 10.9). This strange

reversal in the course of the nerve results because of the migration of neck structures during development. The terminal branch of the RLN, the inferior laryngeal nerve, enters the larynx and innervates the intrinsic laryngeal muscles and also supplies sensation to the lower part of the larynx (Figure 10.8). The RLN also sends fine branches to the trachea and esophagus and some inferior cardiac rami to the heart (Figure 10.9).

Below is an Internet case of a patient who had bilateral RLN injury resulting from thyroid surgery:

> I had a total thyroidectomy for multinodular goiter and difficulty swallowing in December 2007. The general surgeon that performed the surgery told me he was going to use a special device to monitor my nerves during surgery. After the surgery I found out he changed his mind and did not use this device. I have bilateral recurrent laryngeal nerve paresis. I went to an Ear, Nose and Throat doctor two months ago (March) to confirm this. My voice is soft and whispery, I have difficulty doing much in the way of activity related to shortness of breath. The first three months after surgery I was VERY whispery, it has gotten better but is far from normal. I cannot sing, have trouble talking on a cell phone and hard of hearing people can't hear me. I can't raise my voice at all and certain words, letters are impossible to say. The ENT actually recommended I consider a tracheotomy if my shortness of breath does not improve. They are recommending that I wait 5–6 months to see if it comes back and then get another evaluation.

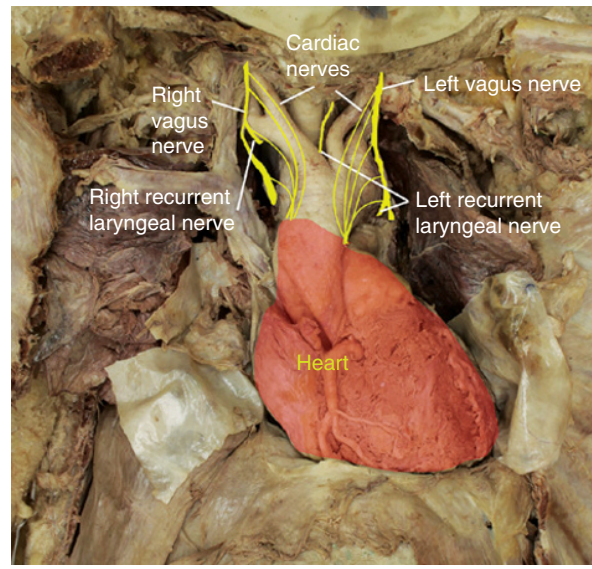

Figure 10.9 Illustration drawn upon a cadaver photograph showing the cardiac nerves arising from the left and right vagus (and left and right recurrent laryngeal) nerves and streaming to plexuses located near the heart. Vagal impulses to these plexuses act to slow the heart whereas sympathetic inputs (not shown) act to speed up the heart.

The most important branches of the vagus nerve to the heart are the superior cardiac rami (Figure 10.9). These leave the vagus nerve between the points of departure of the superior laryngeal nerve and the recurrent nerve and follow the common carotid artery on the left and the brachiocephalic artery to the heart on the right side. The vagal cardiac nerves (preganglionic parasympathetic) terminate with postganglionic (parasympathetic) neurons in cardiac ganglia located on the muscle of the heart. These connections explain how stimulation of the vagus nerve is used in the treatment of heart failure (see Clinical Aspects below).

The thoracic part of the vagus nerve gives off branches to the esophagus, the bronchi, and the pericardium. The bronchial branches form plexuses that continue along the branches of the bronchial tree into the lung. The postganglionic neurons in the plexuses transmit the visceral efferent impulses to the glands and the smooth muscles of the air passages in the lung.

As has been mentioned, the somatic efferent fibers of the vagus nerve innervate the striated musculature of the palate and pharynx and, through the recurrent and the external laryngeal nerves, the muscles of the larynx, thereby controlling speech production.

The visceral efferent (parasympathetic) fibers in the vagus nerve are found in the branches of the vagus nerve to the esophagus, trachea, bronchi, heart, stomach and intestines, pancreas, spleen and liver. In addition, a smaller number run in the superior laryngeal nerve to supply the glands of the larynx.

The numerous visceral afferent vagus axons have their cell bodies in the nodose ganglion. They mediate afferent impulses from the visceral organs that are supplied by the vagus as well as taste impulses from the most posterior part of the tongue and the epiglottis. The somatic afferent vagus fibers have their cell bodies in the jugular ganglion. The majority of these fibers pass in the auricular ramus, which is purely sensory.

The vagus nerve contains fibers of varying diameters and a considerable number of unmyelinated fibers.

CLINICAL ASPECTS

The vagus nerve may be affected by various lesions in the neck, such as tumors or inflammation in the cervical lymph nodes, aneurysms of the internal carotid artery, and open traumatic injuries. It may also suffer from similar conditions in the thorax. Diabetes and chronic alcoholism may also cause vagus nerve conditions as may viral infections (vagal neuritis). Furthermore, because of an intermingling of fibers and functions, it is sometimes difficult to distinguish lesions of CN X, from those of IX and XI in the head; any compressive lesion within the jugular foramen may affect all three nerves.

The effect of a vagal nerve injury is dependent on the location/level of the injury. The more proximal (closer to the origin of the nerve) the injury, the greater the effect of the lesion. There may also be injury to only a branch of the nerve, most commonly the RLN, which we will discuss first because its effects can be rather devastating.

Recurrent laryngeal nerve injury

Unilateral injury to the recurrent laryngeal nerve (RLN) is most often secondary to surgery in the anterior neck such as thyroidectomy (see the earlier case), anterior approaches to the cervical spine, or carotid endarterectomy (removal of plaque from the artery). The nerve is accidentally stretched, irritated, or cut as the surgeon performs the procedure.

The RLN may also be involved in tumors, especially in the chest. The rare cardiovocal syndrome, also known as Ortner's syndrome, occurs when cardiovascular pathology causes a left RLN palsy, resulting in hoarseness. This condition was first described in patients with enlargement of their left atrium (upper chamber of heart) secondary to mitral valve stenosis (narrowing of the valve between the left atrium and left ventricle). It is now known that a variety of cardiac or vascular pathologies may cause impingement of the left RLN between the aorta and pulmonary trunk.

A case of Ortner's syndrome that was published in 2009 and presumably associated with heavy smoking is presented below (Figure 10.10):

> A 79-year-old man visited the ear, nose and throat clinic because of a 1-month history of hoarseness. He had been a heavy smoker for more than 60 years. Chest radiography showed a widening of the internal structures of his chest including his aorta. Flexible larynoscopy identified a paralyzed left vocal cord. A thoracic aneurysm was suspected and confirmed by CT (Figure 10.10). It was thought that the left RLN was compressed between the aortic aneurysm and the pulmonary artery. The patient was referred to a surgeon and underwent aortic arch replacement surgery. Six months later his vocal paralysis had mildly improved (Chen, Lin, and Lu, 2009).

Based on the degree of the injury or damage to the nerve, varying degrees of paralysis of the vocal apparatus may occur. In partial or progressive recurrent nerve lesions, it is common that the muscles that separate the vocal cords and thus open the space between the vocal cords (rima glottidis) suffer first rather than the muscles that close the vocal cords (Semon's law). There is only one set of muscles that can abduct (open) the vocal cords, the posterior cricoarytenoid muscles. Hence, there is greater probability that this action will be eliminated if a particular set of fibers is impaired. When the recurrent nerve paralysis on one side is complete, the vocal cord on this side will be in an intermediate abducted (cadaver) position (Figure 10.11). The patient has a hoarse voice, which tires easily. Usually, after some time the patient learns how to adapt the muscles on the nonaffected side, so that the vocal cords again may be brought into contact, and the hoarseness that was originally present because of the paresis becomes lessened or disappears. This compensation is remarkably good and many patients do not need any further treatment. However, slight hoarseness may become more problematic in the future as voice recognition replaces keyboarding in our interaction with technology.

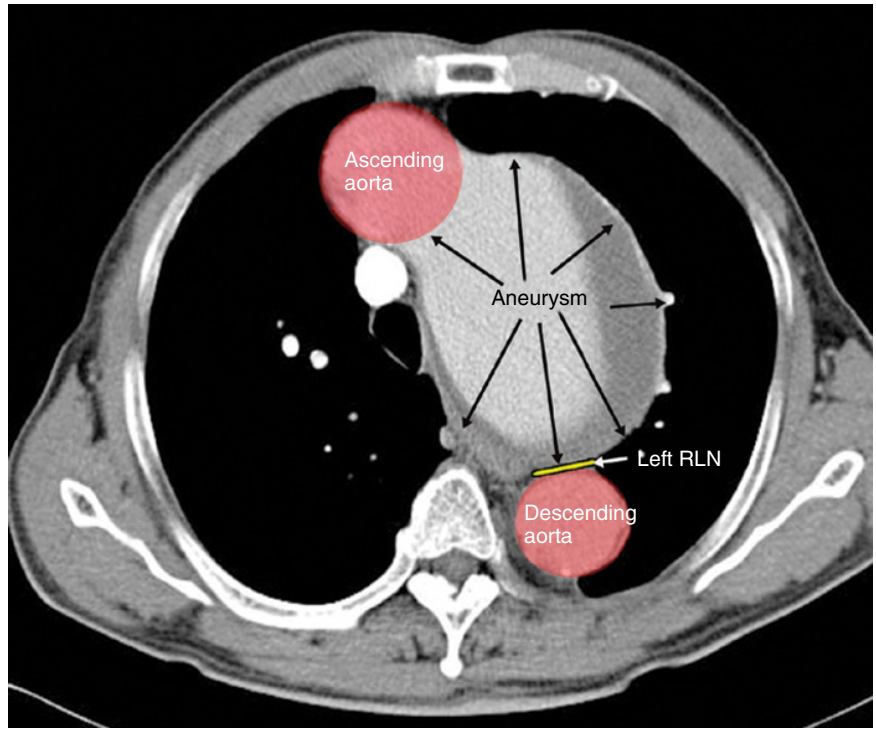

Figure 10.10 Axial (transverse) CT image of the patient described in the case of Ortner's syndrome. Note how the left RLN is compressed by the aneurysm. Courtesy of Dr. Rong-Feng Chen.

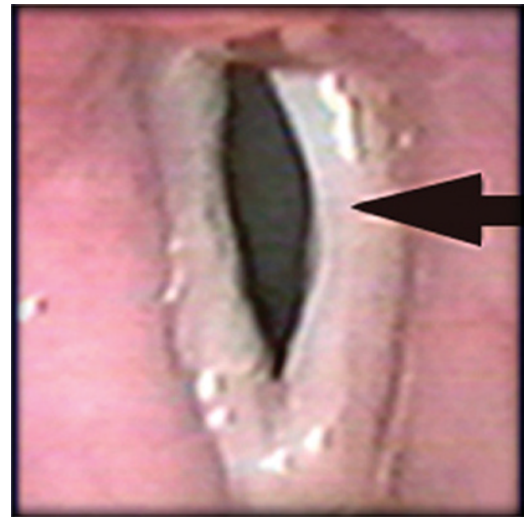

Figure 10.11 Laryngoscopic views of a patient with a paralyzed vocal cord (black arrow). Courtesy of Dr. Jonathan Aviv of ENT and Allergy Associates.

Bilateral complete paralysis of the recurrent nerves is rare, but can occur in systemic diseases and after surgery. The patient has aphonia (loss of the voice) because both vocal cords are in the partially abducted position. However, with time the two cords tend to become apposed (probably as a result of aberrant regrowth of axons in the nerves to the muscles that tend to approximate the vocal cords rather than those that keep the airway open; synkinesis), resulting in a progressive closing of the airway and difficulty breathing. Historically the treatment was tracheotomy (surgically opening the trachea) to improve ventilation, but other surgical procedures are now available.

Injury to gastrointestinal branches

The vagus branches to the gastrointestinal tract stimulate digestion and peristalsis, and may also play a role in satiety and the immune response of the abdomen. In the stomach, acidic digestive enzymes are secreted upon vagal stimulation. During the early and mid 20th century, this fact led to a procedure, vagotomy, by which the vagus nerves were cut in patients who had stomach and intestinal ulcers that were not easily removed surgically. The theory underlying this procedure was that the ulcers were caused by excessive acidity and that reducing the acidity cured the ulcers. This view was considered definitive in terms of the causes of stomach ulcers, as indicated by the following quote from an article by Thornton and colleagues that appeared in the *Journal of the American Medical Association* in 1946:

> The data obtained in this investigation furnish strong support for the view that an excessive continuous secretion of gastric juice occurs in most patients with gastroduodenal ulcer in the absence of any known type of gastric secretory stimulus. The reduction in this secretion produced by complete division of the vagus nerves to the stomach proves that the hypersecretion is neurogenic in character. It probably represents an excessive secretory tonus in the vagus nerves of central origin and points to some functional disturbance in the nervous system as ultimately responsible for the disease. The presence of excessive motility of the stomach in many ulcer patients and its return toward the normal state after section of the vagus nerves indicates that a hypertonus of the motor augmentor fibers in the gastric vagi is often present (Thornton, Storer, and Dragstedt, 1946).

Another article from the period on the procedure indicated that, following this procedure, the patients were "happy and enthusiastic" because of the relief of symptoms.

Below is a case description of the vagus nerve surgery for ulcers that was published in the *Naval Medical Bulletin* in 1949:

> From January 1945 until one month prior to admission, the 45 year old patient had only occasional symptoms of short duration. One month prior to admission he began to have severe pain which was not relieved

by food or antacids. Shortly after admission to this hospital on 21 April 1947, the pain became so severe and was accompanied by such epigastric tenderness and rigidity that he was suspected of having a perforation and was transferred to the surgical service. However, he was treated conservatively and radiologic examination revealed a large ulcer which was estimated to be 1 inch in diameter, high on the lesser curvature of the stomach.

On 13 May 1947 the patient was subjected to operation and a large ulcer 1½ inches in diameter was found on the posterior wall of the stomach near the vertical portion of the lesser curvature of the stomach; it had penetrated into the pancreas. A vagotomy was performed.

The patient received immediate relief from pain and made a rapid recovery. On 21 May 1947, his eighth postoperative day, gastrointestinal X-rays failed to show the large ulcer on the lesser curvature. Gastro-intestinal X-rays on 2 June 1947 again failed to show any evidence of ulcer. The patient was discharged from the hospital on 3 June 1947. At that time he was symptom-free and eating a regular diet. He has been seen twice since, the last time in October 1947, at which time he reported that he was symptom-free, had gained 20 pounds in weight, and was highly satisfied with his operation (Johnson and Kearney, 1949).

Based on this case, the procedure seems quite successful and without complications. However, in the late 1980s, two Australian researchers (Barry Marshall and Robin Warren) proved that ulcers are most often an infectious disease caused by bacteria rather than by excessive acid secretion. Marshall actually self-infected himself in order to demonstrate that the *Helicobactor pylori* bacteria caused ulcers. They won the Nobel Prize for this work.

Lord Robert May of Oxford, President of the Royal Society, said: "The work by Barry Marshall and Robin Warren produced one of the most radical and important changes in the last 50 years in the perception of a medical condition. Their results led to the recognition that gastric disorders are infectious diseases, and overturned the previous view that they were physiological illnesses."

In addition to *H. pylori*, medications such as nonsteroidal anti-inflammatory drugs and stomach tumors that secrete excess acid can cause ulcers, but it is now known that hyperactivity of the vagus nerve is not responsible for ulcers. Today we may question whether all the patients who had vagotomies for ulcers were actually better off after the procedure and, strikingly, we have a rather paradoxical situation with some of today's gastrointestinal ailments. Some patients with delayed or insufficient gastric emptying have a condition called gastroparesis that results from either insufficient activity of the vagus or from a necessary cutting of the vagus during removal of tumors as represented in the Internet case below:

About 3 years ago I had to have a vagotomy due to a bleeding ulcer and had to have over half my stomach removed and over half my intestines removed and reconnected to what was left. After that surgery, that's when ALL my stomach problems began. My Dr. just recently mentioned that my problems were more than likely caused by vagus nerve damage from my surgery. I was just recently diagnosed with gastroparesis. I have literally been sick every single day for a good while now. I throw up every day on a daily basis. I am always having stomach pain.

One contemporary method to treat gastroparesis is electrical stimulation of the stomach, which presumably is augmenting the normal stimulation of the vagus (see the following text). Furthermore, relative to surgically caused gastroparesis, some surgeons are now doing vagal sparing procedures in which the vagus nerve is dissected away from the esophagus before any procedure that would normally involve cutting of the nerves. Such vagal-sparing procedures result in significantly less surgical morbidity and reduced hospital stay compared to older procedures. Furthermore, later complications including weight loss and diarrhea are significantly less likely after a vagal-sparing procedure.

Despite the findings of gastroparesis in some patients in whom the vagus nerve is transected during esophageal or abdominal surgery, some of the positive results from bariatric surgery are now attributed to the cutting of the vagus nerve. Sensory input from the nerve is thought to signal satiety in response to gastrointestinal distension when food is in the gut. High satiety thresholds (causing reduced sensitivity to food in the gastrointestinal tract) may be one cause of obesity, related to impaired vagal afferent impulses.

The vagus nerve and gastroesophageal reflux disease

Gastroesophageal reflux disease (GERD) is common among American adults and is increasing in accordance with obesity and changes in diet and behavior, especially the increase in alcohol consumption and use of cigarettes. One significant complication of GERD is Barrett's esophagus, a disease of the lining of the esophagus that develops in about 10% of people with chronic GERD. Of these, 1% will go on to develop esophageal cancer. The mortality rate for esophageal cancer approaches nearly 85%. Among Asian populations, the incidence of esophageal cancer is 10 to 100 times greater than that in the United States.

What does esophageal cancer have to do with the vagus nerve? Unfortunately, the primary treatment for esophageal cancer today is to remove the offending cancerous organ, and herein is where the vagus nerve becomes involved.

After the vagus nerve gives off its cardiac plexus and the recurrent branches to the neck, the right vagus forms a plexus on the anterior aspect of the esophagus and the left vagus forms a similar plexus posterior to the esophagus (see earlier text). Thus, when surgically removing the esophagus, by definition, the

vagal parasympathetic supply to much of the gastrointestinal tract is typically removed. The result of this removal is that emptying of the pylorus (the lower part of the stomach) can be compromised. In such a situation, diminished gastric output could increase the risk of pulmonary aspiration. Therefore, many surgeons in the United States will perform a pyloroplasty (surgery to widen the lower part of the stomach) at the time of the esophagectomy to eliminate the problem of food not being able to pass into the small intestine.

The vagus nerve and the immune system

The vagus nerve is also now thought to play a role in the immune reaction of the body (Figure 10.12).

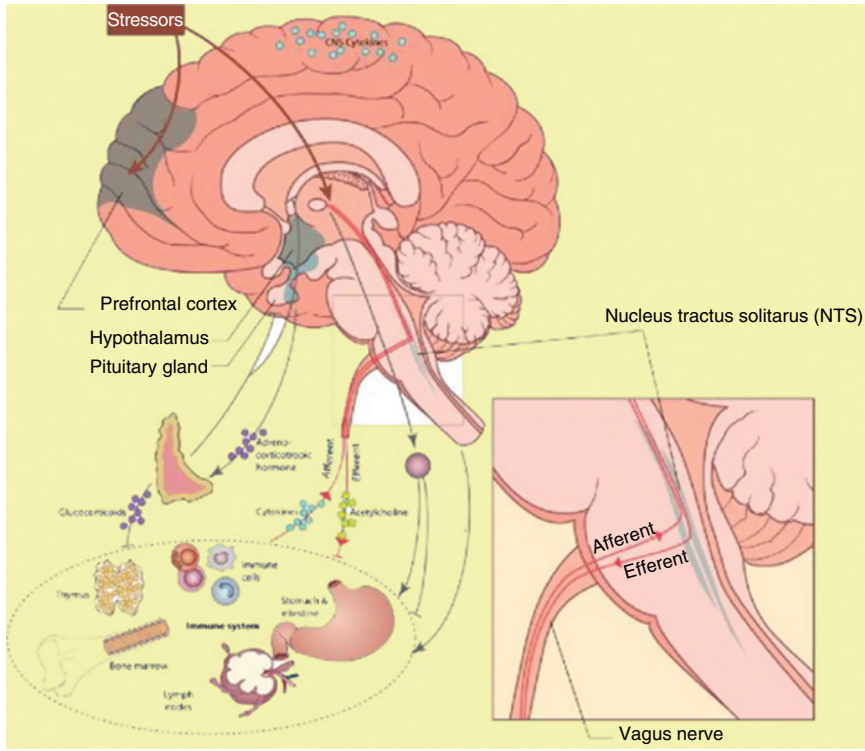

Figure 10.12 Schematic illustration of the hypothesized connections between the brain and the immune system based on the vagal nerve connections (see inset). Reprinted with permission from Thayer, Loerbroks, and Sternberg (2011).

Figure 10.12 shows the hypothesized connections between the brain and the immune system via the vagus nerve. The figure suggests that the nerve both receives information about the body's immune status and responds to this information with efferent impulses to regulate it. This response is known as

the "vagal immune response." This interaction between the vagus nerve and the immune system has great potential for the treatment of diseases associated with inflammation through control of vagal activity.

Vagal nerve branches to the heart and lung

Stimulation of the vagus nerve slows down the heart. Bilateral transection of the nerves results in a faster heartbeat. Data strongly suggest that increased vagal activity could modify mortality associated with heart failure (presumably by "resting" the heart). Accordingly, recently vagal stimulation has been successfully used to treat patients with heart failure in clinical research trials (Figure 10.13).

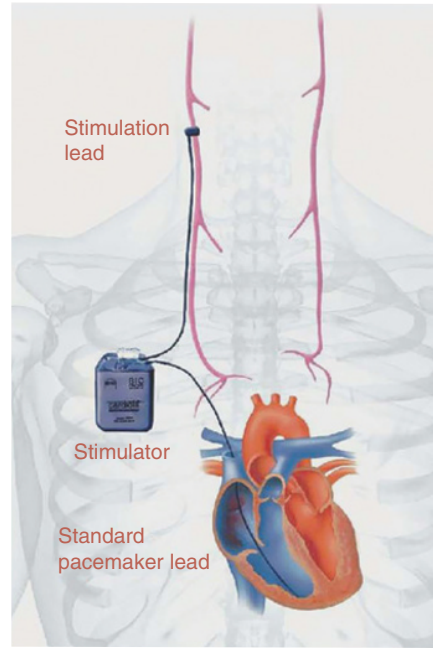

Figure 10.13 Illustration of a how a vagal nerve stimulator is attached to the nerve and the heart to regulate (rest) the heart after heart failure. Copyright and reprinted with permission of Biocontrol-Medical (BCM) Ltd. ("Biocontrol").

With respect to using vagal nerve stimulation in patients with heart failure, the North Mississippi Medical Center (NMMC) put out a press release on February 21, 2013 describing the first use of vagal nerve stimulation for heart failure in the state, which was performed by Drs. Karl Crossen and Louis Rosa. In the previous fall, 61-year-old Jack Aldridge of Mooreville and 59-year-old Annie Richardson of Tupelo became two of NMMC's first patients to benefit from that research and receive the CardioFit® implantable electrical stimulation device.

Aldridge's heart problems began late in 2011. "I was very weak. I couldn't walk anywhere without having to sit down," he said. "I would have to sit up on the edge of the bed to breathe because I couldn't breathe lying down too well. I had a heaviness on my chest."

Richardson suffered her first heart attack in 2006 and a second one in 2012. "The second heart attack was a hard one," she said. "It damaged my heart a lot." Because of the extensive damage, Richardson's heart was pumping at only 10–15% of the heart's normal capacity.

Dr. Crossen explained in the press release that the brain helps to control the function of the heart through two branches. The sympathetic branch activates the "fight-or-flight" response during stress, increasing heart rate and blood pressure. The parasympathetic branch is mediated by the vagus and has a calming effect on the heart through signals carried from the brain to the heart by the vagus nerve. Normally, the two branches are in balance, but in congestive heart failure there is an imbalance.

"In heart failure as the pump function weakens, the body attempts to adapt by using the adrenaline – or sympathetic – nervous system in the same way that when someone exercises the body uses adrenaline to increase heart rate and cardiac contraction," Dr. Crossen said. "We now know that these adaptations over long periods of time are detrimental."

