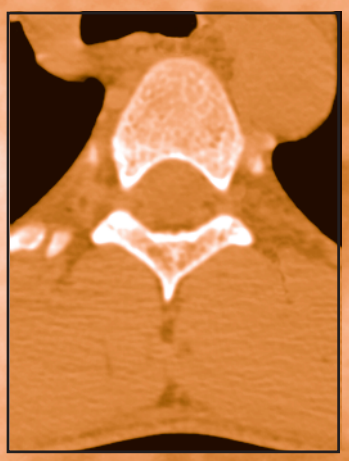
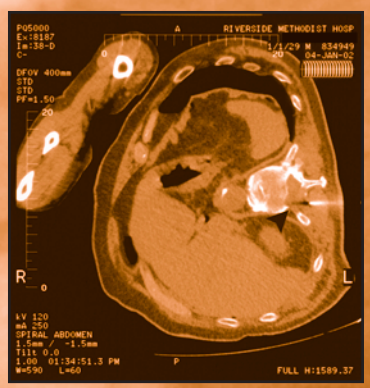
Interventional Radiology of the Spine

Image-Guided Pain Therapy

Edited by

J. Kevin McGraw, MD





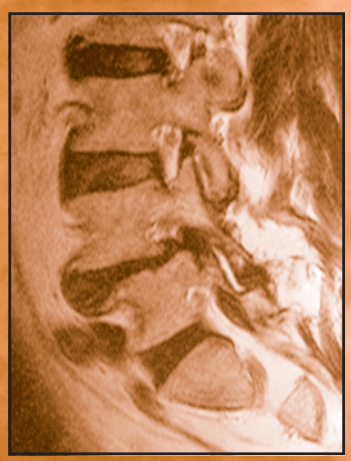


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Image-Guided Pain Therapy

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Dedication

To my parents,

James and *Christine McGraw*,

my wife *Lisa*,

and our sons *Reed* and *Ryan*.

Preface

The last century witnessed many changes in the practice of medicine. As we move into the 21st century, we will see more and more procedures performed with minimally invasive, image-guided techniques. At the forefront of this revolution is the specialty of interventional radiology. Interventional radiology traditionally involves the treatment of vascular disease, but has grown to include nonvascular intervention and, recently, the treatment of spinal disorders.

The objective of *Interventional Radiology of the Spine: Image-Guided Pain Therapy* is to provide the practicing interventional radiologist with a single source for evaluating and treating the patient with back pain. This includes discussion of interventional spinal procedures, spinal imaging, and the clinical evaluation of the spine patient. The practicing pain specialist will also find this work useful because radiological spinal imaging is included, a topic most pain management textbooks lack. Imaging has become an essential element in the evaluation of patients with back pain.

The book is divided into two sections: Part I: Spinal Anatomy, Imaging, and Clinical Evaluation; and Part II: Interventional Spinal Procedures. Topics in Part I include basic spinal anatomy, CT, MRI, and nuclear medicine of the spine, and the clinical evaluation of the spine patient. Topics in Part II include discussion of the history of spinal procedures, review of the pharmacology of medications used in injection procedures, selective nerve root blocks, epidural injections, facet injections, sacroiliac joint injections, discography, treatment of discogenic back pain, spinal biopsy techniques, percutaneous vertebroplasty, and transcatheter therapy for tumors of the spine.

The topics covered in this book should provide the reader with a useful, comprehensive, state-of-the-art reference on minimally invasive, image-guided spinal procedures, as well as a review of anatomy and imaging findings in spinal disorders. The hope is that *Interventional Radiology of the Spine: Image-Guided Pain Therapy* will allow more interventionalists to fully employ the skill and expertise that they possess to the evaluation and treatment of patients with back pain.

J. Kevin McGraw, MD

Acknowledgments

I would first like to acknowledge my parents. They instilled in me a strong work ethic and a desire to succeed. They provided me with the firm foundation on which my career has been built. My wife, Lisa, has been the cornerstone of my career. It was her love and support that allowed me to survive medical school, surgical internship, radiology residency, and interventional fellowship. Our sons, Reed and Ryan, have given me the true meaning for all of the years of hard work. I hope to make all of their dreams come true, as my parents did for me.

I also wish to thank my mentors. As a medical student, Dr. Stephen I. Schabel at the Medical University of South Carolina fostered my interest in diagnostic radiology through his wit and intellect. He told me about interventional radiology when my interests turned to the surgical subspecialties, but also encouraged me to do a surgical internship prior to my residency. Dr. Charles J. "Tunk" Tegtmeyer was the reason I attended the University of Virginia for radiology residency with the intent of doing an interventional fellowship under his tutelage. I was fortunate to have worked with him during residency until he met an untimely death during my fourth year. Had it not been for Dr. Alan H. Matsumoto, I doubt that my career would have been as rewarding and successful as it is today. He taught me the technical skills and expertise to perform minimally invasive procedures, but more importantly, he provided me with a strong clinical background in patient care. He emphasized that virtually anyone could be a technician and perform procedures, but it took a physician to provide clinical care for the patient.

I would also like to acknowledge the contributors to this book who have toiled numerous hours preparing their chapters. They have all done a remarkable job. I would also like to thank my group members in Riverside Radiology Associates for their unyielding support in my professional endeavors.

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I Spinal Anatomy, Imaging, and Clinical Evaluation

1 Spinal Anatomy

ROBERT M