Like driving a car, easing up on the accelerator (sympathetic) will slow down the car a bit, but stepping on the brake (parasympathetic) will reduce the speed more quickly. Some heart failure medications help to 'slow down' the sympathetic branch, but currently there are no proven treatments that help an underactive parasympathetic branch.

Dr. Crossen further said, "There is no medication that predictably increases the effect of the parasympathetic branch to bring better balance to the heart. Stimulating the vagus nerve in the right side of the neck can directly raise the parasympathetic effect on the heart and is the basis for this new treatment."

Immediately after the procedure, Aldridge, who enjoys working on his own vehicles and doing yard work, could tell a difference. "I was fighting for every breath I could get. It has helped me tremendously," he said. "Things I couldn't do before, I'm more able to do now. It has given me more strength and a better outlook on life."

Richardson agreed that the device is making a difference. "I feel pretty good," she said. "I'm glad I have it."

The vagus nerve also innervates the glands and smooth muscles within the bronchi of the lung. Similar to the situation with ulcers, it was believed that cutting the vagal nerve in patients with asthma might alleviate this condition. Below is a case report read at the joint meeting of the American Association of Immunologists and Society for Study of Asthma and Allied Conditions, Washington, May 5, 1925, in which the left vagus was cut as a treatment for asthma:

> The patient who is the subject of this report is a 63 year old asthmatic man. He had been perfectly well until March, 1923, when in the course of an attack of acute bronchitis he suddenly developed a wheezing dyspnea (difficulty breathing) that persisted and after several months forced him to give up his work and go to bed. At first the dyspnea was fairly constant, but in September, 1923, six months after the onset, it began to be worse in

paroxysms. These attacks came several times a day with no obvious relation to any special cause and could be relieved by injections of adrenalin. At this time he was admitted to a hospital where he remained for seven months.

Examination showed a rather emaciated, cyanotic bed-ridden individual with labored wheezing respiration and frequent but unproductive cough. The nose and throat were congested and several decayed snags of teeth were present in the patient's mouth.

The attacks of dyspnea in the course of the next two months became gradually more frequent; adrenalin alone gave less and less relief, and had to be supplemented by pituitrin and frequently by morphine.

But again the relief was only transitory so that early in July, 1924, he was requiring adrenalin injections at intervals of 1 hour or less. It was at this time that in desperation we considered the possibility of surgical relief.

We chose, therefore, left vagus section with its vocal cord paralysis in preference to a possible fatality from right vagus section. The nature of the operation and its possible consequences were explained to the patient and he gladly consented to try anything that might possibly give relief.

Accordingly, on July 19, 1924, the left vagus was cut under local anaesthesia by Dr. I.S. Ravdin of the Surgical Division of the University Hospital. There was no striking immediate effect. In the two weeks that followed, however, the asthmatic paroxysms became somewhat less severe and also less frequent, so that the patient required adrenalin injections at intervals of from 6 to 18 hours only. The pulse rate, to our surprise, was not at all affected at the time of operation, and thereafter gradually fell in the course of 2 weeks to a range between 76 and 100.

There was no further improvement in the patient's condition. While he was no longer bed-fast and gained five pounds in weight, he continued to have dyspnea on slight exertion and from one to three paroxysms of asthma daily. Vaccines, intravenous sodium iodide, local applications through the bronchoscope, failed as before to give relief. A week's stay in a room supplied with dust-free, washed air seemed at first to lessen the severity of the attacks but not permanently. The vocal cord paralysis interfered with coughing to some extent and the patient's voice was little more than a hoarse whisper. On January 8, 1925, he was discharged to his home, but two months later he was readmitted to another hospital because of difficulty with adrenalin hypodermics. His present condition is practically the same as when he left our wards (Kern, 1926).

Based on this report, sectioning of the nerve was somewhat beneficial to the patient. There is some evidence that vagal nerve stimulation may reduce bronchoconstriction, suggesting a possible role for this in the treatment of asthma after further study.

Finally, there is significant data indicating that African Americans have higher vagal mediated heart rate variability than European Americans.

Whereas higher heart rate variability is thought to be protective against heart failure, African Americans have higher cardiovascular morbidity and mortality than European Americans. It has been suggested that this may result, in part, from a difference in the CNS circuitry that regulates the cardiorespiratory system in African Americans, possibly associated with high vagal output.

The vagus nerve and heart transplantation

You probably never thought of this when you read or heard about heart transplantation but clearly, based on the information presented earlier, removal of a diseased heart and replacement by another generally involves transecting the vagal parasympathetic supply to that heart (and the sympathetic supply as well).

The earliest heart transplantations were performed by leaving the upper part of the heart intact and transplanting just the lower part. Because the upper part includes the pacemaker part of the heart and the attachment of the vagus nerve, it was thought that the nerve would still be functional. However, years of observation revealed that the line of attachment between the original and transplanted heart acted as an insulator and thus the recipient heart behaved as if it did not have any vagal influence – so the recipient's pulse rose above 100 when about 80 is normal. Today, this procedure is rarely used and instead the recipient's heart is completely replaced. However, while the pacemaker component of the heart is introduced in the donor heart, it remains detached from the recipient's autonomic nervous system, resulting in a persistently fast heart beat.

Neck and head injuries and diseases

Vagal injuries can occur in the neck or head, as a result of trauma or natural conditions such as infection and tumors (e.g., neuromas). Such injuries affect the action of the nerve in the thorax or abdomen as well as in the head or neck.

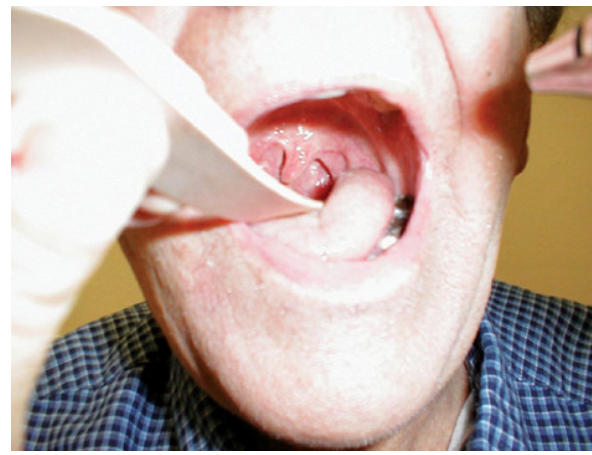

Figure 10.14 Left-sided lesion of the vagus nerve being demonstrated by asking the patient to say "ah." The uvula is deviated to the right because there is no contralateral force being supplied by the damaged left levator veli palatini muscle (normal side pulls the uvula to the right). Courtesy of http://www.wikidoc.org/index.php/File:Left_CN9_Dysfunction.jpg.

A peripheral lesion of the vagus nerve in the neck will be followed by paralysis of the laryngeal muscles on the same side and a varying degree of paresis of the pharynx. If the patient attempts to move the soft palate and the pharynx (e.g., when the patient is asked to say "ah"), the soft palate and pharynx will deviate to the normal side (Figure 10.14). The soft palate will be elevated less on the affected side because of the paresis of the levator veli palatini muscle. This is also observed when a contraction is elicited reflexively by touching the palate or the pharynx (palatal reflex, pharyngeal or gag reflex). Speech and particularly swallowing are difficult, at least acutely. Food and especially drinks tend to enter the nasopharynx in the act of swallowing because the soft palate is unable to seal the connection between the naso- and oropharynges. Sensory deficiency symptoms in lesions of the vagus nerve will manifest themselves as a reduced or abolished sensitivity in the pharynx and larynx, and sometimes in the auricle. Pertaining to the pharynx and the ear, an intact glossopharyngeal nerve may reduce or mask the loss of vagal innervation. Lesions that irritate the superior laryngeal nerve may cause attacks of coughing and other reflex phenomena, elicited from the larynx, such as excessive production of mucus. Rarely, neuralgia of the superior laryngeal nerve occurs, causing paroxysms of pain in the lateral neck under the jaw, radiating to the ear, triggered by swallowing, shouting, or turning the head.

In 1902, Dr. J.B. Page published the case of a boy with what he surmised was a neck abscess, which irritated the vagus causing heart and gastrointestinal symptoms and eventually death:

> The patient, R.J., a boy aged 13, was first seen by me on August 22nd, 1901, in conjunction with Dr. Thorpe. On August 14th he went to a swimming bath, and stayed in the water for several hours. On August 15th, he had a sore throat, felt sick and was feverish. His tonsils were enlarged, but there was no ulceration of the throat and no membrane. On August 16th he was too ill "to come out." His temperature was 101, and the swelling of the tonsils had increased. On the same day a slight swelling was noticed on the left side of the neck, which was attributed to enlargement of the glands secondary to tonsillitis. During the next four days his throat did not trouble him so much, but the swelling on the left side of the neck rapidly increased, and became very painful. Deep fluctuation could be felt, but an incision was not permitted.
>
> On August 21st something seemed to burst in his throat and he brought up a large quantity of blood and matter through his nose and mouth, and at the same time the swelling in his neck decreased very much in size. This seemed to afford him considerable relief, the temperature fell to normal and his pulse, which had hitherto been rapid, dropped in frequency to about 80.
>
> On the morning of August 22nd he suddenly commenced vomiting, and later in the day had a little diarrhea, and became extremely collapsed. Ordinary remedies failed to stop the sickness. He was extremely restless

flinging his arms and legs about continually. His face was livid and his lips had a bluish tinge. His breathing was quite easy. The swelling in his neck had almost disappeared, but the skin was much wrinkled. He was retching every few minutes, and from time to time brought up a little bile-stained water. The heart was beating at the rate of 30 to the minute. Its action was perfectly regular. The beats were forcible, and the two heart sounds distinct and clear. There was not the least sign of any feeble beats between the others, or any murmur audible. The cardiac impulse was in the upper part of the fifth space just inside the nipple line. The cardiac dullness extended out to the level of the nipple. He was prescribed tincture of belladonna every four hours and a hypodermic injection of strychnine sulphate gr. 1/60 was given thrice daily.

I saw him again twice on August 23rd, 1901. He seemed slightly better. The sickness was less violent, and the heart beats were 36 to the minute. He was still very restless in the morning, but towards night he became drowsy and inclined to sleep. In the evening the frequency of his heart beat had risen to 44, and he had only been sick three times during the day.

During the night he again became very restless and was very anxious to get into another room. At about 5:30 a.m. on August 24th, 1901, he was left alone for a few minutes, and got out of bed and out of his room, but fell down in the passage outside in a state of collapse. He was carried back to bed. When Dr. Thorpe arrived he found that his heart was beating feebly (88), he was practically moribund, and died at about 6 a.m. (Page, 1902).

Dr. Page concluded that case by stating that he could not prove that this case was due to irritation of the vagus but that the signs and symptoms were consistent with such irritation.

Below is a World War I case of a combat wound that caused a vagus nerve injury and was published in 1919.

The following case appears to be worthy of record on account of the nature and severity of the injury, and as an example of recovery after complete division of the vagus. Owing to the additional injuries to the great vessels, necessitating ligature of the left common, external and internal carotid arteries as well as of the internal jugular vein, the fact that the man recovered sufficiently to return to his battalion is remarkable without reckoning his recovery from an attack of trench fever, and from a gunshot fracture of the thigh.

Private C. (Australian infantry), aged 20, was wounded in the neck by a fragment of shell on April 28th, 1917, and was admitted to the 3rd Australian Casualty Clearing Station on the same day. He remembered nothing after being wounded with the exception that he had a slight

recollection of being in a motor ambulance until he became conscious after operation.

The wound of entry was on the left side, over the horizontal ramus of the lower jaw, which was splintered. The track then extended inferiorly and posteriorly to a large clot surrounding a wound of the left internal jugular vein, which was almost completely severed immediately below the level of the superior border of the thyroid cartilage. The left common carotid artery, immediately below the bifurcation, was slightly lacerated and contused. The artery was thrombosed (clotted) at this level, and the thrombus extended into the proximal portions of the external and internal carotid arteries. The proximal and distal ends of the divided internal jugular vein were ligatured. I ligatured the left common, external and internal carotid arteries immediately beyond the limits of the injury and thrombus, and the intervening thrombosed portions of these vessels were removed. The left vagus nerve was found completely severed. The track was then followed to the fissured transverse process of a cervical vertebra (sixth), and from this position the shell fragment was removed.

The vagus nerve was sutured with catgut and the wound sutured, free drainage anterior and posterior to the sternomastoid being provided. The patient was in the casualty clearing station for six days; he could only whisper; there was no hemiplegia; the pulse rate was 140.

The remainder of the history I obtained for the most part from the patient. He was admitted to No. 5 General Hospital on May 5th, 1917. The pulse was still 140, and this rate was maintained for about two weeks after the date of being wounded. The sutures were removed on May 12th, 1917. The wound had healed on May 16th, and he arrived in England on May 17th, 1917. There was weakness of the left arm (inability to abduct) for six weeks after being wounded. By the end of June, 1917, he could walk at a slow pace. He noticed that the left armpit and left side of the chest perspired very freely from about May 16 to June 16, 1917; the pulse rate was then about 100. A note made on the medical history sheet previous to August 5th, 1917, states "slight paresis deltoid and biceps." He was admitted to the command depot on that day. Any sudden severe exertion made him feel giddy, and he was unable to do physical drill on account of coughing and severe vomiting. No discomfort was caused by marching at the ordinary rate.

Between August 5th and November 10th, 1917, he was classified four times, and on each occasion the medical officer remarked on his rapid pulse. He rejoined his battalion on November 10, 1917, and was evacuated, suffering from trench fever, on February 2nd, 1918 (Bell, 1919).

The respiratory and gastrointestinal symptoms are commensurate with a vagal injury.

Hiccoughs (hiccups, singultus)

Hiccoughs are thought to be caused by an irritation of the vagus nerve or the phrenic nerve. Many of the conventional cures for hiccoughs involve stimulating the vagus in order to interrupt the abnormal impulses causing the hiccoughs. For example, putting sugar on the most posterior aspect of the tongue is thought to cause strong stimulation of the taste fibers in the vagus nerve. Below is a case of intractable hiccoughs treated with decompression of the vagus nerve:

This 16-year-old girl was knocked to the ground by a blow to the right side of the jaw during an altercation. She did not lose consciousness and sustained no fracture of the mandible but complained of intermittent right-sided retromastoid headaches. Hiccups first occurred 4 days after the injury; initially they subsided during sleep but by the 3rd day they persisted during sleep also.

Examination. The patient did not complain of a sore throat, chest pain, dysphagia, abdominal pain, or vomiting. Neurological examination was normal. Chest X-ray films and computerized tomography (CT) of the brain with and without contrast enhancement were also normal. Trials of chlorpromazine and haloperidol had no therapeutic effect and caused incapacitating sedation. Carbamazepine, 1000 mg daily, was not beneficial. Valproic acid, 1500 mg daily, was effective and the hiccups recurred only when the patient neglected to take her medication; however, after 2 months this treatment also failed. Although intermittent hoarseness was noted by the mother, the patient's neurological examination remained normal. Sequential CT scans showed no abnormality. Fluoroscopy (X-ray) of the diaphragm demonstrated intermittent spasm of the right hemidiaphragm, which coincided with hiccups. Brain-stem evoked potentials were normal.

Operation. The ninth, 10th and 11th cranial nerve complex was approached through a right posterior fossa craniectomy performed with the patient in the sitting position. A branch of the posterior inferior cerebellar artery (PICA) was found anterior to the nerve complex, pressing posteriorly against the rootlets of the vagus nerve at the root entry zone. Another arterial loop lay against the vagus and glossopharyngeal nerves near the jugular foramen. A thin 2 × 2-mm pledget of Teflon felt was placed between the vagus nerve and these two arterial loops.

Postoperative Course. No hiccups occurred after surgery, and the postoperative course was remarkable only for transient hoarseness. The hiccups recurred one year later and responded for a brief time to valproic acid, 1500 mg daily. After 3 months of continuous hiccups, the right ninth, 10th and 11th cranial nerve complex was re-explored. The pledget of Teflon felt had become dislodged and lay free on the floor of the posterior fossa. Precisely when the pledget was displaced is not known. A tuft of Teflon was then wrapped around the loops of the PICA that pressed against the vagus nerve and was secured with a single 8–0 nylon suture. The hiccups once again ceased immediately, and the patient has remained free of hiccups for 3 years (Johnson, 1993).

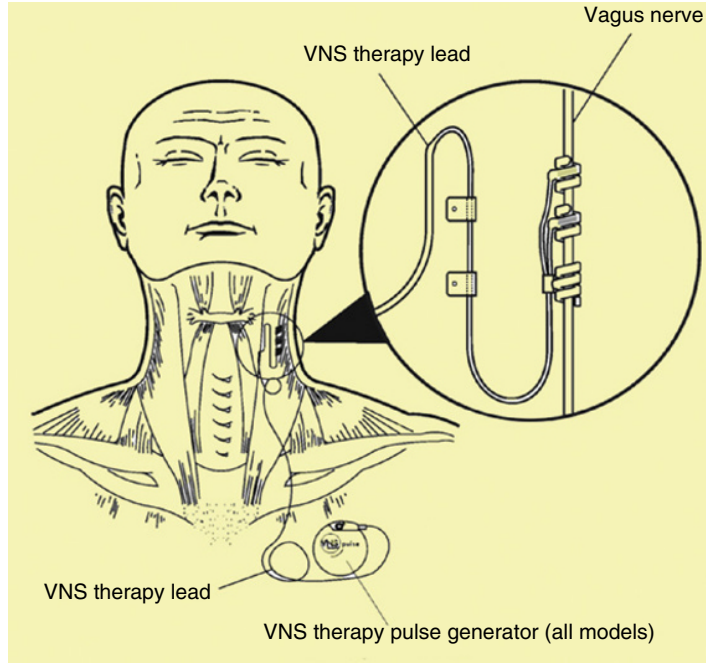

Figure 10.15 Illustration showing placement of a vagal nerve stimulator for epilepsy. Used with permission and copyrighted by Cyberonics, Inc.

Vagal nerve stimulation

As noted earlier, stimulation of the vagus nerve is now being used to treat heart failure and gastroparesis. However, the most widely used purpose of vagal stimulation is for treating intractable epilepsy (Figure 10.15). This treatment was approved by the FDA in 1997 and has been shown to be quite successful, although the mechanism by which this stimulation reduces seizure activity is not known. For this therapy, stimulation is applied to the left vagus nerve in the neck. The impulse generator is placed under the skin and is similar to a cardiac pacemaker in size and shape. With these stimulators, the impulses are not continually delivered but rather have programmable ON–OFF periods.

Adverse effects from vagal stimulation occur only during the "ON" phase and generally consist of the patients feeling some type of altered sensation in the neck and throat. This is not typically painful and the patients rapidly adapt to it. Hoarseness is another common symptom. High-intensity stimulation has resulted in cough, shortness of breath, indigestion, vomiting, and insomnia. Surprisingly, there is no clinically significant alteration of heart rate or respiratory function.

Vagal nerve stimulation is also being used to successfully treat depression. Interestingly, the historical basis for this treatment was an improved mood among patients being treated for epilepsy, which raised

the possibility that the effect on depression is nothing more than an epiphenomenon (a secondary phenomenon related to the decrease in seizure frequency). Further studies, however, have shown improvement in depression in patients without epilepsy although the mechanism underlying this treatment is unknown.

Experimentally, vagal nerve stimulation has also been shown to reduce the size of the brain lesion in animal models of stroke and has been shown to improve memory in rats, prompting hope for beneficial effects in patients with stroke and Alzheimer disease. Based on the theory that the vagus plays a role in the body's immune response, vagal nerve stimulation therapy is being studied in patients with rheumatoid arthritis, an autoimmune inflammatory disorder. If this is beneficial, stimulation may potentially help with other diseases associated with inflammation (Figure 10.16).

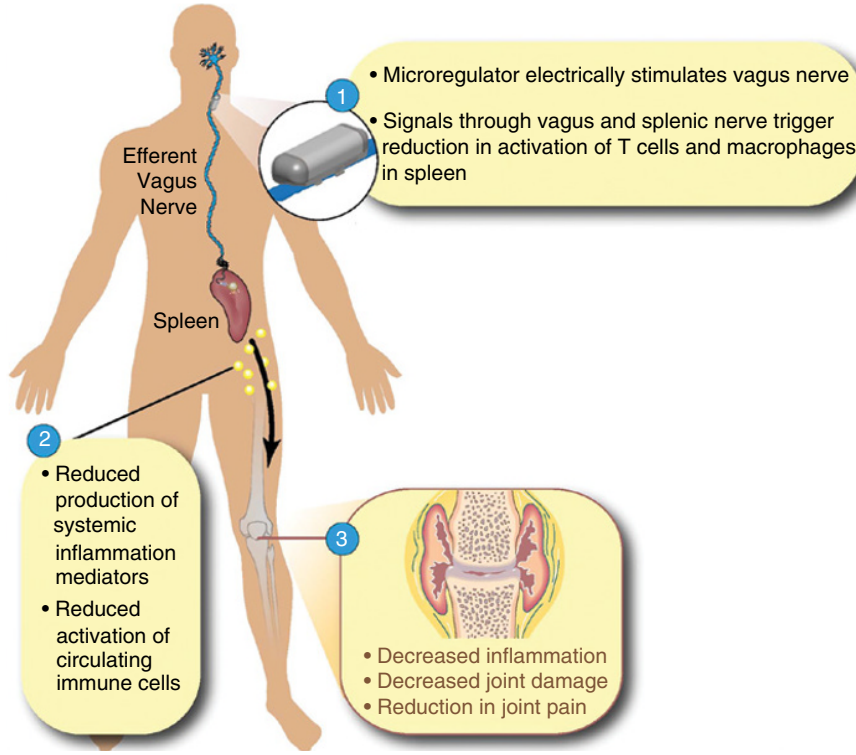

Figure 10.16 Illustration showing how a commercial stimulator may work with the vagus nerve to improve immune health. Courtesy of SetPoint Medical © 2013, Anthony K. Arnold, President and CEO.

Finally, stimulation of the vagus nerve has been used to treat some headaches. Below is a case description of a patient very successfully treated with vagal nerve stimulation for complicated migraine headaches:

This 45-year-old-male presented to the New York Headache Center in March of 1996 with a history of migraine attacks that started at the age of 13. The frequency of attacks was two a week, and each one was preceded by a visual and sometimes sensory and motor auras (perceptual disturbance). The prodrome (early symptom presaging the full onset of symptoms associated with a particular disease) consisted of severe depression and slurred speech for 24 hours prior to the attack and at times some drooling. The pain was always left-sided and lasted for about 24 hours. He had associated photophobia (intolerance to light), phonophobia (intolerance to loud noises) and worsening with light physical activity.

His initial visit was prompted by a change in his headaches. The patient began to have vertical diplopia as part of his aura. Diplopia was present only with both eyes open. On several occasions he had episodes of involuntary twitching of his thumb that lasted several minutes. These were not accompanied by alteration of consciousness. Over the ensuing years, frequency and severity of his attacks increased.

Because of continued deterioration with secondary anxiety and depression, a vagus nerve stimulator was implanted in November of 1999. The patient began to improve within 2–3 months following the implantation. The stimulation first resulted in a reduction in frequency of migraine attacks, elimination of prodromal depression and shortening of his aura symptoms. After several months, attacks of diplopia had decreased in duration to a few seconds instead of minutes, and the frequency of migraine attacks went down to two or three a month. A year after implantation he no longer had near-syncopal attacks, slurred speech or diplopia and the frequency of his attacks declined to 2–3 a month. The remaining attacks respond to 20 mg of sumatriptan nasal spray. Increases in the stimulation settings have been prompted by the return of aura with slurred speech, near-syncopal attacks and diplopia. Eighteen months after implantation, vagal nerve stimulation remains highly effective in controlling symptoms and allowing the patient to remain very functional and employed (Maushop, 2005).

The next cranial nerve, the spinal accessory nerve, the XIth cranial nerve, is strange in that it innervates two muscles, one in the neck and the other in the upper back. It really is a spinal nerve that enters the head and turns around to supply these muscles.

REFERENCES

Bell G (1919) Shell wound of left side of neck: injury of great vessels and division of vagus nerve: recovery and return to firing line. *British Medical Journal* **1**: 604–5.

Chen R-F, Lin C-T, Lu C-H (2009) Ortner's syndrome – a rare case of unilateral vocal cord paralysis: a case report. *Kaohsiung Journal of Medical Sciences* **25**: 203–5.

Hubbard T (1896) Unilateral paralysis of the spinal accessory nerve caused by exposure to cold, associated with motor paralysis of the vagus. *Medical News* **69**: 491.

Johnson DL (1993) Intractable hiccups: treatment by microvascular decompression of the vagus nerve. *Journal of Neurosurgery* **78**: 813–16.

Johnson FH, Kearney EA (1949) Vagus neurectomy in peptic ulcer; analyses of 60 cases. *US Navy Medical Bulletin* **49**: 475–87.

Kern RA (1926) Section of the left vagus for relief of asthma. *Surgery, Gynecology and Obstetrics* **42**: 28–31.

Maushop A (2005) Vagus nerve stimulation relieves chronic refractory migraine and cluster headaches. *Cephalalgia* **25**: 82–6.

Page JB (1902) Case of abscess in the neck, with signs of vagus irritation. *British Medical Journal* **1**: 267.

Thayer JF, Loerbroks A, Sternberg EM (2011) Inflammation and cardiorespiratory control: the role of the vagus nerve. *Respiratory Physiology and Neurobiology* **178**: 387–94.

Thornton Jr. TF, Storer EH, Dragstedt LR (1946) Supradiaphragmatic section of the vagus nerves. *Journal of the American Medical Association* **130**: 764–71.

Van Melle JP, Meyens B, Budts W (2010) Ortner's syndrome, presentation of two cases with cardiovocal hoarseness. *Acta Cardiologica* **65**: 703–5.

11 The Accessory Nerve

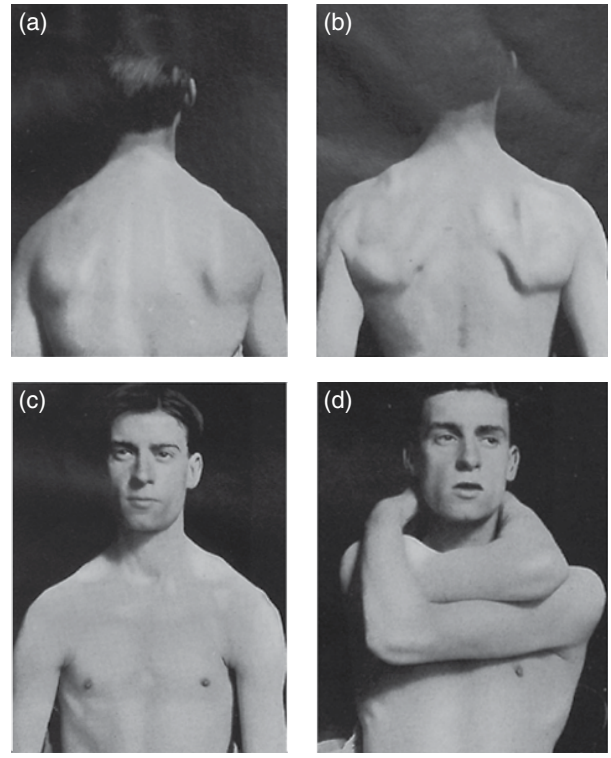

Figure 11.1 Photographs from a patient with bilateral accessory nerve paralysis. (a) Clear droopy position of the shoulders as seen from the back. (b) Shoulders forced backward; note prominent scapulae. (c) Natural position of the shoulders from the front. (d) A "trick" the patient could perform because of the paralysis of the trapezius muscles. The little fingers were locked together and then the arms pulled together so that the elbows completely crossed to the opposite side. The head was then put through the space between the forearms (see text).

ANATOMY/FUNCTION SUMMARY

The spinal accessory nerve is an unusual cranial nerve in that most of it arises from the spinal cord, passes upward through the foramen magnum entering the skull (Figure I.34) and then leaves the skull through the jugular foramen

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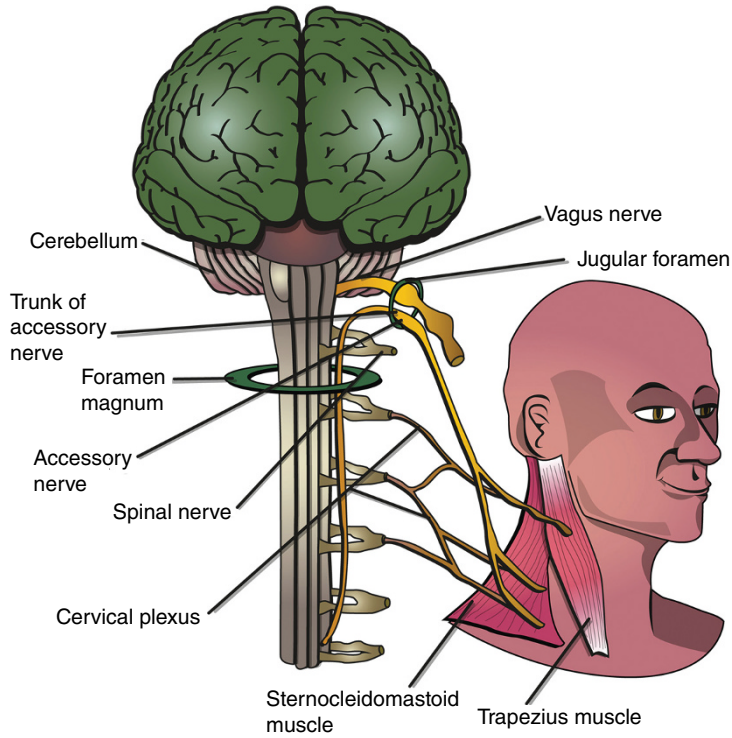

Figure 11.2 Schematic illustration of the path of the accessory nerve.

(in other words, it turns around; Figure 11.2). The nerve only functions to innervate two muscles, neither of which are in the head but both of which move the head, the sternocleidomastoid, and the trapezius.

In 1915, Dr. Ninina Bruce described a case of bilateral spinal accessory paralysis following removal of lymph nodes from the neck.

> A man (R.Y.), aged 21, married, and a rubber worker presented himself at the Medical Out-patient Department of the Royal Infirmary, Edinburgh, on account of two patches of alopecia areata (localized areas of hair loss) on his head, and incidentally asked for advice for a very bad cough which had become much worse during the last three or four months. He was about 5 ft. 7 ½ in. height, and weighed about 8 st. 7 ½ lbs (about 120 lbs). On being questioned he stated that he had been getting much thinner recently, but his cough, although most unpleasant and painful, had never been severe enough to compel him to cease work. On examining his chest the marked drooping of both shoulders was noticed, and he was admitted to the ward.

He stated that when he was about 10 years of age the glands on the left side of his neck began to swell, and were removed by operation the following year. Eighteen months later, the glands on the right side of the neck became swollen, and one suppurated (festered) for several months. Finally, when he was 15 years of age, they were also removed. Both wounds healed perfectly, and no further trouble had since arisen in this region.

He had remained in good health from that time onwards, except for an attack of influenza of a mild type, until the present cough developed some months previously.

His work at the rubber mills consisted chiefly in lifting large bales and extended from 8 a.m. to 6 p.m., with one hour off in the middle of the day for meals. Three months before admission, however, he found he was becoming unable to lift the bales so easily on account of weakness in the shoulders, which he thought was slowly increasing. Besides this he was very musical, and found employment ever since he was a boy by singing in choirs and at private concerts. About a year previous to this admission to hospital he had won a prize in a public vocal competition, but he considered the mental strain involved too much for him because he had never felt really well since then. In spite of this, however, he often appeared on the variety stage and at smoking concerts. At the latter he smoked a great deal, and once or twice took more alcohol than was quite good for him. The combination of work during the day and in the evening over-taxed his strength, and he began to develop pain behind the sternum and on the left side of the chest, accompanied by a dry, unpleasant cough. He noticed at this time that he was losing weight slowly but steadily, and that he caught cold easily. Sudden exertion was apt to cause breathlessness, he lost his sleep, and the cough became worse and was accompanied by a considerable amount of sputum. During the six months before admission, he had lost a little over one stone (14 lbs) in weight. The real reason why he came to the hospital, however, was on account of two patches of alopecia areata which had developed on his head, and while there he had mentioned his feeling of general weakness and cough, and was sent to the medical wards, when the above condition was discovered. His family history showed nothing of importance. His mother and father were still alive and healthy. He had married at the age of 18, and had always lived in comfortable surroundings. He was only a moderate smoker, and although he did not drink regularly, was liable to take too much at a time.

There was marked hollowing of the patient's supraclavicular fossae. Both sterno-mastoids stand out prominently and contract well, but they appear to be somewhat atrophied.

The trapezius on each side is greatly atrophied, and is represented above the scapula by only thin sheets of muscle. There are no fibrillary

tremors. The shoulders droop greatly (see Figure 11.1a–c), being drawn forwards and downwards; the scapulae are displaced outwards and downwards, and the clavicles form a perfectly straight horizontal line instead of running upwards and backwards. Further there is marked hollowing above the clavicles, and on the back the vertebral border of the scapula is prominent and the inferior angle is displaced inwards. The patient is unable to shrug his shoulders without pain, and cannot hold them up for any length of time. The arms can be abducted to a right angle, but there is slight pain and tiredness, and they cannot be held in this position long. The arms can be lifted above the head, but only for a short time. The power of the shoulder movements is fair, and that of the elbow movements unimpaired.

He is also able to perform a curious "trick." The little fingers are linked together, the arms are then abducted so that the elbows cross to the opposite sides, and the head is then pushed through the intervals between the posterior surfaces of the forearms as shown in the accompanying figure (Figure 11.1d).

The absence of involvement of other muscles than the sternomastoid and the trapezius excluded the possibility of a fascioscapulo-humeral (Landouzy–Dejerine) type of muscular dystrophy, and left no doubt of the correctness of the diagnosis of double spinal accessory paralysis, a somewhat rare condition. It is undoubtedly associated with the operations for the removal of the tuberculous glands from the neck. At the time of the operations the nerves do not appear to have been injured, but later they have in some way become involved in the scar tissue, with the above ultimate result (Bruce 1915).

This case is particularly interesting because of the delay in the effect on the accessory nerve. Either growth or the development of scar tissue affected the nerve; the nerve seemed not to have been injured at the time of the surgery. However, it is also possible that the muscles were affected immediately after the surgery but for some reason the patient did not notice the paralysis. The fact that the paralysis of the muscles was incidental to his visit to the hospital suggests this possibility.

ANATOMY/FUNCTION

The XIth cranial nerve, the (spinal) accessory nerve, in our view, serves only to innervate two muscles, the sternocleidomastoid and the trapezius (Figure 11.3).

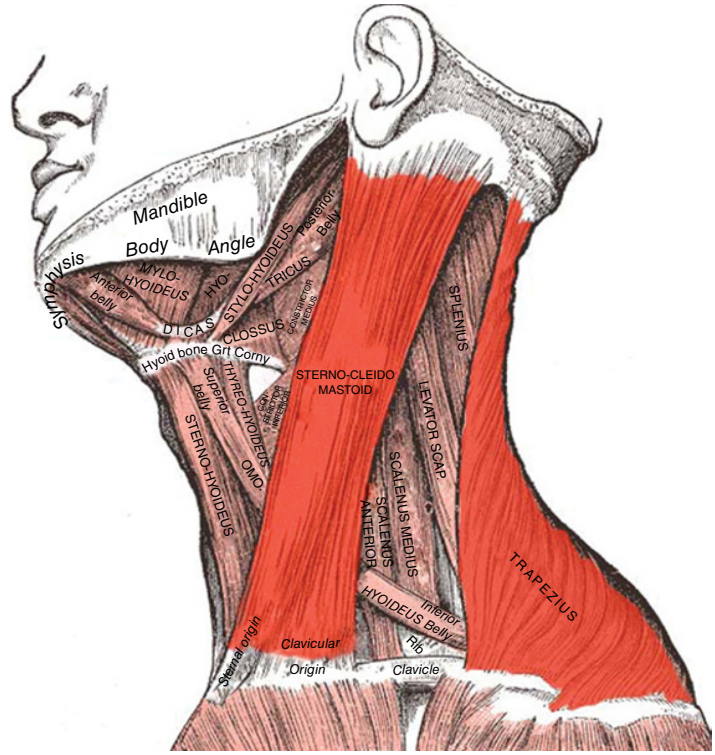

Figure 11.3 Modification of an image originally published in the classic *Gray's Anatomy* from 1858. The sternocleidomastoid and trapezius muscles are highlighted.

Contrary to our view, most other textbooks describe the nerve as consisting of a cranial root and a spinal root. The spinal root is what we are considering to be the true accessory nerve (Figures 11.4 and 11.5). The cranial root, the portion of the nerve in question here, has been considered to consist of (special) somatic efferent fibers that leave the medulla below the lowermost fibers of the vagus nerve and join the fibers of the spinal root (Figures 11.4 and 11.5). However, these cranial root fibers are classically reported to leave the spinal nerve trunk (as a so-called internal ramus) almost immediately to join the vagus nerve proper above the nodose ganglion. It is these fibers that are believed to innervate the muscles of the larynx and pharynx including those involved in speech production (see Chapter 10).

In 2002, an article by Lachman and colleagues reported that there is really no cranial root of the accessory nerve. They reported that the fibers that emerge from the medulla do not actually join the accessory nerve but join the vagus directly and have no association with XI (Figures 11.4 and 11.5). The authors of the article trace the history of this discrepancy primarily to an 1838 error by Arnold that was repeated in Gray's original

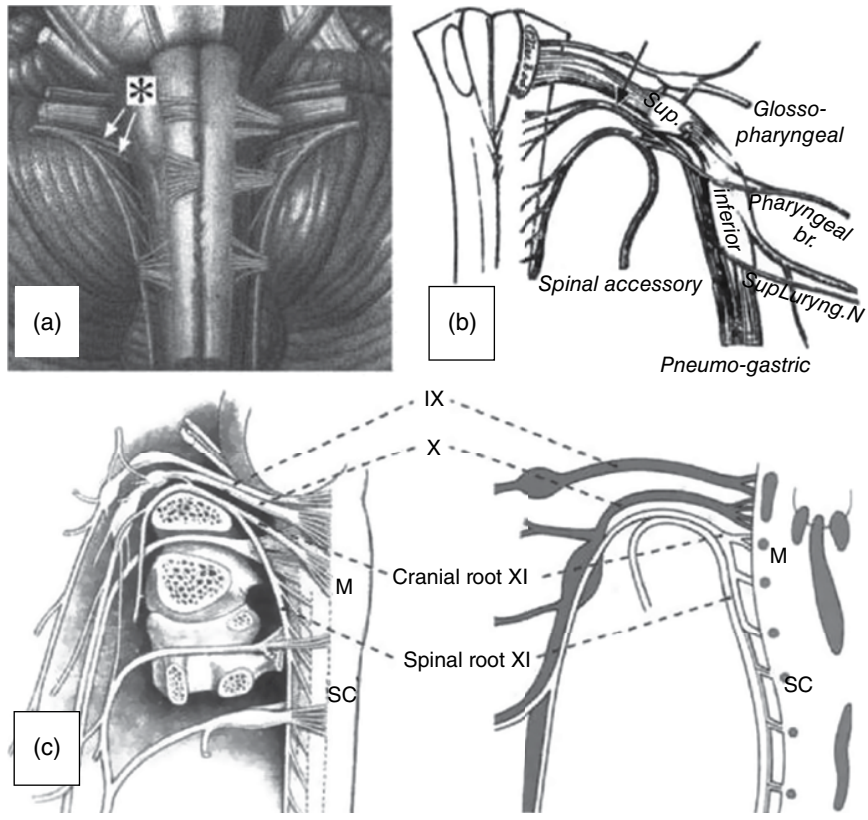

Figure 11.4 (a) Image from Arnold (1838); asterisk and arrows (added): rootlets of accessory nerve depicted as arising from the medulla. (b) Figure from *Gray's Anatomy* (1858). Asterisk and arrow (added): unlabeled nerve trunk described in the text as the "cranial part" of accessory nerve. (c) The prevailing view of cranial nerve XI. In our view and that of Lachman and colleagues from which this entire image was reprinted (Figure 5 with slight modification; Lachman, Acland, and Rosse, 2002), this prevailing view is not correct and the cranial root of the accessory nerve should be considered part of cranial nerve X. M, medulla; SC, spinal cord.

Anatomy textbook from 1858 and continued to be repeated since then without evaluation (Figure 11.4).

Although in accordance with Lachman *et al.*, we will consider only the "spinal root" of the accessory nerve here, Lachman *et al*. did note a problem with this change. In order for a nerve to be a "cranial nerve," it has to originate from the brain and exit through a foramen in the skull. The "spinal root" of the accessory nerve only meets one of these criteria. Rather, it is a "spinal nerve with a cranial exit." However, for historical reasons, we will continue to consider it a cranial nerve.

The XIth nerve is formed by bundles of somatic efferent fibers that emerge from the lateral column of the spinal cord in the upper cervical segments and together make up the nerve (Figures 11.2, 11.4, 11.5, and 11.6). The fibers ascend within the vertebral canal, fuse with each other, and enter the cranial

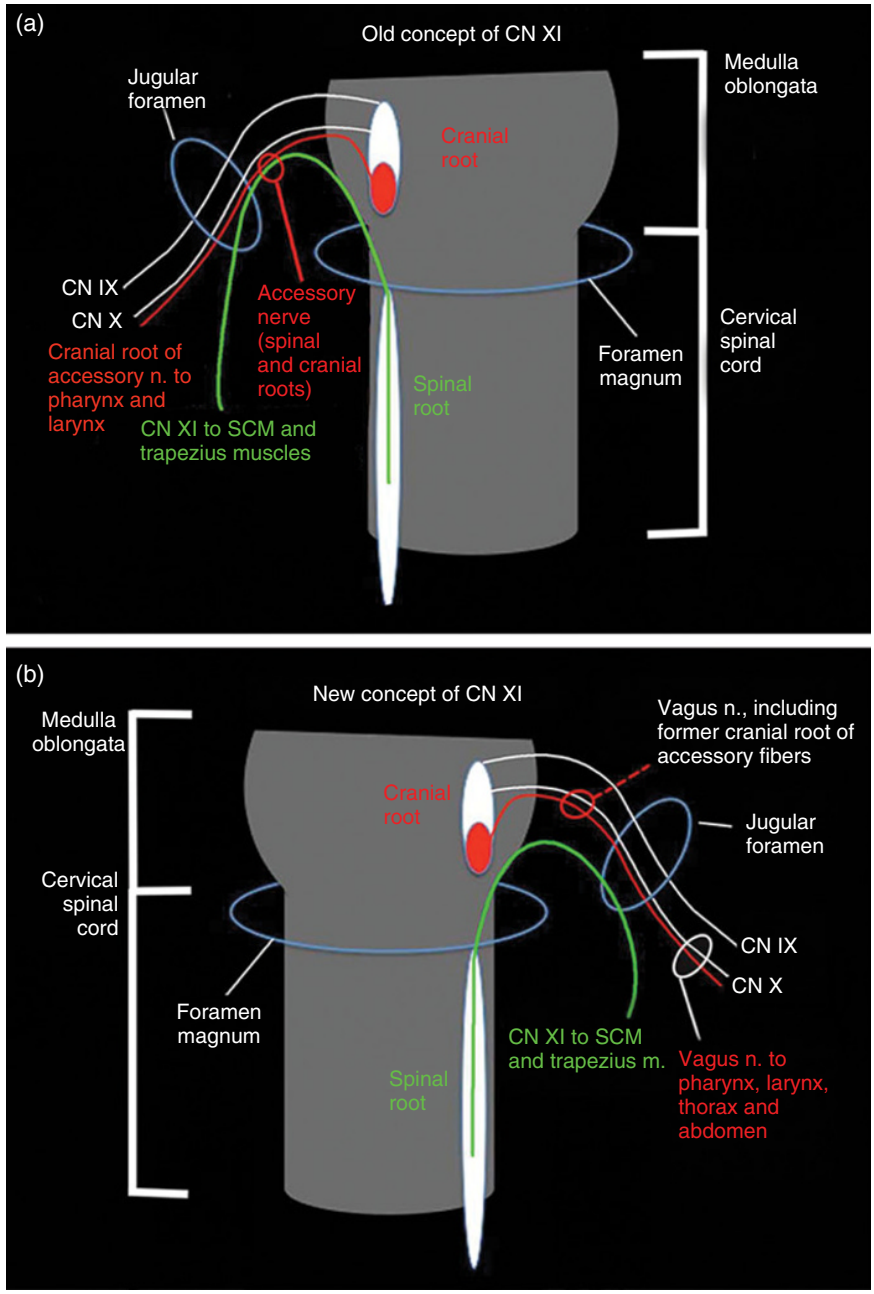

Figure 11.5 (a) Classic view of the accessory nerve, with a spinal and a cranial root (see also Figure 11.4). (b) Our view, as well as that of other modern anatomists, in which the accessory nerve consists exclusively of the "spinal root." The previously named "cranial root" is considered part of the vagus (see text).

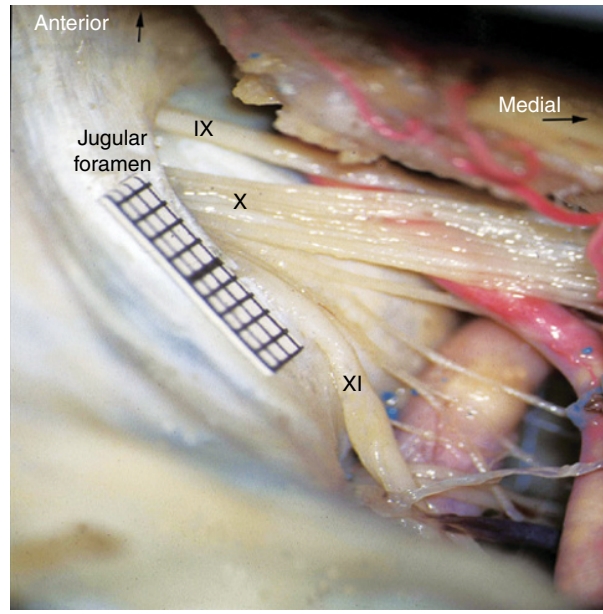

Figure 11.6 High magnification view of CNs IX, X, and XI exiting the brainstem and entering the jugular foramen. The grid shows 1-mm squares. Courtesy of Dr. P. Mercier. (If orientation is not clear please compare with Figure 10.3.)

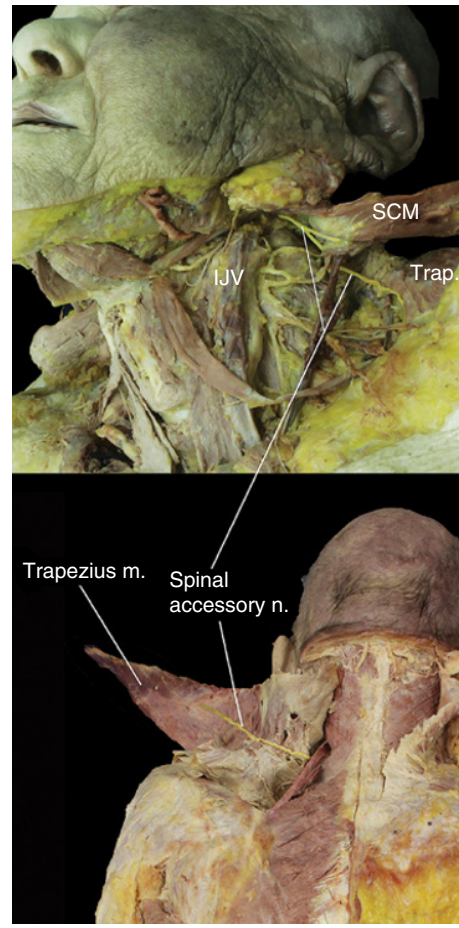

Figure 11.7 Top: cadaver photograph showing nerve XI in the posterior triangle of the neck entering the reflected sternocleidomastoid and the trapezius muscles from the side. IJV, internal jugular vein. Bottom: the spinal accessory nerve is shown coursing along the large reflected trapezius muscle.

cavity through the foramen magnum. They then make an almost 180° turn and exit the skull through the jugular foramen.

From the jugular foramen, the accessory nerve descends in close relation to the internal jugular vein (IJV) (usually posterior, more rarely anterior, to it). It then enters the sternocleidomastoid muscle on its medial aspect (Figure 11.7). During its further posteroinferior course, the nerve, as a rule, is embedded in this muscle and gives off motor branches to it. Approximately at the middle of the posterior aspect of the sternocleidomastoid muscle, the accessory nerve leaves the muscle and continues inferiorly and somewhat posteriorly (surrounded by cervical lymph nodes) and finally reaches the trapezius muscle, to which it gives off its terminal branches.

In the neck, the accessory nerve anastomoses with nerve filaments from cervical nerves derived directly from the spinal cord, chiefly from the 3rd and 4th cervical segments. There is some indication that these fibers may supply a limited amount of motor innervation to the trapezius, as well as proprioceptive fibers to this muscle and also to the sternocleidomastoid.

The reason that the accessory nerve takes such a strange course to innervate the sternocleidomastoid and trapezius muscles is based on the embryology of the growth and formation of the two muscles. These muscles are unique in their development, having elements from both the head and the trunk regions. Furthermore, these muscles are critical to moving the head in response to hearing or seeing a new object (e.g., a predator), and thus there is some admittedly anecdotal reason why these muscles are innervated by a "cranial nerve." However, we do also admit that what the accessory nerve does is a bit "out of character" for a cranial nerve and contributes to our overall wonder and amazement at these nerves.

CLINICAL ASPECTS

Each sternocleidomastoid functions to turn and raise the head so that the face turns to the opposite side. The right sternocleidomastoid is evaluated by placing your right palm on the patient's left cheek and asking the patient to turn the head to the left while resisting the pressure you exert in the opposite direction. The reverse procedure is used to test the left sternocleidomastoid.

Paresis or paralysis of the trapezius muscle is more incapacitating than paresis of the sternocleidomastoid. Because this muscle enables the scapula to elevate and rotate upward, it is very important in the elevation of the upper limb beyond 90°. Thus, when the trapezius is weak, elevation of the arm beyond 90° is carried out with reduced force. The scapula in a patient with a weakened trapezius will tend to be somewhat lowered, and its medial border will be a little further lateral than normal ("winging"; see Figure 11.1). The shoulder droops, which can result in pain, commonly described as a persistent dull ache. Pain is most likely related to tension on the shoulder joint or on the nerves that supply the upper limb.

The intracranial portion of XI may be affected by intrinsic spinal cord lesions that are very high, such as posterior fossa meningiomas or intracranial metastases. Tumors in the foramen magnum or the nearby bony parts of the skull

(Figure I.34) can compress the brainstem and CN XI, usually with concomitant CN X involvement.

Spasmodic torticollis, also known as cervical dystonia, is a localized type of movement disorder characterized by abnormal head posture and movements (spasms), most often from excessive activity of one of the sternocleidomastoid and/or trapezius muscles. This is likely to be related to excessive activity of the accessory nerve. Often, there may be associated shoulder elevation.

A 72-year-old man was admitted to our department with a two-year history of spasmodic tilting of the neck to the right side associated with elevation of the right shoulder, which was caused by arrhythmic, paroxysmal contractions of the right trapezius and sternocleidomastoid muscles. The patient's spasms occurred frequently (approximately every 20 s). The symptoms were exacerbated with the head at rest, and they disappeared during sleep. Magnetic resonance imaging clearly confirmed that an abnormal loop of the right anterior inferior cerebellar artery was pressing on the nerve. Using a microsurgical technique, the artery was displaced and the XIth cranial nerve was decompressed. After surgery, the patient demonstrated gradual improvement of symptoms and two years after his surgery all of his symptoms had been relieved (Alafaci *et al*., 2000).

In 2000, a case study was published associating this condition with vascular compression of the nerve.

The authors of this report noted that this was the first case of spasmodic torticollis associated with this particular artery, although it has been associated with presumed compression by other cranial arteries.

As it crosses the neck, the accessory nerve's superficial location makes it very susceptible to inadvertent injury. In the early 1900s, removal of lymph nodes in the neck in patients with tuberculosis was a common surgical procedure with as many as 10% of surgeries resulting in spinal accessory nerve injury (see the case at the beginning of the chapter). Any surgical procedure in the posterior part of the neck can injure the nerve, including biopsy of the lymph nodes in the neck, excision of benign masses, and radical neck dissection (usually performed for cancerous tumors).

Traumatic injury can also cause spinal accessory nerve dysfunction. Penetrating trauma and direct trauma to the neck during contact sports, such as a blow from a hockey or lacrosse stick, may injure the nerve.

Below is a recent case of iatrogenic (inadvertent surgical) injury to the accessory nerve.

A 15-year-old right-handed student got an abscess in the right neck region associated with mononucleosis. It was partly below the sternocleidomastoid muscle, and it was drained of about 200 ml of pus. Postoperative healing was uneventful and he recovered. However, about a month later

he noticed weakness in the right shoulder region with reduced ability to stabilize the shoulder. Muscle evaluation showed an accessory nerve injury distal to the branch of the sternocleidomastoid muscle with total degeneration of the axons to the trapezius muscle. He had atrophy of the trapezius muscle with pain and reduced ability to abduct the right arm, but no winging of the scapula. Two years after the initial injury the area was explored surgically and just distal to the sternocleidomastoid muscle there was a neuroma of the accessory nerve, which was removed. The nerve was sutured end-to-end and the postoperative period was uneventful. The patient continued school, and planned to find another job (he was a bricklayer) with less loading on his right shoulder. Clinical examination one year and nine months after the nerve had been sutured showed limited contracting ability in the trapezius muscle with weak innervation, but abduction of the arm was better when the scapula was stabilized (Blackwell, Landman, and Calcaterra, 1994).

Clearly, the patient's accessory nerve was cut during the abscess draining procedure. Although his movements appeared better after repair, they were not normal. It would seem that the long time span between the injury and the repair may have limited the nerve's regeneration.

Another case of the nerve being injured during a normal surgical procedure is presented below:

A 64-year-old woman underwent her second rhytidectomy (face lift) in January 1991. Approximately 5 years earlier she had her first face lift operation without experiencing complications. Three weeks after the second procedure, she developed pain in the left shoulder and noticed drooping of the left shoulder girdle. She became unable to bear any weight on the left arm and had difficulty raising this arm over her head. She underwent neurologic evaluation and was diagnosed to have a mononeuropathy of the left spinal accessory nerve. Initial management with phenytoin and amitriptyline was ineffective. She began a course of physical therapy that included exercises to increase the strength of the shoulder muscles and transcutaneous electrical stimulation of the trapezius. After failing to make improvement, she was offered the option of surgical exploration. She underwent exploration of the posterior left neck 5 months after her rhytidectomy. The spinal accessory nerve was identified at the posterior border of the sternocleidomastoid muscle and followed to the anterior margin of the trapezius. Three centimeters posterior to the sternocleidomastoid, an incomplete, 75%, transection was seen in the nerve. On microscopic examination, a small neuroma on the proximal nerve stump was noted. The entire distal nerve segment was hyperemic relative to the proximal portion. Electrical stimulation

of both the proximal and distal nerve segments produced movement of the shoulder. Under microscopic control, the partial nerve transection was completed, the proximal neuroma was excised, and an end-to-end perineural connection was achieved. Postoperatively, she continued with her course of physical therapy. The shoulder paresis was largely resolved, although the shoulder pain persists but is diminished (Bostrom and Dahlin, 2007).

In this case, the reattachment of the nerve appears to have been largely successful.

We move on to the last well-recognized cranial nerve, the hypoglossal, which innervates the muscles that move the tongue.

REFERENCES

Alafaci C, Salpietro FM, Montemagno G, Grasso G, Tomasello F (2000) Spasmodic torticollis due to neurovascular compression of the spinal accessory nerve by the anteroinferior cerebellar artery: case report. *Neurosurgery* **47**: 768–72.

Blackwell KE, Landman MD, Calcaterra TC (1994) Spinal accessory nerve palsy: an unusual complication of rhytidectomy. *Head and Neck* **16**: 181–5.

Bostrom D, Dahlin LB (2007) Iatrogenic injury to the accessory nerve. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery* **41**: 82–7.

Bruce AN (1915) Paralysis of the spinal accessory nerve following many years after the removal of tuberculous glands from the neck. *Review of Neurology and Psychiatry, Edinburgh* **xiii**: 51–5.

Lachman N, Acland RD, Rosse C (2002) Anatomical evidence for the absence of a morphologically distinct cranial root of the accessory nerve in man. *Clinical Anatomy* **15**: 4–10.

12 The Hypoglossal Nerve

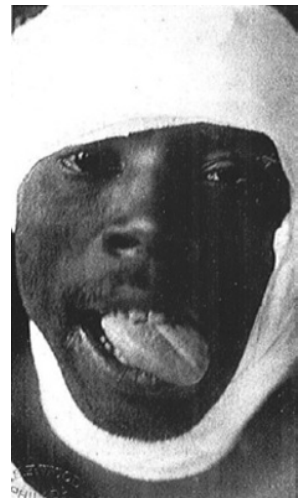

Figure 12.1 Patient with gunshot wound to left hypoglossal nerve. The patient exhibits typical lesion (see text for explanation). Reprinted from Roberts (1908).

ANATOMY/FUNCTION SUMMARY

The hypoglossal nerve, the XIIth cranial nerve, is the motor nerve to the muscles of the tongue. You probably didn't realize that your tongue is primarily a muscle and the control you have of it is exquisite. The hypoglossal nerve is composed of nerve fibers that enable you to perform these movements without thought. The variability among individuals in their ability to conduct some tongue movements (e.g., whether one is able to curl one's tongue) probably reflects variation in the connections of this nerve.

Projectiles (bullets) in the lower face can damage the XIIth nerve. Dr. John Roberts described such a case in 1908 and presented the photograph of the patient shown as Figure 12.1.

> A man was admitted to the Polyclinic Hospital on the 28th of March, 1907, with a gunshot wound of the left cheek over the ramus of the lower jaw. The tongue, when protruded, pointed very much to the left showing that

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the hypoglossal nerve was paralyzed. The left side of the man's face was covered with sweat, and the left pupil slightly dilated suggesting irritation of the sympathetic nerve.

When the man was admitted there was a good deal of difficulty in swallowing from want of control of the saliva; but after the bullet was removed he had gained fair control of these functions. The patient later died of pneumonia and the left hypoglossal nerve was found to be completely severed.

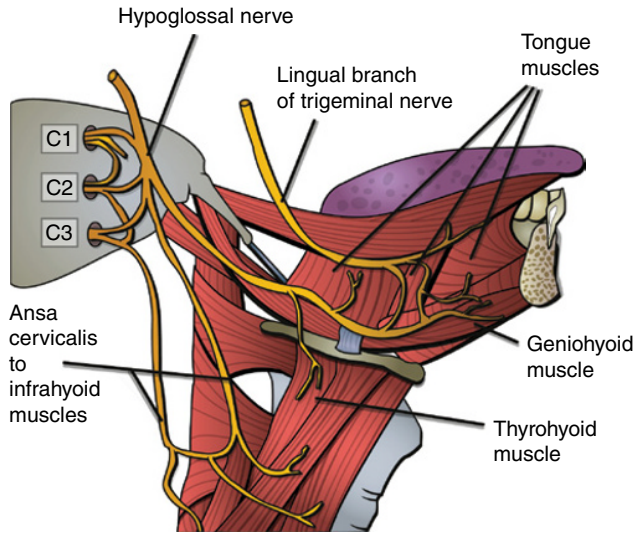

Figure 12.2 The pathway of the hypoglossal nerve is illustrated in the image. The name hypoglossal is derived from the fact that the nerve enters the tongue (glossus) from below, as clearly shown in the image.

ANATOMY/FUNCTION

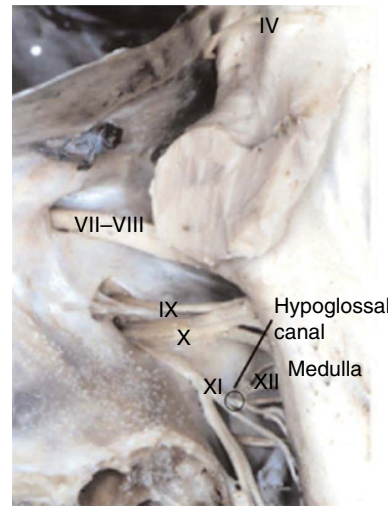

Figure 12.3 Photograph showing rootlets of the hypoglossal nerve arising from the medulla and entering the hypoglossal canal. Courtesy of Dr. Ugur Ture.

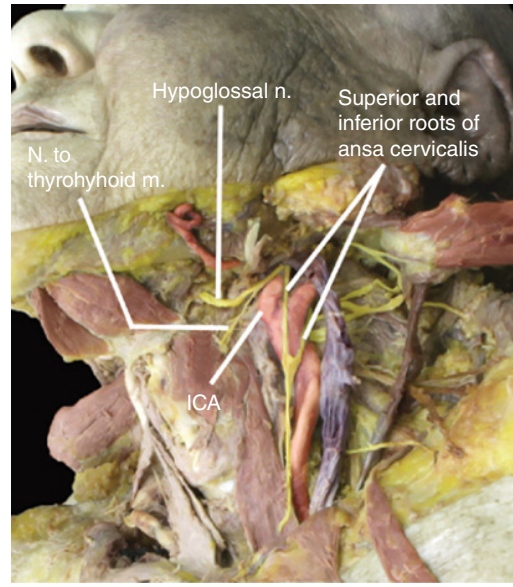

Figure 12.4 Cadaver photograph showing the path of the hypoglossal nerve in the neck. ICA, internal carotid artery.

The axons of the hypoglossal nucleus run in a ventral and slightly lateral direction and emerge as 10–15 fiber bundles on the ventral surface of the lower medulla (Figures 12.2 and 12.3). The rootlets fuse and leave the skull through the hypoglossal canal in the occipital bone (Figures I.34 and 12.3). The nerve then bends behind the vagus nerve and the internal carotid artery, courses caudally, lateral to these structures, and then continues in an inferior convex arch to the root of the tongue (Figure 12.2 and 12.4). A little above the greater horn of the hyoid bone, it disappears between the mylohyoid and hyoglossus muscles and branches to the intrinsic and all but one of the extrinsic muscles of the tongue. The extrinsic tongue muscles innervated by CN XII are the hyoglossus, genioglossus, and styloglossus (Figure 12.5). The tongue muscle not innervated by the hypoglossal nerve, the palatoglossus, is innervated by CN X.

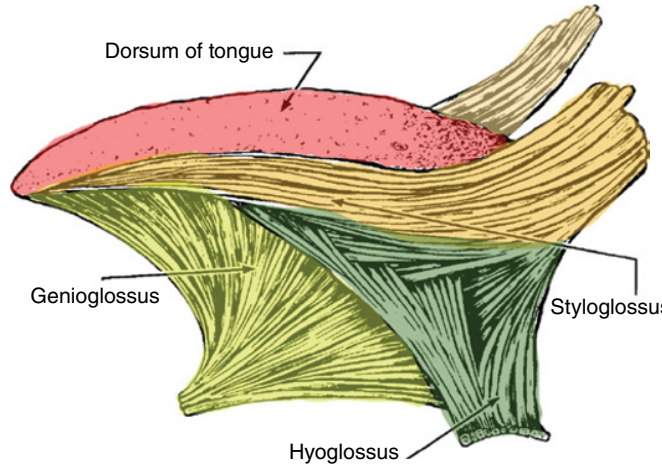

Figure 12.5 Extrinsic muscles of the tongue. The tongue also has intrinsic muscles that do not attach outside of the tongue.

During its peripheral course in the neck, the nerve passes below the posterior belly of the digastric muscle and lateral to the internal and external carotid arteries and the branches of the latter. In the tongue, the hypoglossal fibers anastomose (join) with branches from the lingual nerve (Figure 12.2).

The fibers of the hypoglossal nerve are joined by some sympathetic (postganglionic) fibers from the superior cervical ganglion of the sympathetic trunk and by fiber bundles from the 1st and 2nd cervical nerves (Figure 12.2). The latter fibers "piggy-back" on to the nerve, but do not form part of the nerve proper. This is often a confusing point for beginning students to appreciate. These cervical fibers follow CN XII until approximately where they cross the internal carotid artery. Here they leave it again and descend as the superior root of the ansa cervicalis (Figure 12.4), which courses in a caudal direction on the internal carotid artery and the upper part of the common carotid artery. Ansa means loop in Latin, whereas cervicalis is the adverb of the term describing its physical location in the neck. As Figure 12.4 illustrates, the ansa cervicalis is a prominent structure of the neck, although during cadaveric dissections it can be easily missed because it becomes embedded and often intertwined within the connective tissue fascial planes of the neck. Superficial to the carotid sheath, the superior root unites with the inferior root, which is formed by fibers from the 2nd and 3rd cervical nerves. In this way, a loop of fibers, the ansa cervicalis (Figure 12.4), is formed. It gives off branches to three of the infrahyoid muscles (the sternohyoid, omohyoid, and sternothyroid muscles; Figure 12.6), while the fourth of these, the thyrohyoid muscle, is supplied by cervical fibers that follow the hypoglossal nerve proper beyond the departure of the superior root of the ansa (Figure 12.4).

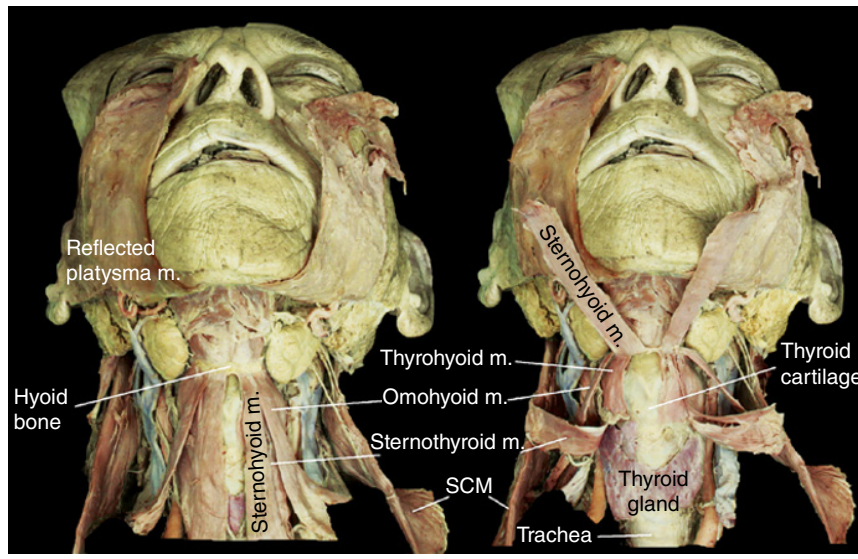

Figure 12.6 Cadaver photograph showing the infrahyoid or "strap" muscles (sternohyoid, sternothyroid, and omohyoid) that are innervated by the ansa cervicalis. The sternocleidomastoid muscle (SCM) is not a strap muscle. It is innervated by the spinal accessory nerve, CN XI (see Chapter 11).

Before moving on to discuss the clinical aspects of the hypoglossal nerve, we want to call your attention to Figure 12.7, which presents an overall plate showing the innervation of the tongue, both motor and sensory. It would seem that if an engineer would design the body today, he or she would place a single nerve to the tongue that would provide both motor and sensory innervation (taste and general sensation). However, the tongue has a complex embryologic origin and therefore actually has five cranial nerves involved in its innervation: V, VII, IX, X, and XII. We wish it were not so complex, but it is, and all clinicians who are concerned with disorders of the head and neck need to know this pattern of innervation.

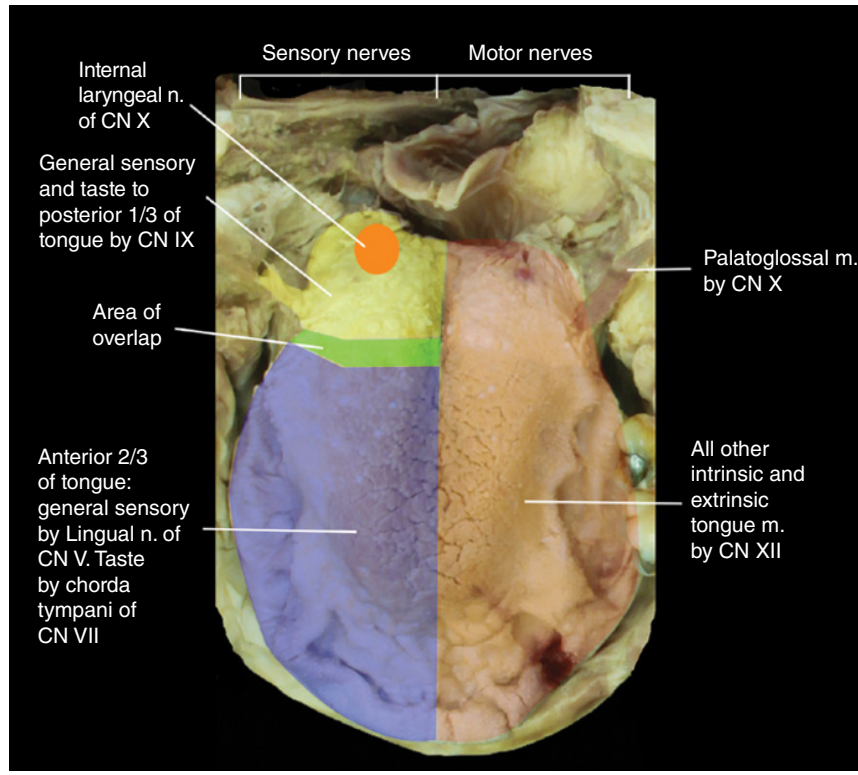

Figure 12.7 Illustration showing all of the nerves that take part in providing innervation to the tongue.

CLINICAL ASPECTS

A complex network of extrinsic and intrinsic muscles enables the tongue to execute a large repertoire of movements and functions (Figure 12.5). The intrinsic muscles of the tongue are interlaced into a complex mass. This intrinsic muscle complex and the extrinsic muscles, genioglossus, hypoglossus, and styloglossus (Figures 12.2 and 12.5), allow the tongue to assume many different positions and shapes, which facilitate swallowing, speaking, and breathing.

If a patient with a unilateral hypoglossal nerve lesion attempts to protrude the tongue, it will deviate to the affected side; the intact genioglossus muscle pushes its half of the tongue forward and toward the inactive affected side (Figure 12.1).

Examination of the hypoglossal nerve involves observing the tongue at rest and with movement. With the tongue at rest within the mouth, it can be assessed for atrophy (loss of muscle bulk). This can cause a scalloped appearance sometimes associated with involuntary muscle twitches in the tongue (fasciculations or myokymia). To assess the strength of the tongue, the patient is asked to protrude the tongue and move it in all directions.

Patients with unilateral lesions of the hypoglossal nerve can typically compensate for the deficiency. However, in cases of bilateral hypoglossal nerve lesions, the patient may not be able to protrude the tongue at all and may have profound difficulty with speech and swallowing, because tongue movement is necessary for these functions.

The hypoglossal nerve can be damaged by tumors, infection, or trauma. Direct trauma can occur from injury (such as the gunshot wound described at the beginning of this chapter) or surgical trauma.

Hypoglossal nerve lesions are a known complication of carotid endarterectomy (removal of plaque from the carotid arteries in the neck). When there is aberrant reinnervation of the nerve, the tongue's coordination may be impaired due to synkinesis, resulting in speech difficulties.

Because the infrahyoid muscles are not supplied by fibers of the hypoglossal nerve, they will escape paralysis in lesions that affect the hypoglossal nucleus or are limited to the brainstem. (This is further evidence that the roots of the ansa cervicalis do not form part of the hypoglossal nerve proper.) Asking the patient to press the lower jaw downward against resistance, tests these muscles. The omohyoid muscle in particular can then easily be felt when it contracts, and as a rule can also be seen.

Although uncommon, radiation therapy to the neck can cause bilateral hypoglossal nerve dysfunction, as described in a patient seen by one of the authors:

A 63 year old man had been treated with radiation therapy for right tonsillar carcinoma 11 years before he noticed a change in his speech. His speech had become slurred, worsening as the day went on, particularly after he coached his softball team. Over the course of a year, his speech continued to deteriorate and he had difficulty moving food in his mouth while eating. On examination, he had a lingual dysarthria (more difficulty producing L and T sounds than K or P sounds). He had diffuse atrophy of the tongue, which had a furrowed appearance and showed involuntary muscle twitches on the right more than the left (fasciculations or myokymia). When first seen, he had weakness of the tongue on the right more than the left, with difficulty pushing his tongue into his cheek. After one year, he had bilateral tongue weakness with difficulty protruding his tongue beyond his lips. He was

unable to move the tongue from side to side or lick his lips. A swallowing study showed severe impairment with oropharyngeal dysphagia (difficulty moving a food bolus in the mouth and directing it down his throat).

This patient had hypoglossal nerve damage from radiation therapy that was initially worse on the side receiving radiation, but eventually involved both sides equally.

Neck–tongue syndrome

Neck–tongue syndrome (NTS) is pain in one side of the upper neck and/or back of the head, with numbness in the tongue on the same side. Typically, the symptoms are associated with a quick, sudden rotation of the neck. The symptoms typically last less than a minute at a time.

The mechanism accounting for the syndrome is unknown although two theories have been proposed. One suggests that a temporary incongruity between the first and second cervical vertebrae causes sudden pain in the neck and a stretching of the second cervical nerve, which is known to contain afferent as well as efferent fibers. A second theory suggests that spasms in a small muscle in the back of the head (inferior oblique capitus) put pressure on the same nerve. Because of the connections between the hypoglossal nerve and the upper cervical nerves (ansa cervicalis), pain may be felt in the tongue.

Below is a case of NTS:

A 24-year-old woman entered the clinic complaining of short episodes of upper neck pain. The recurrent episodes of right-sided neck pain began insidiously when she was 8 years old. She explained that the neck pain was "sharp" or "piercing" and rated the intensity as a 7 on a 10-point scale (10 most intense pain). She stated that the pain occurred when she briskly turned her head to the right. As an avid dancer/figure skater, the pain limited her ability to perform; although she was still physically able to dance, the intensity and unpredictability of the symptoms affected her concentration and expressiveness. The frequency of the complaint varied with her activity level. She had virtually no neck or tongue symptoms until she committed the aggravating head movement. The intensity of the neck and tongue symptoms was consistent from one episode to the next. There was no past medical history of trauma or inflammatory arthritis that could predispose her to upper cervical instability. She reported that slow deliberate movement did not aggravate the condition and demonstrated that a quick glance over her right shoulder (i.e., shoulder-checking while driving) elicited the neck pain. She said that her neck pain was usually accompanied by a sensation of "7-Up bubbling" on the right half of her tongue that lasted roughly 30 seconds despite moving her head back to neutral. A neurological examination was within normal limits.

The patient was treated by a chiropractor. Other reported treatment options (cervical collar, exercises, medication) were not employed. The patient has sought treatment at various intervals since the onset of the symptoms and reported a significant reduction in the frequency and intensity of the symptoms, particularly the paresthesia felt in the tongue. Although she still experiences NTS, she describes its occurrence as "rare" (Borody, 2004).

Hypoglossal nerve stimulation

A fully functional tongue is instrumental in maintaining an open airway. When a patient lays flat on their back the tongue may fall backward and its mass can cover the opening of the airway. The simple act of tilting the head of a comatose patient backward may suffice to open the airway sufficiently to allow inspired air to enter the upper respiratory tract. Similarly, in obstructive sleep apnea (OSA), there is a decrease in muscle tone in the tongue during sleep, including the main tongue muscle, the genioglossus, allowing the tongue to fall back and impede airflow into the upper respiratory tract (Figure 12.8). If a patient cannot tolerate the usual treatments for OSA, such as continuous positive airway pressure (CPAP), oral devices, or surgery, another treatment option is an implantable hypoglossal nerve stimulator. The tongue muscles (especially the genioglossus) receive mild stimulation that has been demonstrated, in small studies, to reduce the severity of obstructive sleep apnea.

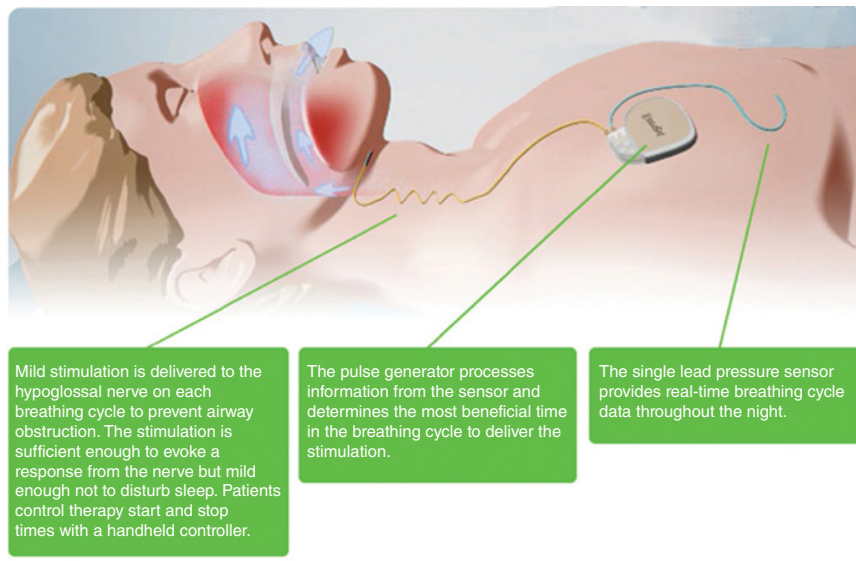

Figure 12.8 Promotional illustration showing hypoglossal nerve stimulation for sleep apnea. In this condition, the tongue may fall backward and block the upper airway. The mild stimulation provided by the stimulator maintains the tone of the major tongue muscles preventing this backward displacement. Courtesy and with permission of Inspire Medical Systems.

We have completed our journey through the 12 major cranial nerves. The next chapter briefly describes an enigmatic 13th nerve, the terminal nerve.

REFERENCES

Borody C (2004) Neck-tongue syndrome. *Journal of Manipulative and Physiological Therapeutics* **27**: 367.

Roberts JB (1908) Gunshot injury of the left hypoglossal nerve. *Annals of Surgery, Philadelphia* **xlviii**: 155–60.

13 Nervus Terminalis (Cranial Nerve *N*)

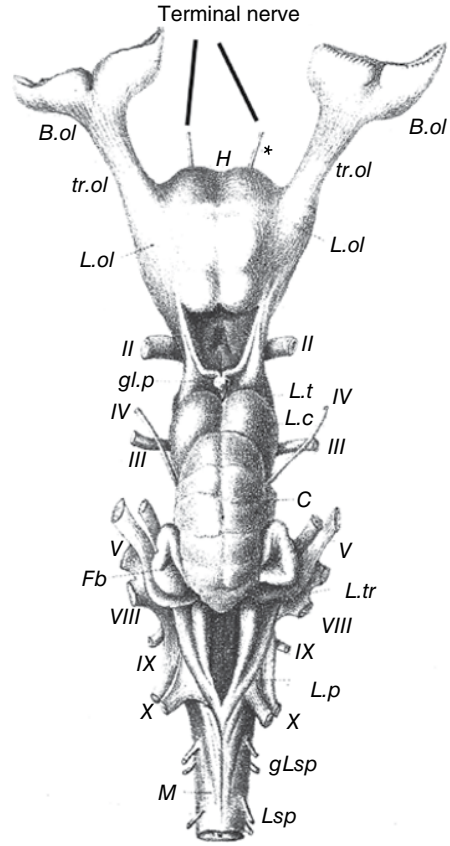

Figure 13.1 Illustration from Fritsch (1878) showing his drawing of the dogfish shark brain. The terminal nerve is labeled although Fritsch did not name it as such.

ANATOMY/FUNCTION

The thirteenth cranial nerve (also known as the nervus terminalis (NT), nerve 0, and nerve *N*) was initially identified in the dogfish shark by Gustav Theodore Fritsch. In 1878, Fritsch depicted on a drawing of the brain of a dogfish shark an "überzähliger nerv" (Figure 13.1), which is probably best

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translated as "supernumerary nerve." Fritsch did not devote any additional text to the nerve and justifiably the nerve was not named for him.

Locy in 1905 called it the "nervus terminalis" (NT) because, in the species he examined, the fibers were seen entering the brain in a region known as the lamina terminalis. The existence of this nerve in humans and other mammals was originally documented by Johnston in 1914 and later by others (Figure 13.2). Although this nerve is very small, Johnston noted that in some cases it could be seen without the aid of a microscope.

Much later, in 1987, Demski and Schwanzel-Fukuda stated that "it [NT] was designated cranial nerve zero because it was rostral to the other 12 nerves, which had been identified previously." Although there was no symbol in the Roman numbering system for a "placeholder" similar to the Arabic zero, in the 8th century monks who used Roman numerals began using the symbol *N* (as an abbreviation of the Latin word *nulla* (none)) to symbolize zero. Thus, one of the authors of this book (JAV) proposed in a 2012 article that when listed as a number, the terminal nerve be listed as cranial nerve *N*.

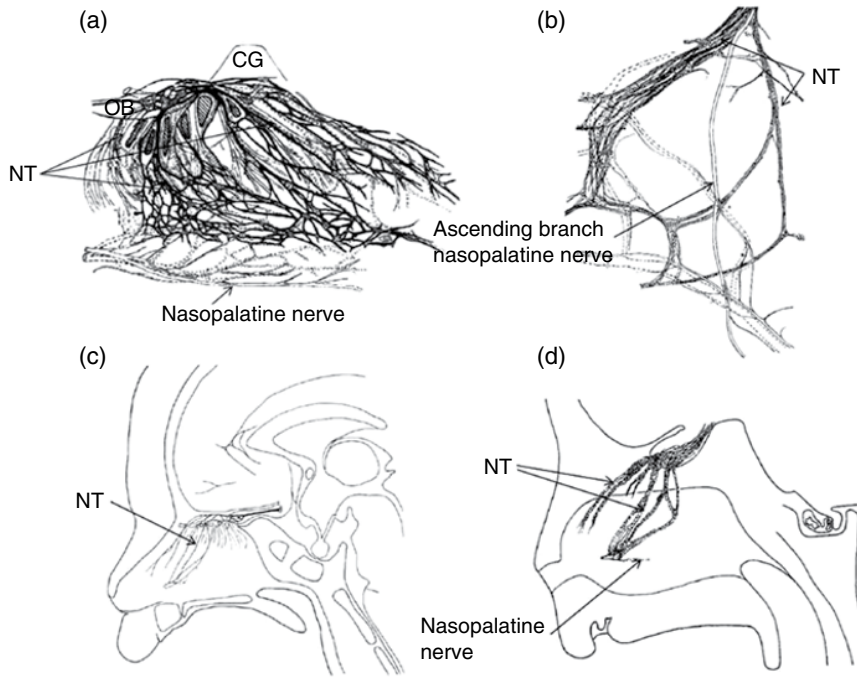

Figure 13.2 (a) Semidiagrammatic illustration of the nasal septal view of the NT in a human infant. Dashed lines represent vessels (also in (b)). Modified from Figure 1 in Brookover (1917). (b) Enlargement of the posterior ventral portion of (a) to show a possible sympathetic nerve connection between the NT and the ascending septal branch of the nasopalatine nerve. Modified from Figure 2 in Brookover (1917). (c) Illustration showing a nasal septum view of the NT in a six-month-old human fetus. Modified from Figure 1 in McCotter (1915). (d) Nasal septal view showing the NT in a 45 mm human fetus. Modified from Pearson (1941). All images used with permission. CG, crista galli.

In 1980, Schwanzel-Fukuda and Silverman demonstrated a relationship between the neurons and ganglia of the NT of guinea pigs and a hormone that helps regulate ovulation. A few years later (1983), Demski and Northcutt in *Science* suggested, based on data from goldfish, that the NT is the primary chemosensory pathway mediating response to sexual pheromones, rather than the olfactory system, as previously thought. They also suggested that this may apply to humans.

Following up on this hypothesis, Fields in a 2007 *Scientific American Mind* article suggested that the terminal nerve functions in humans, as in goldfish, to detect pheromones and therefore is important for mate selection. There are many associations between reproductive behavior and smell in humans, such as a woman's sense of smell being most acute when she is ovulating, women rating smell as the most attractive feature of a man, and women living together tending to have synchronized menstrual cycles. It would thus seem reasonable that the NT is releasing hormones near the olfactory epithelium (see Chapter 1) that presumably enhance olfaction of selected odors that affect reproductive behavior. Accordingly, traumatic loss of the olfactory nerves is anecdotally associated with a reduction in libido. Furthermore, because the NT appears to connect to blood vessels and glands, it is likely carrying autonomic fibers that also act to enhance olfactory input.

The functionality of the NT in humans is likely, although more research is needed to demonstrate this definitively. Therefore, at the moment, we tentatively welcome nerve *N* to the family of human cranial nerves.

REFERENCES

Brookover C (1917) The peripheral distribution of the nervus terminalis in an infant. *Journal of Comparative Neurology* **28**: 349–60.

Demski LS, Northcutt RG (1983) The terminal nerve: a new chemosensory system in vertebrates? *Science* **220**: 345–347.

Demski LS, Schwanzel-Fukuda M (1987) The terminal nerve (nervus terminalis). Structure, function and evolution. *Annals of the New York Academy of Science* Introduction: x–xi.

Fields RD (2007) Sex and the secret nerve. *Scientific American Mind* **18**: 20–2.

Fritsch G (1878) *Untersuchungen über den fieneren Bau des Fischgehirns mit besonderer Berücksichtigung der Homologien bei anderen Wirbelthierklassen*, Verlag der Gutmann'schen Buchhandlung, Berlin.

Johnston JB (1914) The nervus terminalis in man and mammals. *Anatomical Record* **8**: 185–98.

Locy WA (1905) On a newly recognized nerve connected with the forebrain of selachians. *Anatomischer Anzeiger* **26**: 33–63.

McCotter RE (1915) A note on the course and distribution of the nervus terminalis in man. *Anatomical Record* **9**: 243–6.

Pearson AA (1941) The development of the nervus terminalis in man. *Journal of Comparative Neurology* **75**: 39–66.

Schwanzel-Fukuda M, Silverman AJ (1980) The nervus terminalis of the guinea pig: a new luteinizing hormone-releasing hormone (LHRH) neuronal system. *Journal of Comparative Neurology* **191**: 213–25.

14 Concluding Remarks: The Past and Future and Magic of the Cranial Nerves

Two of the authors of this book (JAV and CASQ) teach medical gross anatomy at two major medical schools (Indiana University and Georgetown University, respectively). Often, when we meet new people, especially physicians, and tell them what we do, the new acquaintances will say, "you have an easy job because anatomy does not change."

We both do admit that knowledge about anatomy probably does not change as much as new knowledge accumulates in some of the other basic sciences, for example, cell and molecular biology, but both of us teach a very different anatomy course than we taught 30 years ago, and we anticipate that the anatomy taught 30 years from now will be very different than what we are currently teaching.

Both dissection and modern medical imaging reveal new anatomical knowledge each year, and even modern developmental genetics can provide a new perspective on anatomy. These new insights need to be incorporated in modern gross anatomy courses. As an example of how anatomical knowledge changes, look at how the numbering of the cranial nerves has changed through time. When Galen (AD 129–210) first identified the cranial nerves, he identified seven pairs of nerves. More than a millennium later, in 1664, Sir Thomas Willis suggested that cranial nerves consist of 10 pairs. Finally, in 1778, Soemmering regrouped the cranial nerves into 12 nerves, essentially the system we use today.

However, the 12 pairs of cranial nerves commonly described in most anatomy texts are not accepted universally. As noted in Chapter 7, there have been numerous suggestions throughout recent history to separate the intermediate nerve from the facial nerve. Furthermore, the cranial root of the accessory nerve has been considered part of the accessory or part of the vagus nerves in different classification schemes (see Chapter 11).

Most recently, based partly on molecular developmental neuroanatomy in combination with gross anatomy, a 2010 article by Benninger and McNeil advocated a radical renumbering of the cranial nerves (Benninger and McNeil, 2010). In this proposed scheme, there are still 12 cranial nerves, but they are very different from the current system. The optic and olfactory nerves are no longer considered cranial nerves because they do not originate from the brainstem (as we said in the pertinent chapters, these nerves are really brain tracts).

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The intermediate nerve does become its own nerve. The vestibulocochlear nerve is split into two nerves, a most reasonable proposal that affirms the dual functionality that the current CN VIII is assigned as well as its segregated fiber distribution. Finally, the vagus is also split into two nerves, one that supplies the head and neck and one that supplies the thorax and abdomen (again, a very reasonable approach based on topographical distribution). In contrast, the accessory nerve is eliminated because, similar to CN I and II, its nucleus is not in the brainstem.

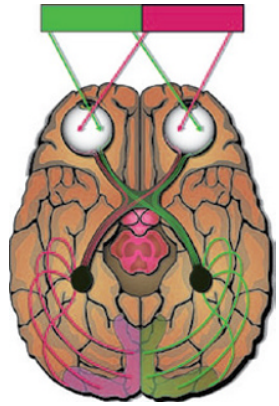
Will this radical renumbering take hold? And will medical students then require a new mnemonic to remember the numbering of the nerves? The Benninger/McNeil scheme is certainly a reasonable one. However, any change in medical nomenclature is very slow to take hold. In addition, altering the current numbering scheme will present clinicians with a logistical nightmare that does not merit this change. For example, there are so many case reports pertaining to specific cranial nerve lesions and so much interesting information available on the cranial nerves as they are currently numbered that changing the numbering might result in loss of some of this material. However, as we have stressed throughout this book, we view the cranial nerves as if they were part of a magician's repertoire, being able to fool us into believing we are witnessing the impossible. Thus, what they will reveal and how they will be viewed (and numbered) in the future awaits the magicians to come.

We trust that you now agree that the cranial nerves are magical. The cranial nerves allow us to experience the incredible senses that make life worth living, the smells of a home cooked meal at holiday time, seeing that special someone smile at us in the morning, tasting a vintage Bordeaux, hearing Beethoven (or the Stones), and even feeling the caress on our cheeks during special moments. One cranial nerve, the Xth, also wanders as far inferiorly as our intestinal tract and helps to regulate digestion, and on its way modulates heart function and respiration, the movement of our vocal cords, and aids swallowing. No wonder the action and anatomy of these nerves have fascinated clinicians for centuries.

In this concluding chapter, we asked clinicians who treat patients suffering from cranial nerve disorders to write brief essays about the human nature associated with a particular cranial nerve. In most instances, this was by describing one of their most interesting cases. Some of these stories are sad and poignant, but real. They highlight how relevant these nerves are to our everyday lives. All of the cranial nerves are important, although clinicians will argue among themselves that losing one nerve may have a greater impact on the quality of life than another. Ophthalmologists, for example, will emphatically consider that losing CN II, sight, may impact life more than any of the other nerves. However, if someone makes their living as a chef, then a lesion of the olfactory nerve or CN VII (taste to anterior two-thirds of the tongue) will likely be felt more intensely than any of the others. Beethoven would argue that his going deaf, CN VIII, kept him from hearing his greatest work, symphony number IX, the Eroica. It is said that he would have gladly given up sight in order to hear his greatest composition. Thus, the perception of

which cranial nerve reigns supreme will vary depending on the individual's profession and aspirations. As a group, however, they are truly magical. The essays are presented in ascending order of the nerves.

CRANIAL NERVE II: TAKE CARE OF YOUR SIGHT



The second cranial nerve or optic nerve is considered one of the most important. It carries from the retina all sensation of vision. Vision is considered one of the most valued senses, without which one would not be able to perform most independent functions of everyday life. If one closes one's eyes, imagine how difficult it would be to leave home, walk down the street, find a grocery store, pick out one's favorite cereal, pay for it, count the change, walk home, and find the bowl, sugar, and milk before savoring the first bite. Reading, television, phone texting, and driving would not be possible. One would have to rely on other senses, which do not give nearly as much information.

Afflictions that cause changes in vision transmission by cranial nerve II may be classified as:

1. Those that affect the optic nerve directly.
2. Those that are the result of external pressure on the optic nerve.
3. Those that are the result of diseases of the eye.
4. Those that are the result of systemic disease.

A clinical vignette will serve to illustrate:

When first seen in Washington, DC, the seven-year-old-male patient presented to me with the symptom of difficulty seeing the classroom blackboard. This symptom occurred mainly about one hour after eating lunch. This timing is important. Mid-morning ocular examination revealed a normal exam and visual acuity. But an examination one hour after lunch revealed a decrease in

visual acuity to 20/80 and evidence of myopia (near-sightedness). Suspecting diabetes mellitus, I immediately sent the patient to his pediatrician who confirmed the diagnosis of insulin-dependent diabetes mellitus.

I followed the patient over the next ten years, per the guidelines set forth by the American Academy of Ophthalmology for patients who have insulin-dependent diabetes mellitus. At his last visit, prior to entering college, the patient did not have signs of diabetic retinopathy (deterioration of the retina due to diabetes) or signs of other systemic complications of diabetes.

The patient entered college in a distant city. He later revealed that during college he was careless with his diet and medications resulting in his diabetes often being out of control. Further, during this period the academically smart patient did not see an ophthalmologist. Even while in graduate school the patient was careless with his condition.

Finally, at age 25, he came back to see me. Although visual acuity was still normal, examination of the retina, of both eyes, revealed evidence of proliferative diabetic retinopathy. Retinal surgery consultation was obtained and he was treated with the appropriate pan-retinal laser photocoagulation (a procedure to stop dangerous proliferation of abnormal retinal blood vessels). The surgery successfully stopped the proliferative diabetic retinopathy. The patient was, again, instructed to control his diet and medications or his conditions would worsen. Over the next three years, the patient's ocular diabetic condition remained stable and his visual acuity normal. However, his systemic diabetes mellitus became more difficult to control and he began to develop signs of other complications. He developed peripheral neuropathy (disease of the nerves) in the lower extremities, hypertension and signs of early kidney failure.

The patient returned to the retinal surgeon at age 28 with sudden loss of vision in the right eye. Nonclearing vitreous hemorrhage was found on examination (free blood in his eye), another complication of diabetes. Vitreous surgery was performed to remove the hemorrhage. Vision again returned to normal after the surgery. A year later, the left eye was involved in the same manner; vitreous surgery was carried out on the left eye and vision returned to normal.

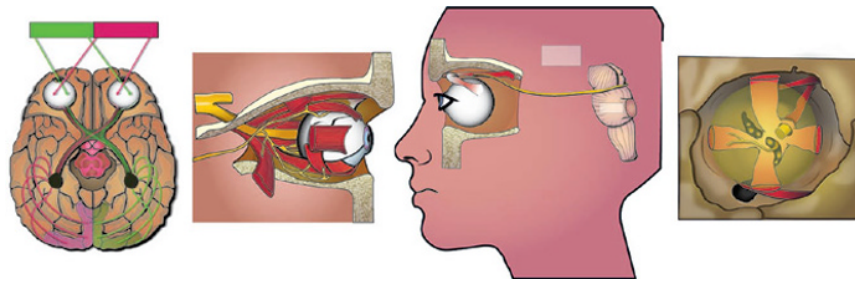
Kidney function decreased further, and at age 32, the patient required a kidney transplant. Postoperatively, the patient developed sudden loss of vision in the right eye. Ophthalmic examination revealed no blood flow in the central retinal artery, which runs through the middle of the optic nerve. I instituted appropriate therapy without return of vision. Later examination revealed a pale optic nerve head indicative of severe nerve fiber damage within the optic nerve.

This patient's story illustrates how a systemic disease, in this instance diabetes mellitus with its complications, can affect the function of the optic nerve. At the onset, swelling of the lens of the eye occurred when diabetes mellitus resulted in elevated blood sugar levels. This caused the patient's poor vision after lunch. The optic nerve was at this time carrying blurred images. Later, the vitreous hemorrhage blocked the image from reaching the retina, thereby resulting in no image transmission in the optic nerve. Lastly, loss of blood supply to the optic nerve resulted in atrophy of the optic nerve on the right and blindness in the eye.

As the patient's physician it was very frustrating to me to see him lose his vision from a condition that good care could have prevented. There was no need for this patient to have ever lost his sight. The optic nerve is a wonderful and magical part of our sensory system and we should all take care to keep it working well throughout our lives.

Howard P. Cupples, M.D.
Department of Ophthalmology
Georgetown University Medical Center
Washington, DC, USA

CRANIAL NERVES II, III, IV, AND VI: VISUAL ABNORMALITIES IN CHILDREN IN A DEVELOPING COUNTRY



In developing countries similar to Nepal, most children are born at home assisted by trained birth attendants (TBAs) or in a health care center. The concept of the importance of antenatal, perinatal, and postnatal care of the mother and child is very limited in Nepal. Typically, after many hurdles, a mother in Nepal gives birth to her child.

There is a general lack of awareness of the importance of monitoring infant health and the child's eye health is often overlooked. It is rare for a Nepalese mother to notice that her child has difficulty looking directly at her face. Some mothers, however, do notice that their child does have deviated eyes or involuntary to-and-fro oscillations of the eyeball, suggesting an abnormality of the cranial nerves that move the eyeball, III, IV, and VI. Mothers also may notice the whitish pupillary reflex in an eye due to a congenital cataract (opacification of the lens and its capsule), which would prevent impulses for clear vision from traveling within the optic nerve. When the mothers do notice these eye abnormalities in their child, they must then travel long distances from the mountainous and hilly region to the Eye Hospitals in Kathmandu for an ophthalmic consultation. We ophthalmologists then take the antenatal, perinatal, and postnatal history. These histories are especially important in the context of a congenital cataract. Cataracts are the opacification of the lens and capsule. Cataracts in infants are typically associated with a history suggestive of fever and rashes during the first trimester of pregnancy. We also determine whether the child was full term or preterm. Preterm babies can have disease of the retina known as retinopathy of prematurity, which would again interfere with visual clarity.

Intrauterine infection, cerebral dysgenesis, asphyxia, intracranial hemorrhage, hydrocephalus, meningitis, and encephalitis are usually the pre-, peri-, and postnatal causes of cortical vision impairment.

When mothers give a history of high fever and unconsciousness of their child within a few weeks of delivery, they also often relate that their child was admitted to a hospital and was given intravenous medication. Most of the mothers are illiterate, so we have to obtain and rely on the documents of the previous hospitals to learn what the child was admitted for and what drugs were administered to the child. The most common cause of admission is meningitis, which can affect any of the nerves that enter the orbit.

When we see a child with this history in Kathmandu, we do a routine ocular examination. We see whether the child can follow and fixate on a target. We observe the pupillary reactions. Failure to fixate or to show proper pupillary reactions could mean an abnormality in cranial nerves II and III.

In order to determine whether these children have refractive error (not able to focus on an object correctly), we dilate their pupils and look at their retina. In this way, we also can see if they have a problem with their optic disk, where cranial nerve II begins. Often meningitis leads to inflammation of the optic nerve and subsequent optic atrophy.

Usually, children who have a history of meningitis show a negative pupillary light reflex, which likely means a lesion in the afferent limb (cranial nerve II) or efferent limb (cranial nerve III) of the pupillary light reflex. Sometimes an abnormal pupillary reaction known as relative afferent pupillary defect (RAPD) is seen. This occurs due to asymmetrical deficits in the two optic nerves.

Cranial nerves III, IV, and VI all travel within the cavernous sinus and may be affected in meningococcal meningitis at this location. If affected, the child may have various ocular movement disorders and be unable to fixate on a single object (may have double vision).

Lesions of the ocular cranial nerves in children are very frustrating diagnoses to a pediatric ophthalmologist in a developing country because they are preventable, but, unfortunately, typically not treatable. The mothers come to us with expectations of a cure and we can do very little. The mothers also believe that if they have money to travel, their children likely could get additional treatment in a country with a more advanced medical care system than in Nepal. But in most cases, after damage is caused by meningitis to the cranial nerves, there is nothing that can be done anywhere.

The most common isolated muscle palsy in children is superior oblique paresis due to fourth (trochlear) nerve palsy. Acquired fourth nerve palsy sometimes occurs in closed head trauma. The parents complain that their child's eyes do not move together and that the child has a head tilt.

The oculomotor nerve innervates the superior rectus, inferior rectus, medial rectus, inferior oblique and levator palpebrae muscles, ciliary muscle, and the iris sphincter. Any lesion between the oculomotor nucleus in the midbrain and the extra-ocular muscles in the orbit results in third nerve palsy in children. Third nerve paresis can be either congenital (40–50%) or acquired (traumatic). Congenital third nerve palsy can also result from aplasia or hypoplasia of one or more of the muscles supplied by the oculomotor nerve.

The most important advice for change that we clinicians can give here is to create awareness among the parents that they should seek medical advice if there are any signs of sickness in their children. Meningococcal meningitis is a medical emergency with varied neurological and ophthalmic manifestations.

In Nepal, mothers are busy with household work and farming. Children are often left neglected. One child had a history of a fall from a rock in the forest. She had a history of loss of consciousness followed by deviation of the eyes. That was a case of posttraumatic third nerve palsy with pupillary involvement. The involved eye usually is deviated down and out with ptosis. In addition, pupillary dilatation can also occur. The parasympathetic fibers of the Edinger–Westphal nucleus of the third nerve supply the smooth muscle of the ciliary body and the sphincter of the iris. Hence, the pupil is dilated in third nerve paresis.

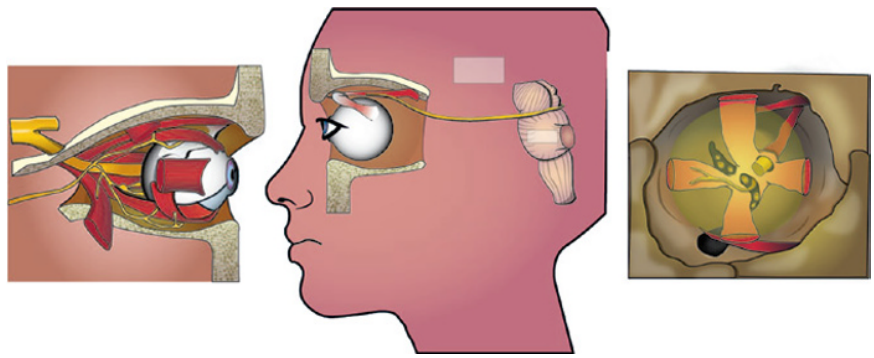
In viral illness, sixth nerve palsy can occur. In contrast to traumatic sixth nerve palsy, sixth nerve palsy due to viral illness generally resolves within six months. These cases are managed conservatively. One 13-year-old child had a history of fever, malaise, and common cold. Later, that child developed diplopia and inward (nasal) deviation of the eyes. The MRI was negative and the visual abnormalities resolved within six weeks.

Optic nerve hypoplasia is one of the congenital anomalies where there is minimal or complete absence of the nerve and the accompanying vessels. This can occur in association with other developmental abnormalities. Coloboma (hole) of the optic nerve is another developmental anomaly we sometimes see.

Hence, in Nepal, children can have various visual abnormalities. Therefore, in developing countries like Nepal, parents are advised to have a routine screening ocular examination of their children between six and eight weeks after birth.

Ujjowala D. Shrestha, M.D.
Consultant Pediatric Ophthalmologist
Tilganga Institute of Ophthalmology
Kathmandu, Nepal

CRANIAL NERVES III, IV, AND VI: NOT ALL IS AS IT SEEMS WITH EYE MOVEMENTS



Although I know the authors of this book have cautioned that the diagnosis of palsies of the cranial nerves that control the extraocular muscles is sometimes subtle, patients and clinicians still may get the impression from books that diagnosis is trivial. I want to emphasize here that it is not. After 40 years of practice as a neuro-ophthalmologist in a university setting, I still sometimes have to look carefully at the eyes – and at the history and rest of the physical examination of the patient – to be certain of the diagnosis.

Cranial nerve III (oculomotor nerve)

As the chapters in this book have made clear, this is a complicated nerve because it supplies four extraocular muscles (medial, superior, inferior recti, and inferior oblique), the levator palpebrae superioris, the iris constrictor, and ciliary muscles. Contrary to what would seem obvious, you cannot diagnose a third nerve palsy merely by observing incomplete movements of the eyes. That might work for profound palsies, but not for subtle ones, which are common and must be diagnosed by actually *measuring ocular alignment in various positions of gaze*. Keep in mind that what looks like a third nerve palsy can be due to myasthenia gravis, restricted extraocular movement owing to inflammatory muscular contracture, or the presence of an orbital tumor that is restricting the movements of the eye. Also, a "blown pupil" (pupil that does not constrict to light) does not necessarily mean the patient has a problem with the oculomotor nerve. Blown pupils by themselves are more often associated with dysfunction in the ciliary ganglion, persistence of pupil-dilating medications, or iris sphincter damage from trauma or inflammation.

I cannot count the number of patients I have seen after they have undergone needless uncomfortable and expensive catheter angiographic exams (which involve injecting dye into blood vessels) in a fruitless search for a cerebral aneurysm when the cause of an isolated blown pupil is within the eye! The same is true of patients who look like they have a third nerve palsy and are wrongly being investigated for an aneurysm when they actually have internuclear ophthalmoplegia (which is due to damage to a nerve fiber tract within the pons) or myasthenia gravis. On the other hand, I also know of at least one patient who had partial third nerve palsy with a normal pupil who did not undergo emergency angiography and who died the following day of a ruptured aneurysm. So, diagnosis and management of third nerve palsy is tricky and misdiagnosis can have grave implications for the patient.

Cranial nerve IV (trochlear nerve)

This is a seemingly simple nerve because it supplies only one extraocular muscle – the superior oblique. But diagnosis of its malfunction is surprisingly difficult. Why? Because this palsy often causes profound and symptomatic vertical and rotational misalignment without showing any detectable loss

of overall eye movements. Therefore, the clinician must make careful measurement of ocular misalignment between the two eyes in many gaze positions before concluding that a patient does not have a trochlear nerve palsy. Because few examiners do this properly, fourth cranial nerve palsy is the most commonly misdiagnosed of the three ocular-motor palsies. Many patients see a variety of clinical specialists before they receive the correct diagnosis. This is of course very frustrating and expensive for the patient.

Most of the time, the cause of a fourth nerve palsy is not serious, but I well remember a patient who had a fourth nerve palsy caused by a meningioma growing off the tentorium cerebelli (dural covering of the cerebellum). The diagnosis was long delayed because of incorrect diagnoses, allowing the meningioma to grow to the point that its surgical removal caused debilitating and persistent neurologic deficits for the patient.

Cranial nerve VI (abducent nerve)

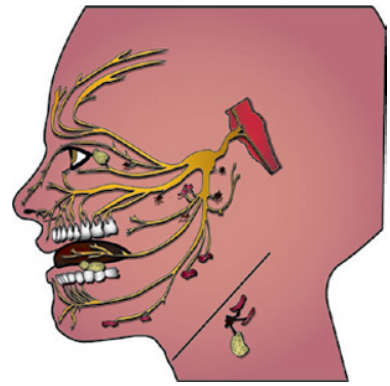
Here is another seemingly simple nerve that supplies only one extraocular muscle—the lateral rectus. However, diagnosis is again often wrong with this nerve because abduction is not always impaired in milder palsies and, as with the other extraocular muscle palsies, it can be beautifully mimicked by myasthenia gravis. When the abducent nerve is not working properly, the lesion may lie in its intracranial path ("localizing sixth nerve palsy"), or far away, such as when a downward shift of the brain stretches the sixth nerve ("false-localizing sixth nerve palsy").

I remember a woman who had undergone a lung operation and afterward had a catheter placed in her spine to allow for the injection of anesthetics to control pain. The patient subsequently complained of diplopia and an examination revealed a sixth nerve palsy. Her surgeons – and many other examiners – did not think to connect the palsy to the catheter, which had reduced cerebrospinal fluid (CSF) pressure, and caused the brain to slide downward and pinch her sixth cranial nerve as it traveled toward the cavernous sinus. The diagnosis was finally made by reviewing the patient's MRI, which showed signs of intracranial hypotension (reduced CSF pressure). Making that diagnosis saved the patient a subsequent lumbar puncture, which could have made her condition even worse. A blood patch was used like a Band-Aid to prevent additional CSF leakage and this eventually acted to return her pressure to normal. Thus, her sixth nerve palsy resolved.

So remember, even a clinician who has practiced a very long time may still have to be cautious in diagnosing palsies of these amazing nerves.

Jonathan Trobe, M.D.
Department of Ophthalmology
University of Michigan School of Medicine
Ann Arbor, Michigan, USA

CRANIAL NERVE V: BE CAREFUL WHAT YOU ASK FOR!



The trigeminal nerve, the fifth cranial nerve, with its branches, supplies sensation to most of the face and also is the motor nerve to the muscles of mastication. In many respects, its lower two divisions (the maxillary and mandibular branches) can be called the "dentists' nerves," because they are the nerves that dentists work with all the time in their clinical practices. The inferior maxillary and mandibular nerves frequently need to be anesthetized with local anesthetic for many dental procedures and dentists can thus on occasion be responsible for damaging them.

A typical story would be that of Alice, a 66-year-old recently widowed lady who had decided to spend some money on herself. She decided to replace two missing teeth on the left side at the back of her lower jaw with dental implants. These are screw fixtures, normally made of titanium, which are screwed into predrilled holes in the jaw bone and on to which dentists can construct new teeth that are the best substitute currently available to replace missing teeth. The only issue in the back of the lower jaw is that the inferior alveolar nerve runs right through the middle of it. This nerve (a branch of the mandibular division of the trigeminal nerve) is unique in that it is the only nerve in the body that runs in the middle of a bone, and this is presumably to give nervous innervation to the adjacent teeth. It is a purely sensory nerve, giving sensation to the bone, teeth, and gum of the lower jaw as well as the lip and chin on the ipsilateral side. Thus, damaging this nerve will cause alteration of sensation along its distribution that will include the jaw bone, teeth, gum, lip, and chin on the same side. The altered sensation can take any form from total anesthesia (if the nerve is cut or damaged) to dysesthesia (pain), or paresthesia (abnormal sensations), and also hypersensitivity. For this reason, the dentist must be careful when preparing the holes for implants in the back of the lower jaw to avoid injuring the inferior alveolar nerve. In order to do this, dentists will often take specialized images called cone-beam CT scans and will use specially adapted drills set to the correct length.

Nevertheless, mishaps do occur, and in Alice's case, unfortunately the site preparation hole and the implant itself were too long and came into contact with the inferior alveolar nerve. As soon as the local anesthetic wore off, about 2–3 h later, Alice was in pain and returned to the dentist where an X-ray showed the position of the implant. It was immediately removed (as advised in nearly every protocol) and the pain largely resolved. However, she was left with permanent, markedly decreased sensation and a pins-and-needle-type feeling that she finds most irritating. Alice also complains of the following:

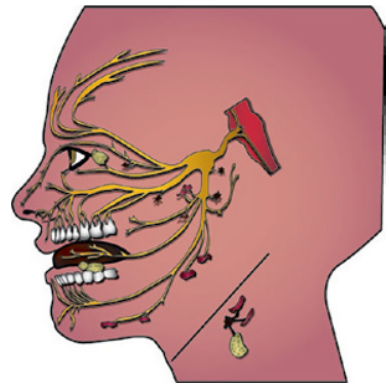
A sensation of drooling from the side of her mouth because she cannot feel her lip properly.
She bites her lower lip in frustration because it is numb.
She is unaware when food is caught on her lip and she finds this embarrassing when she eats out.
She does have to take medication to try and suppress the pins-and-needle-type feeling and to make life pleasant.
In the early stages, she felt her speech was affected because she could not feel her lower lip, but this seemed to have resolved after 3–4 months.
She is scared about future dental treatment.

Alice found the whole experience very frustrating and said that although it is not a life-threatening condition, she feels it has impacted her quality of life and makes her miserable at times. Unfortunately, after 9 months or so, there is unlikely to be any additional recovery, and she is probably in a stable state at the moment. I would like to be able to predictably operate on Alice and help her, but unfortunately over the years I have come to realize that surgery on the peripheral branches of the trigeminal nerve is unpredictable. A nerve cleanly cut with a scalpel is relatively straightforward to repair with good results, but a nerve injured by a dental drill or some of the medicaments used in dentistry are very difficult, if not impossible, to repair. Nevertheless, we do get occasional spectacular results, which make life worthwhile for us, and even late spontaneous improvement has been reported in the literature. The behavior of these nerves never ceases to surprise me, and I may end up offering Alice surgical exploration and possible repair.

One of the more frustrating things for Alice is that she never got her implants or her new teeth, so in some ways for her it was an exercise in frustration. The issue with the face is that it is "the window to our emotions," so damage to the main sensory nerve to the face can be particularly noticeable and distressing. We just have to remember that every medical advance has its associated risks and complications, and patients must be made aware of them.

M. Anthony Pogrel, D.D.S., M.D.
Department of Oral and Maxillofacial Surgery
University of California
San Francisco, California, USA

CRANIAL NERVE V: THE BEST LAID PLANS …



At first glance upon entering the examination room, there was nothing remarkable about Mr. W. A 57-year-old retired heavy-equipment operator whose weathered exterior belied his soft-spoken disposition, he appeared to be in no acute distress. However, when he turned his head, he revealed a strange idiosyncrasy. Despite being otherwise clean-shaven, Mr. W had neglected to trim approximately a 1 × 1 cm patch of beard near the right corner of his lower lip. Was this a bizarre manifestation of hemineglect syndrome? Had his razor broken that morning? In fact, neither of these was true. Mr. W had intentionally avoided shaving that area, a habit he began about 3 years prior.

For all this time, Mr. W had been suffering from trigeminal neuralgia (TN), a syndrome of severe, intermittent, shock-like pain that occurs unilaterally in any of the three distributions of the trigeminal nerve. The pain, which has been referred to as "the most severe known to mankind" can occur randomly throughout the day and can also be triggered by specific stimulatory actions such as a cool breeze, using a washcloth, eating, drinking, and, of course, shaving. While attacks often started unpredictably for Mr. W, he had determined that touching a certain area of his face could set off an attack and he avoided shaving near this trigger zone for fear of putting himself through great pain. For this unfortunate man, the attacks had become quite disabling. When the pain struck, there was nothing else he could do but lie quietly and will himself through the torment until it finally subsided.

As excruciating as the attacks were, he later recounted that the worst part of his ailment was living in constant fear of the next episode. When the pain began, over time, to occur more frequently, he became increasingly withdrawn for fear of being forced to endure an attack in public, away from the marginal respite provided by his darkened bedroom. The possibility of being stuck in traffic during an attack was enough to keep him off the road during rush hour and because the wind could trigger his pain, motorcycle riding went from being a favorite pastime to a nightmare he avoided.

At once, the explanation for Mr. W's symptoms was both elegantly simple and bafflingly mysterious. Magnetic resonance imaging (MRI) revealed that a loop of his superior cerebellar artery (SCA) was compressing his right fifth cranial nerve precisely at the point where it emerged from the pons. With an operation called microvascular decompression (MVD), a surgeon can treat this pathologic compression by lifting the offending blood vessel off the nerve and maintaining separation with a small Teflon® cushion. This operation is successful in eliminating the pain in more than 90% of patients like Mr. W.

It is well established that patients who exhibit "classical" symptoms of TN (i.e., episodes of lancinating, shock-like pain that can be triggered, and who have an initial positive response to anticonvulsant medication) have a better prognosis following MVD than patients with other features, such as a constant burning pain or pain that does not respond to anticonvulsant medication. Mr. W undoubtedly fell into the favorable category. The clear evidence of SCA compression seen on the MRI bolstered confidence that he would do well. Upon waking one day, Mr. W reported the happy news that his pain attacks had ceased. Although he was thrilled to be out of pain and he had every reason to believe that he was now cured, Mr. W still could not manage to relax. Mr. W knew that while he was very likely to remain pain-free, he also knew that approximately 1% of patients like him experience a recurrence every year. The bliss of being cured was overshadowed by the fear that it could only be temporary. Mr. W continued to avoid shaving his "trigger zone" and would not stop taking his anticonvulsant medication despite its side effects.

There is no good explanation for why we cannot precisely foresee which patients will benefit from MVD and, of those, which will be the unlucky few to experience a recurrence. Clearly, the knowledge that the medical community has accumulated over the decades since the procedure was first introduced has been of tremendous benefit to many people but large gaps in our understanding of TN remain. Perhaps the greatest mystery of this disease is not why some people continue to experience facial pain in the absence of neurovascular compression but instead why more people do not develop symptoms. After all, both radiographic and cadaveric studies have shown that many people have a blood vessel impinging on their trigeminal nerves, yet TN is a relatively rare phenomenon.

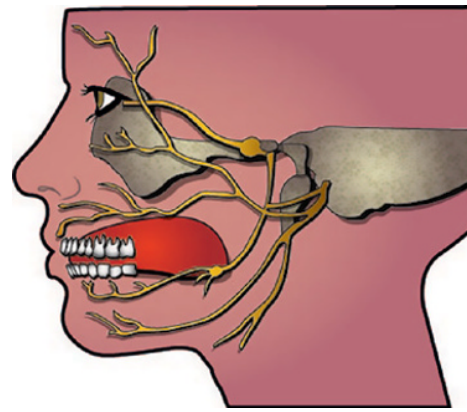
The anatomy and physiology of the trigeminal system is well characterized and this knowledge is applied for the benefit of patients in many clinical contexts. Yet, for all that is known, it is clear that the trigeminal nerves still harbor many secrets. The varied reactions to a compressive insult seem to imply that there must be layers of unseen variability in this nerve among individuals.

A few months after his operation, Mr. W returned to the clinic and a change was immediately obvious: he had shaved his face completely. He explained that as he grew more accustomed to his pain-free status, the worries about a recurrence had vanished. The true test of the operation's success was when he went for a motorcycle ride on an autumn morning and felt nothing more than a cool breeze hitting his face. His perplexing trigeminal nerve was once again functioning perfectly. Why some patients with TN experience a recurrence of their pain after MVD and others do not is among one of the remaining

mysteries of the trigeminal nerve and this area of uncertainty can be a source of great stress to patients who have been cured.

Raymond Sekula, M.D. and Andrew Frederickson, M.S.
Department of Neurosurgery
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania, USA

CRANIAL NERVE VII: SOMETIMES IT IS HIT OR MISS



The worst year of Mrs. P's life began insidiously enough. With an important deadline looming, the 48-year-old attorney was working late in her office one evening. Deep in thought and tapping her foot nervously as she worked, the tired and overly caffeinated woman scarcely took notice of a twitching sensation in her right eyelid. The nervous tic of her eyelid persisted as she drove home later but within moments of climbing into bed, she relaxed and fell off to sleep.

Throughout the next few days, Mrs. P continued to experience twitching about her right eye, but she paid the phenomenon little attention. The following week, however, the mounting twitches could no longer be ignored. As Mrs. P was addressing a jury, the twitching worsened dramatically. Panicked, she rushed through her argument as she struggled to keep her eye open. Against her will, her right-sided facial musculature began to convulse with a powerful autonomous rhythm. As she excused herself to the restroom, her normal facial tone returned for a minute only to have the pattern repeat even more violently than before: closure of her eye, sneering of the right corner of her mouth, and the upward deflection of her right eyebrow. As she involuntarily grimaced at herself in the bathroom mirror, she turned flush with embarrassment and wondered how she would ever be able to return and face the same jury again.

It soon became clear that something was seriously wrong. With the spasms starting to occur throughout the day, she consulted her doctor, but on the day

of her appointment, the spasms were comparatively diminished. Her physician assured her that stress and caffeine were the likely culprits and that she was not in any physical danger. Over the next few months, Mrs. P attempted to live with the affliction, but with increasing bouts of uncontrolled spasms throughout the day, this proved to be difficult. She relied on her partners to go to court and relegated herself only to legal work she could accomplish from the seclusion of her office. Everywhere she went, people stared at her disfigurement and she became increasingly withdrawn, leaving the house only when absolutely necessary. She finished each day exhausted with a terrible cramp in her cheek from the constant muscular activation. The formerly active woman began to sink into a state of depression. Upon finally receiving a diagnosis from a neurologist, after months of uncertainty, Mrs. P learned that her tormentor had a name: hemifacial spasm (HFS).

Similar to many essential components of life, the facial nerve performs its duties unnoticed and comes to our conscious attention only when something goes horribly awry. In Mrs. P's case, her facial nerve had performed flawlessly for 48 years. Every facial expression she had ever made, every tear she had ever shed, and every sweet sensation she had ever tasted on the tip of her tongue were all the result of her facial nerve functioning perfectly. However, with the motor branches on one side now deregulated, Mrs. P's facial nerve had transitioned from being her servant to becoming her captor and torturer.

HFS is, in most cases, caused by a wayward blood vessel that compresses the facial nerve close to the point where it emerges from the brainstem. Chronic compression appears to damage the nerve in a way that causes ephaptic (abnormal) transmission of electrical impulses, eventually leading to symptoms such as Mrs. P's. This knowledge forms the basis for an operation called a microvascular decompression (MVD), which involves placing a small Teflon® cushion between the facial nerve and compressive vessel. When Mrs. P was eventually referred to our center, she was cured by this very operation. MVD's high success rate is a triumph of modern medicine. Yet, despite the ability to tame the facial nerve in many cases this disease remains an enigma.

The idea that vascular compression of the facial nerve leads to HFS seems quite straightforward and the high cure rate of MVD is strong support for this hypothesis. However, this theory also leaves a number of unexplained points, noticed by many who have treated this condition and first formally articulated by Adams in 1989. For example, a minority of patients with HFS continue to have severe symptoms even after multiple surgical explorations have confirmed that the compressive vessel has been treated. For this, we have no satisfactory explanation. Additionally, it is not apparent why vascular compression of the seventh cranial nerve causes hyperactivity of the motor segment of the nerve only. Recall that in addition to its key role in innervating the facial musculature, the facial nerve carries tactile and gustatory sensations from large areas of the tongue. Yet no patients with HFS experience sensory symptoms related to the facial nerve. It would be tempting to declare that only motor neurons are susceptible to vascular compression injury if it were not for

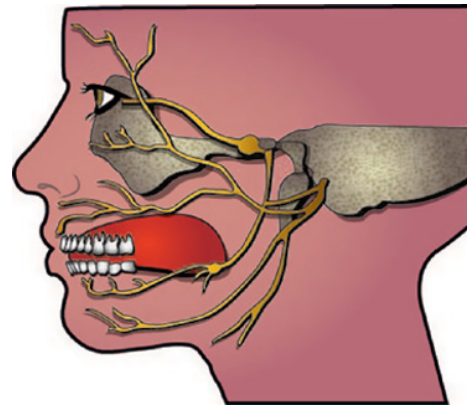
the fact that nearly the opposite situation occurs in an analogous condition, trigeminal neuralgia (TN). In TN, vascular compression of the fifth cranial nerve causes agonizing facial pain, yet never spasm of the masseter muscle, which receives its innervation from the trigeminal nerve.

Even the process by which vascular compression causes aberrant nerve impulses is poorly understood. It is often assumed that compression causes degradation of the nerve's myelin sheath and axons, allowing nerve impulses to spread inappropriately. However, patients routinely awake spasm free from MVD surgery within an hour of the actual decompression. If demyelination was the cause of patients' symptoms, it is difficult to accept that repair of the myelin sheath could occur so quickly.

MVD is an operation of practical necessity. HFS is life-altering and MVD offers a good chance at a cure. For patients like Mrs. P, it does not matter that the mechanism by which MVD cures is poorly understood, as long as it works. Some patients are, however, not as lucky as Mrs. P. Although the cure rate with MVD is high, it is not a universal cure. For the patients who cannot be helped by MVD, unraveling the mysteries of the facial nerve is not merely an intellectual puzzle but a matter of dire consequence.

Raymond Sekula, M.D. and Andrew Frederickson, M.S.
Department of Neurosurgery
University of Pittsburgh School of Medicine
Pittsburgh, Pennsylvania, USA

CRANIAL NERVE VII: TRAGEDY BEHIND A FACIAL NERVE PARALYSIS



The facial nerve plays a role in several functions, including taste, conduction of autonomic functions (of involuntary nervous system that, e.g., transmit signals to innervate the lacrimal glands to produce tears), and, above all, the control of the muscles of facial expression. The latter has always intrigued

human beings. It was the electrical stimulation studies of the facial muscles by the French physician Guillaume Duchenne that served as the foundation for Charles Darwin's well-known book, *The Expression of the Emotions in Man and Animals* (1872).

Facial nerve palsy in neurological practice is not rare (occurring in 20–30 per 100,000 persons) and, although disfiguring, is usually a benign and reversible condition. If no cause is evident, it is referred to as idiopathic facial palsy, called Bell Palsy, named after Charles Bell, the Scottish surgeon. Bell was one of the first to write a description of the affliction (early 19th century), including the phenomenon that the eye may be observed to turn upward upon trying to close it (Bell phenomenon). Although most cases are idiopathic and have a good prognosis, there are other conditions that may cause facial nerve palsy, including middle ear infections and Lyme disease, in which the patient may even be affected bilaterally. Other causes are relatively rare, including tumors. I have seen many patients with facial palsy during the past 30 years; they come and go, usually recover spontaneously, often with a 10-day course of steroids, and do not leave special memories or feelings with the neurologist. One patient, however, remains in my memory and whenever I think of facial palsy her face reappears in my mind.

Complaining of tinnitus, mimicking "the sound of a heating pipe," I saw her for the first time in 2000, aged 48 years. She had hearing loss as well as facial palsy on the right side following a surgical procedure 20 years previously, done elsewhere, and had not been followed up. She was married and had four children. In addition to raising their children, she took care of the business administration of her husband's enterprise. At neurological examination, the most striking finding was a complete peripheral facial paralysis on the right side. She could not lift her eyebrow or close her eye and her face was wry (twisted). Furthermore, she had hearing loss on that side and a spontaneous horizontal right beating nystagmus (a quick, spontaneous horizontal eye movement). Clearly, a new MR scan of the brain was necessary and demonstrated a new cerebello-pontine angle (CPA) tumor on the left side, as well as a remnant or recurrent tumor on the right (these tumors usually arise from the VIIIth cranial nerve). In addition, there were a significant number of supratentorial meningioma type tumors (about 9!). A diagnosis of neurofibromatosis type II (NF-II) was made. This is a genetic defect with bilateral acoustic nerve schwannomas in the CPA, often accompanied by intracranial meningiomas. Both are benign tumors. Schwannomas grow from nerve sheaths and meningiomas from the meninges covering the brain. Sometimes it is difficult to remove them without damaging brain and nerves. She had careful surgery on the left CPA, taking care not to further damage the acoustic nerve (CN VIII) and save the facial nerve. Although complete resection was impossible, she did well afterward, with just some transient hoarseness and swallowing difficulties. Genetic studies in Paris did not reveal mutations in the NF-II gene at the time, although that did not exclude a hereditary nature. Her four children seemed to be unaffected, but were still young (between 6 and 15 years of age). This was reassuring both for the family and for me.

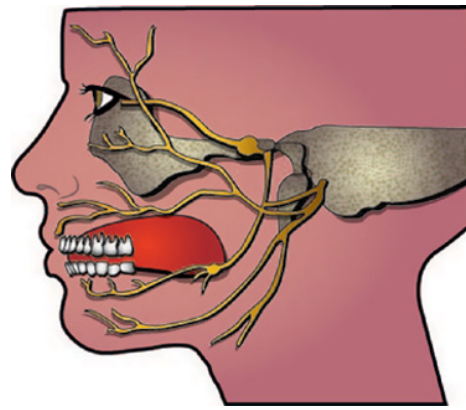
Since then, I have seen her and her husband for follow-up several times a year. As expected, the hearing loss (CN VIII) and facial paralysis (CN VII) on the right side did not disappear, but more importantly, the functions of the same nerves on the contralateral, left side remained stable (i.e., CN VII function appeared normal and only mild hearing loss had been noted). Every time I saw her at the outpatient clinic, it was astonishing to realize that although the right facial paralysis caused considerable disfigurement, she did not have any other significant symptoms despite the astonishing number of tumors in her head. Fortunately, during the course of her disease, the slight hearing loss on the left side did not interfere with communication. She tried to carry on with her life as well as possible, for which she earned my utmost respect. But disasters sometimes come in clusters. During the course of her disease, one of her children suddenly died and another needed an implantable cardioverter-defibrillator (ICD) following cardiac arrhythmia.

During the past few years, a slowly progressive paralysis of the left side developed, due to brainstem compression by the right-sided CPA tumor. Her case was discussed in our multidisciplinary oncology team and radiation therapy was recommended to try and stabilize the tumor. This was carried out in 2010. In the meantime, she needed a ventriculo-peritoneal shunt, because of hydrocephalus (excessive fluid in her brain) that had resulted in visual disturbance due to papilledema (damage to the optic nerve by increased intracranial pressure). Despite all these treatments, she gradually deteriorated. We, the patient, her husband, children, and I, had many discussions about end-of-life decisions. These were emotional times that were even hard for an experienced physician. In fact, the children had a greater sense of the reality of the situation than either her husband or I had, perhaps because they dealt with the events on a daily basis and had gradually learned to let go. Their behavior was helpful for me in making the right decisions.

She developed severe swallowing problems, decided not to have a gastric tube inserted (PEG), and died in September of 2011. And what of the children? Fortunately, at present, none of them has developed hearing loss (or facial palsy) and their MR scans remain normal. However, only after reaching the age of 30 is "the coast clear" and the diagnosis (NF-II) can be ruled out with certainty for them. I wonder how they are doing now. Patients like their mother make you realize that even in the 21st century, with all modern techniques and therapies, physicians are often powerless. Ancient aphorisms are still applicable: "la médicine c'est guérir parfois, soulager souvent, consoler toujours" [medicine is curing sometimes, relieving often, consoling always]. Fortunately, NF-II is a rare cause of facial palsy.

Peter J. Koehler, M.D., Ph.D., FAAN
Department of Neurology
Atrium Medical Centre
Heerlen, the Netherlands

CRANIAL NERVE VII: FACIAL NERVE AND FACIAL FUNCTION



The facial nerve's primary function is to control the muscles of facial expression. Your face is important in how you present yourself to the surrounding world. Your smile, emotions, blinking of your eyes, and closure of your lips are all controlled by the facial nerve. It emerges out of the stylomastoid foramen as a single trunk just below and deep to the ear and promptly enters the parotid salivary gland, which serves as its protective layer and provides fullness to the cheek. The course of the facial nerve divides the parotid into two lobes: a smaller *deep* (underneath the nerve) lobe and much larger *superficial* (above the plane of the facial nerve) lobe. The parotid glands make saliva and its enzyme helps to start digestion of sugars. It is innervated by the glossopharyngeal nerve (CN IX).

In the parotid gland, the nerve divides first into divisions and then into a series of branches. The cervical branch controls the platysma muscle that stretches the skin of your neck in excitement and anticipation, but also forms objectionable neck bands that are very prominent in slender older women. As once was said, "The neck bespeaks the age of a woman." As plastic and head-and-neck surgeons, we stretch and release these bands during rejuvenating facelift procedures. Many patients have benefited from a profound result of this operation with new levels of confidence in their appearance.

The marginal mandibular branch of the facial nerve, also known as "*marg*," is critical to lip symmetry and function. As described in Chapter 7, minor weakness of this nerve will make your smile look uneven and complete loss will prevent the patient from closing the mouth completely. The person will have trouble eating, chewing, and preventing drooling. We are very particular about operating around the *marg* and meticulously protect this important structure during lymph node dissection for head-and-neck tumors and removal of the adjacent submandibular salivary gland for either tumors or infections. This precision of surgical dissection is what helps to control aggressive cancer with the hope of giving the cancer patient a smile and a cure.

The buccal branch supplies the muscle of the cheek and helps us avoid biting it while chewing. This is the least important branch of the facial nerve and we often cut it when we need exposure of the deep parotid tissue to facilitate the removal of a large parotid tumor. Then we suture the ends of the branch back together. The buccal branch of one side of the face can be used for restoration of some facial nerve function of the opposite side in facial nerve paralysis in children and young adults. In order for us to use the buccal branch for this, we extend the length of the nerve by using a graft from the patient's lower leg. By this approach, a young patient with complete congenital paralysis of one half of her face now can appear relatively normal. Furthermore, if there is an additional problem with some of the facial musculature, we will take a small working muscle from the leg or chest and reconnect its 1–2 mm vessels to the facial vessels and to the nerve graft. In this way, the muscle flap gets a blood supply as well as motor innervation so that this muscle can survive and function to move the face. These are *microsurgical* techniques involving connecting these miniature structures under the high magnification of an operative microscope.

The zygomatic branch is the most important facial nerve branch. It serves the eyelid muscles to both keep them tight and facilitate eye closure. Without blinking, the cornea of the eye will dry out and lose its transparency; eyesight will be lost. The loss of function of the zygomatic branch will certainly require surgical correction. We remove a section of the lower eyelid and suspend it to the orbital wall to give it its natural snug tone. To further eye closure, we implant a small bar of real gold that weighs just a bit over 1 g into the upper lid. This *gold weight* allows gravity to assist with upper-lid closure. The "blink," however, is a voluntary maneuver, which requires active muscle contraction. An exciting technology consisting of an implantable eyelid pacemaker is being studied to facilitate blinking in patients with facial nerve paralysis.

The last, but not least important, branch is the temporal branch of the facial nerve. It controls function of the forehead muscle. This nerve is at risk of injury as it passes over the bony arch of the zygoma. If the function of the nerve is lost, the patient will have a droopy, asymmetric brow, which will need to be corrected surgically by a browlift procedure.

The facial nerve can be afflicted by various disease processes. Strokes and brain tumors may damage the central nervous system origin (brain stem centers) of the facial nerve or affect parts of the course of the nerve fibers inside the brain. Some viral diseases such as herpes may selectively affect the facial nerve, causing Bell Palsy. Distortion of sound perception is a sign of involvement of the portion of the facial nerve that traverses the temporal bone and innervates a very small muscle that maintains the tension of a sound-conducting bone ossicle of the middle ear. Remarkably, in some cases, steroid treatment can have a profound effect and abort the palsy; in others, the treatment can be as radical as drilling the nerve out of the important, convoluted, and anatomically complex temporal bone, thus giving the patient hope of recovery by decompressing the nerve.

Traumatic injuries of the facial nerve are rare because of the rather deep position of the nerve trunk inside the face. The bulk of facial nerve problems

are generally related to tumors and their treatments. Tumors of the parotid glands are relatively common. Fortunately, the vast majority of them are benign and do not endanger a patient's life if treated properly with a technically demanding operation called *parotidectomy*. In this procedure, the nerve is anatomically identified and carefully dissected out of the parotid tissue to protect its function. At least superficial, and sometimes deep, lobes of the parotid gland containing the tumor need to be removed. Similarly, for malignant parotid tumors that comprise about 20% of tumors, a total parotidectomy and sometimes neck lymph node removal are performed. The facial nerve is sacrificed only if directly involved in the tumor. Nerve involvement poses the danger of tumor spread along the nerve into the brain, and that is why paralysis of the nerve in a parotid tumor patient is an ominous sign of advanced life-threatening malignancy. Radiation therapy is used after surgical removal to enhance the result of treatment, but the prognosis is often realized in the initial histologic diagnosis of the tumor.

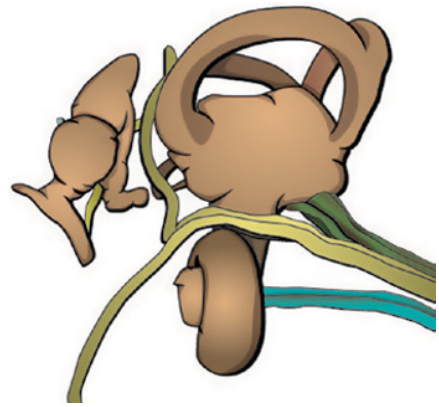
An interesting feature of the parotid gland is the fact that lymph nodes are trapped within the gland during embryologic development. These lymph nodes have the function of draining part of the face and scalp, orbital structures, and paranasal sinuses. Lymph nodes function as filters or perhaps as part of a "sewage system," which eliminate cell breakdown debris and excess tissue fluid. In a cancer patient, the tumor cells are also washed into the lymphatic system where they are sometimes destroyed by the immune system. When the immune system fails to do that, the tumor can gain a foothold and starts to grow in the lymph nodes. Such foci of tumor are known as *lymphatic metastases*.

Skin cancers and melanoma of the face and scalp, and mucosal tumors of the sinuses and eye, are all prone to spread into the lymph nodes of the parotid gland. In such cases, parotidectomy (surgical removal of the gland) is performed as a part of lymph node dissection to ensure that the involved or at-risk lymph nodes are removed to prevent further dissemination of cancer. These operations comprise a significant percentage of parotidectomy procedures in which anatomic knowledge and very careful surgical techniques are critical in the preservation of facial nerve function.

Lastly, a new and promising area of reconstructive surgical practice is *reconstructive transplantation*. With the advent of better immunosuppression techniques, transplantation of the face became possible for selected individuals who lost their face due to burns and trauma. The facial nerve branches in the transplanted face are connected to the recipient's facial nerve branches, thus making the new face functional. Interestingly, regeneration of the nerve is enhanced by immunosuppressive medications. This new frontier in microsurgery will provide an opportunity to help patients whose faces cannot be reconstructed with traditional surgical techniques. We are privileged to witness and be a part of this progress.

Alex Senchenkov, M.D. and John E. Woods, M.D.
Department of Surgery
Mayo Clinic
Rochester, Minnesota, USA

CRANIAL NERVE VIII: SPINNING WHEELS



The elderly male adult came into my physical therapy clinic and stated, "I need you to do that maneuver that moves the crystals around in my ear."

He knew exactly what was happening to him because he'd had this same problem a few years earlier. The diagnosis, benign paroxysmal positional vertigo (BPPV) can sound scary, but it is actually a simple problem. Tiny crystals called otoconia are found in the otolith organs, and these otoconia help us perceive acceleration and deceleration movements of our bodies. Occasionally, the otoconia migrate away from their bed in the otolithic membrane and float through the endolymph. If they travel into a semicircular canal, they can cause disruptions in the neural messages that are transmitted to the brainstem through the vestibular portion of cranial nerve VIII. This disruption typically causes severe episodes of vertigo with certain changes in head position because the crystals cause movement of the endolymph fluid in the affected canal.

The patient's history is by far the most important information that is needed in working with people who have inner ear disorders, and so I listened carefully as he articulated his story. The man was a World War II veteran. He had been in Europe standing in a trench in the ground. He turned his head as far as he could to the right to talk to his comrade who was standing next to him. At that moment, an enemy grenade landed in front of their trench and exploded. The man lost all hearing and function of his left ear which was facing the explosion, but his right ear was spared. He had led a normal life after returning from the war. He married, had children and grandchildren, and now that he was retired, spent a lot of time woodworking. Both he and his wife were in good health and very active in their community. A few weeks before he walked into my clinic, the patient and his wife had taken their grandchildren on a vacation to Disney World

in Florida. And yes, the man had gone on many of the rides with his grandchildren in Disney World.

Given the patient's history, it was no surprise that he had BPPV. It occurs more commonly with advancing age, and more commonly in people who have had some sort of trauma or infection to the inner ear. This man's BPPV was occurring in his left ear that had sustained the trauma so many years ago in World War II. Once a person has an episode of BPPV, they are at a higher risk to have another episode in the future. It most likely occurred in this case due to the high velocity and spinning movements inherent in the rides at Disney World. The otoconia were displaced from their bed, migrated into a posterior semicircular canal, and caused that canal to send neural messages via cranial nerve VIII to the brain that the head was in motion, when actually the man's head was still. This difference in neural impulses between the vestibular nerves from each ear was causing the man's vertigo.

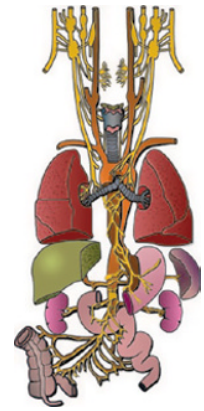
The treatment was not complicated. After performing a Dix–Hallpike maneuver to confirm which canal was the offending canal, I performed the Epley repositioning maneuver. This is a series of very specific head movements that "reposition" the otoconia by moving them around the semicircular canal, and returns them to the otolith organ where they came from. Most patients are immediately relieved of their vertigo symptoms, although they can feel as if they are floating and off-balance for a few days. I asked the man to come back and see me two days later and to bring his wife with him. At that appointment, he stated that his vertigo was gone and he had no residual symptoms. There was again balance in the impulses between the right and left vestibular nerves.

I gave the man pictures of how to perform the repositioning maneuver and I taught his wife how to perform the maneuver on her husband. I instructed them that if the man had another episode in the future, they could try the repositioning maneuver on their own as it would most likely resolve his symptoms.

I started my career as a physical therapist working in general neurology with patients with strokes, traumatic brain injuries, spinal cord injuries, etc., and at that time I never imagined there could be a more interesting and rewarding career. But several years after I started working, I attended a continuing education class on vestibular rehabilitation and was astounded to find that there was something even more interesting than general neurology! And that was the functions associated with the vestibular aspects of cranial nerve VIII. This one single cranial nerve is my major clinical concern every day and continues to astound me each and every day.

Laurie Swan, P.T., Ph.D.
Pierce College
Synaptic Seminars
Seattle, Washington, USA

CRANIAL NERVE X: SPEAK UP, PLEASE, I CANNOT HEAR YOU



The vagus, the Xth cranial nerve, has many branches. As a speech–language pathologist, I have seen several clients who have had damage to one or more of the branches. Perhaps the most interesting is a case that involved damage to the recurrent laryngeal nerve branch of the right vagus. The right recurrent laryngeal branch enters the laryngopharynx below the laryngeal inferior constrictor muscle to innervate most of the muscles of the larynx responsible for controlling the opening and closing of the vocal folds. Closure of the vocal folds is necessary to produce voice. If a person does not have adequate vocal fold closure, then breathiness, hoarseness, and poor volume is a result. Usually, this is bothersome and frightening; the client wants the voice "fixed."

While grading papers in my office one day, I had a phone call from a colleague. When she began talking her voice was hoarse with low volume. Because she was hard to understand over the phone, she asked if she could come to my office to talk with me. When she arrived she explained that she had had parathyroid surgery a few weeks earlier and that her voice was hoarse after the surgery. She was frustrated with her voice and its lack of volume. This condition was particularly disturbing to her because she was a college instructor and used her voice in classes several hours daily. Her hope was that I, as a speech–language pathologist, might be able to help her achieve volume and perhaps reduce the hoarseness.

Although I knew I may be able to assist her with volume, I realized that there may be little I could do to reduce the hoarseness. My colleague was told that the recurrent laryngeal nerve may have been bruised during the surgery, something that is not that uncommon after any type of thyroid or parathyroid surgery. She was told she may need to wait about four to six months to see if the bruising would heal and she would return to normal voicing. If, however, the nerve was more than bruised, she would not have the return of normal function of her vocal fold. Four to six months was more than a semester and that was too long for her to just wait to see if it would heal and, besides, she was fatigued at the end of the day and her students were struggling to hear her in class. So she wanted me to do something.

In my colleague's case, her right vocal fold was paralyzed in the open position, which resulted in hoarseness and the inability to produce sounds much

above a whisper. The left vocal fold was trying to compensate to achieve normal voicing, but the opening was too large due to the paralysis of the right vocal fold.

We discussed how she was handling her classes. Mostly she was trying to whisper as loudly as she could. This, of course, was inadequate, was exhausting and may even fatigue the left vocal fold causing problems later. She estimated that she was talking in class about six hours daily. No wonder she was exhausted at the end of the day. We discussed using a pocket microphone system that would project her voice loudly to the class. At least she would not experience as much fatigue and the left vocal fold would not have to work so hard to compensate.

Unfortunately, there was little to be done at this time about her hoarseness. Needless to say, the amplification system was helpful but not satisfactory for her students because they still needed to adjust to her hoarseness.

I also counseled her to use her voice wisely, conserving how much she talked in and out of class. She had children and a husband so she was used to talking often and sometimes loudly at home. I encouraged her to use the amplification system at home also. For a woman who enjoyed talking and talked so much of the day, reducing talking was challenging. For school, we explored how she could use more class discussion, use overhead projections of some of the material and slow her rate of talking so the students could adjust to the distortion of the information due to her hoarseness.

We discussed how she could reduce talking at home using similar techniques with her family. Although she was committed to try all the suggestions, the actual use of the strategies proved to be difficult. She would begin talking before she turned on the amplification or before trying the alternative methods of communicating. Of course, these alternative methods were slower, required cooperation from her listeners and demanded vigilance for use. Frustrating!

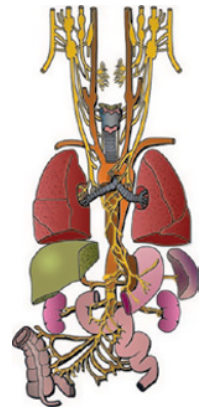
We kept in touch over the course of the next four months. She had managed to implement some of the strategies; her family and students were adjusting to her hoarseness and she was not as fatigued at the end of the day. Unfortunately, there had been no change in her voice over the months. Although I was glad she had some success with the suggested strategies, I was concerned that she would not regain recovery of the right vocal fold. Finally, it was clear that her right vocal fold was to remain in the paralyzed condition. Surgery to implant tissue into her right vocal fold making it easier to achieve closure and have good voice quality and volume was suggested by her physicians. My colleague thought that when this procedure was done, she would then return to her normal voice and daily life. She was excited about regaining her voice.

For most of us, our voice is unique to us because people often recognize us on the phone when we just say hello. Our voice is part of our identity and any change in the quality can be annoying or even disturbing. When changes in the voice occur, people often report that they "do not sound like themselves." Such was the case with my colleague. She came to my office after she received the implant and asked me to listen to her voice. I did and reported to her it was clear with good volume. But she said, "It is not me!" She was frustrated and concerned that she did not sound like herself. Although her voice was clear, the implant changed her vocal fold thickness and vibratory pattern slightly, resulting in what she heard no longer sounding like her own voice to her. Her observations were frustrating for both of us because there was little

I could do to improve how she perceived her new voice. People hear their own voices not only through their ears but also through the skull bones, which makes our voices sound different to us than what others hear. Often people respond to their voice hearing it the first time on a recording, as "Is that me?" It would take my colleague some time to adjust and, one would hope, accept what she heard in her own head as her voice. Others, including her family and students did not seem to notice that her repaired voice was not like what she remembered it to be. For her though, her voice was different. In time, she did come to accept her new voice, or perhaps simply became accustomed to the new sound as her own. Cases like these keep me humble and remind me of the challenges and limitations we have when assisting others and helping them find and accept their "new normal." All of these life changes occurred as a result of an injury to one small branch of the Xth cranial nerve, the recurrent laryngeal nerve.

Lucille Hess, Ph.D., CCC-SLP
Department of Communication Sciences and Disorders
Indiana-Purdue University-FW
Fort Wayne, Indiana, USA

CRANIAL NERVE X: VEXING VOCALS



In my experience as a physician, there are two types of conversations that are very difficult to have with patients. The first type is when they have cancer and the second is when they have very real symptoms but there is absolutely, positively, nothing wrong with them physically. Treating an ostensibly "phantom condition" is challenging as it mimics symptoms of more serious conditions. This makes it all the more difficult for a patient to find confidence in the doctor's assertion that everything is, in fact, "normal." Making such an assertion is both a difficult and delicate endeavor, for it requires both the acknowledgement and negation of a perceived problem on the part of the patient.

Having these patients walk out of the exam room in about 10–15 min, completely cured of a problem that they may have had for weeks, months, or occasionally years, is as satisfying as any surgery. The satisfaction is derived from the fact that the cure occurs not from drugs or surgery; it occurs after gaining the trust of the patient and persuading them to adopt alternate behavior – a true "laying on of the hands."

In this discussion, I will expound upon two conditions that lead to the curious "phantom symptoms" I have just described: functional dysphonia and paradoxical vocal cord dysfunction (PVCD or VCD). Both of these conditions are aberrations of the function of cranial nerve X, the vagus nerve. A branch of this nerve, the recurrent laryngeal nerve, innervates the muscles that control the vocal cords and hence produce speech.

In order for vocal cords to produce a sound, they have to adduct, or approximate with each other. In functional dysphonia, the patient will not approximate the cords completely. The resulting gap between the cords creates a hoarse, breathy voice or, in an extreme situation, no voice at all. Individuals are typically anxious or highly somatic (body oriented) individuals. Some may be facing very stressful situations in their lives and their hoarseness is a form of conversion disorder, to use a psychological term – they simply cannot or will not "give voice" to their troubles.

To treat the physical symptoms of functional dysphonia, doctors and speech pathologists work on building a consistent voice once the patient has shown he or she has the physiological ability to speak. Rediscovering the voice may start with throat clearing, then a simple hum, and then extend to vocalization. At all points, the patient is cheered on and encouraged every time they produce normal vocalization. Usually, normal voice can be produced within 5–10 min. There are some in whom the condition is difficult to break – this may require more intensive speech therapy or addressing the psychological issues at play in the dysphonia.

In paradoxical vocal cord dysfunction (PVCD or VCD), the patient presents with the opposite vocal cord mobility problem; they fail to abduct, or bring apart, the cords while breathing. Breathing against closed or nearly closed cords causes a loud crowing noise, or stridor, along with obvious shortness of breath. This condition typically occurs in patients with anxiety, either psychological or physiological. In the latter, the condition usually starts accidentally during the body's physiologic need for air during heavy exertion. It recurs during future exertions as patients think this is "normal" for them. In fact, in these cases, VCD is often misdiagnosed as asthma or exercise-induced asthma. Ultimately, VCD requires patients to stop their activity, which makes it especially vexing for athletes.

To treat VCD, the patient is informed that they have developed an unhelpful response to exertion with respect to their breathing that has now become habitual. A couple of useful techniques are to have the patient mimic the stridor that they exhibit during exertion and then have them sniff and follow that with deep nasal breathing. During a sniff, the vocal cords will reflexively abduct, or open, thus immediately resolving the stridor that is brought on by adducting the cords. Another strategy is to push the tip of the tongue against

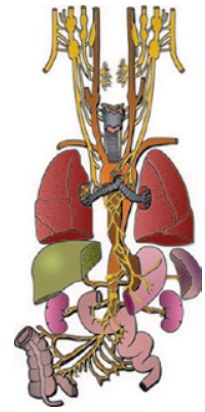
the front teeth and breathe through the mouth. The patient is at once surprised and relieved that a chronic breathing problem is able to be instantly resolved. They are encouraged to practice the techniques so that they are calm and confident when faced with this issue in the future.

The path to curing either functional dysphonia or VCD must be tread very delicately because the patient has seen many specialists without help. They may be clinging to the various erroneous diagnoses they have acquired or there may be family dynamics at play. In one instance, an individual presented with a sudden onset of hoarseness. Although his exam was normal, in private questioning it was revealed that he was dealing with the difficulties of acknowledging his homosexuality to his very conservative parents. In this case, as in others like it, speech therapy is required to correct the physical inability to produce sound; however, if the patient does not understand the psychological underpinnings of the condition, he or she will not have sustained improvement.

These conditions reveal that the vagus nerve is somehow linked to our emotional (limbic) brain. Though the anatomical connections that underlie this linkage are beyond my expertise, my clinical experience with patients has made it clear to me that you cannot treat cranial nerve disorders without being aware of how often dysfunction in these nerves can be related to the emotional condition of the patient; it can be interpreted as the vagus nerve's "cry for help."

Mohan K. Rao, M.D.
Ear, Nose, & Throat Associates, P.C.
Fort Wayne, Indiana, USA

CRANIAL NERVE X: VAGOTOMY – FOND MEMORIES OF AN OBSOLETE OPERATION



For many years I thoroughly enjoyed, and considered myself expert at, operations that involved deliberately cutting the vagus nerves. At the same point

in my career as a general surgeon, I was equally adept at other operations (such as thyroid and parathyroid surgery) in which preservation of branches of the vagus nerve were of utmost importance. Perhaps it was the deliberate care we always took to preserve the vagus and its branches in the neck that contributed to the sheer pleasure of cutting the vagus nerves in the abdomen. Let me explain.

The vagus nerve is responsible for the so-called cephalic phase of gastric acid secretion. The sight, smell, or even the thought of food causes the parietal cells of the gastric mucosa to secrete acid in anticipation of food on the way. Gastric acid hypersecretion is one of the factors implicated in ulcer formation. For many years, before *Helicobacter pylori* bacterium was demonstrated to be the cause of stomach and duodenal ulcers (peptic ulcers), antacids and H2-blocking drugs such as cimetidine were the only ways to treat peptic ulcers or prevent recurrence. When these methods failed, or when emergency surgery was needed for complications of ulcer disease, we surgeons deliberately cut the vagus nerves in the abdomen to abolish the cephalic phase of gastric secretion.

The first such operation was truncal vagotomy. To perform a truncal vagotomy, one incised the peritoneum (lining) over the junction between the esophagus and stomach and mobilized the esophagus from the surrounding tissues. The esophagus felt a bit like a limp cylinder of flesh, perhaps the diameter of my thumb. It was normally collapsed and, in order to make it easier to feel, it was routine to have a nasogastric tube in place. One held the mobilized esophagus with gentle but firm tension, with the index finger of the nondominant hand behind the "goose" (surgeon slang for esophagus) and the thumb helping to maintain traction on the stomach. The vagal trunks (an anterior and a posterior one) were not as mobile as the "goose" and were then palpable like taut banjo strings against the flesh of the esophagus. Often, the anterior trunk was visible as a satiny white cord with a tiny blood vessel running along its surface. We placed the tip of a long right-angle clamp under the vagal trunk (usually the anterior one first), elevated it off the "goose" (taking good care not to dig into the esophagus and cause a perforation), and then cut it.

Myelinated nerve tissue cuts with a distinctive crunch that is felt through the tip of the scissors if one trains one's fingers to be alert for it. Blood vessels or muscle fibers do not crunch when cut. Nonetheless, we generally placed a hemostatic clip about 1 cm long on each side of a section of vagus and removed that piece. We always sent the cut nerve to pathology to confirm that the nerve had indeed been cut (inexperienced surgeons had been known to mistake blood vessels or other non-nerve tissue for vagal fibers).

Having found the anterior vagus, we rotated the "goose" and sought the posterior trunk. That was always more difficult to find, and sometimes it had separated from the esophagus and was to be found in the tissue in front of the aorta. We similarly cut and sent this trunk to the pathology laboratory.

Then the hunt for additional fibers began. Each suspected fiber was cut and sent to pathology; it was not uncommon for the pathologist to receive, in

addition to an anterior and posterior vagal trunks, a "Vagus #3" or even "Vagus #4" specimen. I believe that I once sent six specimens of possible nerve tissue.

The vagus nerve, once cut, does not grow back. Although most patients responded favorably to such aggressive treatment, the surgery was not without complications and sometimes generated problems of its own. In the abdomen, the vagus nerve is responsible for more than just gastric secretion. The branch of the vagus to the liver, for example, innervates part of the ducts from the liver, and patients who have had a truncal vagotomy, such as I described, became more prone to gallstones. Terminal fibers of the vagus – we surgeons call these the "crow's foot" or terminal branches of the nerves of Laterjet – are also important for normal gastric emptying. Patients would often complain of feeling full for long periods of time following a meal and this often times led to a second surgery to open up the duodenum to ameliorate this condition. Finally, truncal vagotomy also altered small bowel motility that usually manifested as diarrhea.

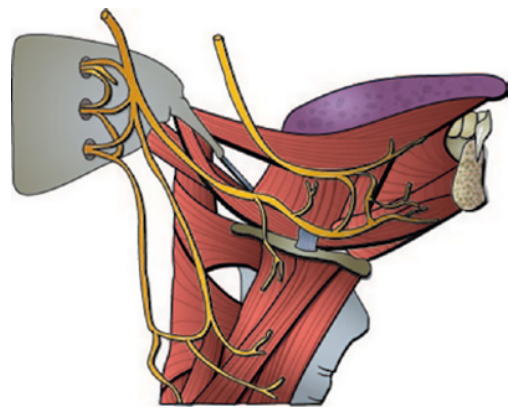
Later, more selective forms of vagotomy were developed in the hope of cutting just those fibers that were responsible for gastric hypersecretion while leaving intact the branches to the more distal parts of the gastrointestinal tract.

With more selective surgery came a higher failure rate, unless a meticulous search was made for extra fibers (including the so-called "criminal nerve of Grassi") that hug the distal esophagus.

In time, better treatments for peptic ulcer disease were developed and the sensuous pleasure associated with finding and deliberately cutting (!) branches of a major cranial nerve passed into surgical history.

Carol E.H. Scott-Conner, M.D., Ph.D.
Department of Surgery
University of Iowa Carver College of Medicine
Iowa City, Iowa, USA

CRANIAL NERVE XII: SOMETIMES THE BAD NEWS IS REALLY BAD



As described in the earlier chapters of this book, the tongue is innervated by four cranial nerves, V, VII, IX, and XII. (The vagus may innervate taste buds in the epiglottis, but the epiglottis is neither the tongue nor the mouth. Thus, as an academic who studies the tongue, I specifically exclude the vagus when I discuss the tongue.) No other single organ in the body has such a complicated innervation pattern. Below I describe clinical sequelae that an individual is likely to encounter following the diagnosis of cancer of the tongue. It will show how difficult it is at times to differentiate hypoglossal nerve damage from loss of movement of the tongue remnant following surgery for cancer of the tongue. Clinically, they are often very interrelated. Yet, the patient's limitations are generally due much more to absence of much of the tongue rather than to damage to the hypoglossal nerve fibers responsible for tongue movements.

H.G. is a 74-year-old attorney specializing in commercial real estate who smoked cigarettes since the age of 15. For the past 50 years or so, he smoked about half a pack daily. As an adult, he smoked an occasional cigar, generally with clients. Furthermore, for many decades, he often had an alcoholic drink with lunch, and one or two more "to relax" when he returned home. (Whereas H.G. may think he is accurately describing his tobacco and alcohol exposure as he "remembers" it, many, perhaps most, patients routinely underreport these to their physicians. This combination of chronic, extensive use of tobacco and alcohol frequently predisposes a person to cancer in various sites in the mouth and throat.) Last year, Mr. G noticed progressive difficulty articulating when speaking. Consequently, he went to his physician who noticed a mass about 1.5 cm in diameter on the upper surface of the tongue, toward the rear. Because of this observation, his physician referred him to an otolaryngologist who biopsied the mass. The pathologist examined it under the microscope and found it to be epidermoid carcinoma, a lesion that is usually unresponsive to radiation or chemotherapy.

On entering the hospital, an oral surgeon examined him. The midline mass felt very hard. Mr. G was informed that his condition was serious and was told details of the operative procedure. Unfortunately, removing just the local midline area was not the optimal procedure. To improve the chances of his survival, most of the tongue (front part) was removed. The incision began several millimeters behind the lesion. Because the mass was in the midline, it was not sufficient to remove just one side of the tongue. A more extensive procedure was employed to impede lymphatic drainage of the site, thereby lessening the chance of metastatic spread to the deep cervical lymph nodes. Of course, this removal transected many of the fine nerve branches from the trunks of the cranial nerves that provide the tongue with *movement* and *sensations*.

Postoperatively, Mr. G tolerated the procedure well. However, he was extremely upset by his new limitations. Psychiatric consultation was provided in the hope of calming his reactions to the surgery.

Preoperatively, no matter how much a patient tries to intellectually accept what may occur, after the surgery the great anatomical and functional defects are often too much to bear. Mr. G immediately noted that his speech was horrible. He was unable to articulate the linguo-dental and linguo-palatal

consonants, sounds provided by "d," soft "g," "j," "n," "t," and "z". In one sense, Mr. G was fortunate. Had his lesion been further back on his tongue, necessitating greater removal of its base, his tongue would have been totally unable to rise up toward his soft palate.

The aforementioned loss is the result of physically having the tip of the tongue removed; the tip helps make these sounds by pressing against the back of the teeth or palate.

Much less common in surgery of the tongue for cancer is the complete loss of the hypoglossal nerve, because the nerve enters the rear of the tongue from its inferior aspect where it joins the floor of the mouth. This site is termed the base of the tongue. Nevertheless, the partial glossectomy done for Mr. G does damage the microscopic branches of CN XII that in turn will lead to a profound effect on the intrinsic muscles of the tongue, with ensuing clinical complications besides his speech problems. That is, while the extrinsic muscles move the entire tongue the intrinsic muscles that begin and end within the tongue allow the organ itself to curl and/or twist, the movement used, for example, when trying to dislodge some food from between the back teeth. This is what Mr. G was also encountering following the surgery.

Because Mr. G's tongue remnant was no longer able to sweep over most surfaces of the teeth to remove food particles from them, his oral hygiene became impaired, predisposing Mr. G to dental caries. He was advised to be extremely conscientious in using a toothbrush after every meal and flossing before bedtime. Nonetheless, because of his now much smaller tongue, food particles often became trapped in the gum margins adjacent to the teeth. Bacterial growth set in and infection of the gum (gingivitis) was the result. (If gingivitis is not checked it can rapidly progress to loss of the surrounding bone and loosening of the teeth. These are characteristics of periodontitis, the greatest cause of tooth loss in adults.) The gingivitis caused Mr. G significant discomfort. The pain was conveyed by fibers in the mandibular branch of the trigeminal nerve (CN V) that supplies sensations, not only of pain but also of touch, texture, and temperature from the lower part of the oral mucosa, including the tongue. Although most of the anterior two-thirds of his tongue had been removed, any remaining sensory endings of the lingual nerve branch of the mandibular division of CN V, and particularly the lingual branches of CN IX, could frequently lead to Mr. G's awareness of his remnant. He would sometimes complain that food touching it would be painful, minimizing his enjoyment of food.

Several months after surgery, pneumonia developed, probably due to aspiration of food particles and oral bacteria. Mr. G soon discovered that he was unable to swallow medications in tablet or capsule form because his tongue remnant was unable to flip them rearward toward the pharynx. However, he was able to take liquid and injectable medications and to breathe in the vapor from a humidifier.

Around this time, Mr. G became aware of an additional problem when his wife cut a watermelon. He would have enjoyed it more had he been able to expectorate the seeds. Since then he or she also had to remove the seeds from

cantaloupe and to slice cherries and remove the pits before he ate them. This is not only an inconvenience, but also loss of a protective mechanism that is used to expel food from our mouths when we ingest irritating ingredients. The mechanism by which we spit out a seed, or hot or physically irritating food requires three cranial nerves: (1) CN V, which is responsible for jaw movements and general sensation of the oral tissues, and also dental pain if tooth decay is present; (2) CN VII, which separates the lips; and (3) CN XII, which moves the tongue. As the latter is but a remnant, Mr. G is unable to propel unpalatable food forward through his open mouth. Consequently, if what he eats scratches his mouth, is unusually brittle or hard, or if soup or other food such as pizza is excessively hot, rather than rapidly expectorating the mouthful into his napkin, Mr. G. must tilt his head down to allow the food item to drop out of his open mouth to avoid damaging the oral mucosa that lines his mouth. This obvious movement is embarrassing for him to do and keeps him from enjoying going out with friends.

The surgery of the tongue also impacted Mr. G's life in other unforeseen ways that he did not consider following his initial diagnosis. Decades ago when Mr. G was a teenager he played the trumpet and took pride in his ability when necessary to do "triple-tonguing" to fully demonstrate his mastery of the instrument. This took much practice to learn and clearly involved the hypoglossal nerve to move his tongue rapidly and repeatedly against the mouthpiece. As an adult, he occasionally played for his own enjoyment. Now, lacking the tip of his tongue he realizes that that is no longer possible. Perhaps he will channel his musical talents into playing some other instrument. He has not yet decided whether he wants to attempt this at all, and it saddens him that life is forever changed.

One final note on how the surgery on his tongue (and thus the severing of cranial nerves) has diminished many pleasures that Mr. G once took for granted. The surface of the normal tongue has four types of projections termed papillae: filiform, fungiform, foliate, and circumvallate, all but the first of these having taste buds providing taste sensations mediated by the chorda tympani branch of the facial nerve (CN VII) or by the glossopharyngeal nerve (CN IX). The fungiform papillae are especially important because they are concentrated in the tip of the tongue. They provide gustatory information, particularly when potential food is licked, thereby appraising its palatability. It is difficult to convey to someone how life altering it is to lose the tip of one's tongue with respect to the enjoyment of food.

Try this experiment on yourself now: close your eyes, stick your tongue out, have someone place a small amount of ice cream on top of the middle of your tongue, and then try and swallow it without ever letting it touch the tip of your tongue. It is still ice cream, but the pleasure of first having the taste, temperature, and feel of the ice cream on the tip of your tongue is missing. It is also not a totally accurate experiment to try and sense what missing the tip of one's tongue actually feels like because it is natural to move the ice cream throughout the mouth and enjoy both its texture and taste. Carrying it deeper into the mouth warms the ice cream so that its original coldness is no longer as prominent. Nevertheless, it is a close approximation of what Mr. G now

feels when he tries to enjoy memories of his youth, licking a cold ice cream on a sunny afternoon.

The sensations from the tip of the tongue are also recognized as providing a valuable protective mechanism that allowed humans to survive as a species. Perhaps we may speculate that it is the reason that many children do not like to eat their vegetables. The initial contact with food by the tip of the tongue allows people of all ages to decide if they will enjoy it or not. It has been hypothesized that young children of our ancestors would spit out bitter tasting plants, etc.

Unfortunately for Mr. G, he no longer has the anterior part of his tongue. His remaining oral taste buds are in the palate and in the circumvallate papillae that occupy a wide "V" shape in the posterior dorsum of the tongue, the apex pointing rearward. In addition, the foliate papillae are at the sides of the tongue base near the floor of the mouth. They are innervated by the glossopharyngeal nerve (CN IX). They do receive taste sensation, but because of their location they are not immediately stimulated when food enters the mouth. Thus, Mr. G is left to exclaim longingly that overall appreciation of taste is not as intense as before surgery.

Mr. G hopes that somebody will soon invent a tongue-shaped prosthesis that can be attached to his lingual remnant so that he will be able to manipulate it easily for speech, swallowing, and oral hygiene. Ideally, this prosthesis would respond to his thoughts via his cranial nerves as is currently being done for some lower limb prostheses in soldiers. Realistically, Mr. G doubts that his ability to lick an ice cream cone will ever be restored.

Mr. G has learned to live with his limitations and in the hope of preventing a recurrence of his tongue cancer he stopped drinking alcohol and smoking. Limitations in other areas have become manifest. Regarding his law practice, although he prepares briefs on behalf of his clients he no longer appears personally in court, leaving that task to a fellow member of his firm. He is also unable to participate fully in religious services, being unable to sing the words of hymns and join in congregational responses and greetings of fellow congregants. Because of his speech and also because of not being able to dine without constant awareness of his mouth, his social life became confined to but a few very close friends and relatives, causing him great unhappiness.

One final note: of all the limitations resulting from damage or loss of a cranial nerve, those resulting from hypoglossal damage have perhaps the greatest effect on a patient's social life. They can no longer use the telephone or speak easily to anyone. A pen and paper are often required to communicate the simplest of ideas. Should Mr. G continue to drive and perhaps commit an infraction, the initial reaction by a policeman may be that Mr. G. was inebriated as he tried to converse with him. Fortunately, a breathalyzer would dispel that possibility.

Mortimer Lorber, D.M.D., M.D.
Department of Physiology and Biophysics
Georgetown University School of Medicine
Washington, DC, USA

REFERENCES

Adams CB (1989) Microvascular compression: an alternative view and hypothesis. *Journal of Neurosurgery* **70**: 1–12.

Benninger B, McNeil J (2010) Transitional nerve: a new and original classification of a peripheral nerve supported by the nature of the accessory nerve (CN XI). *Neurology Research International* **2010**: 1–15.

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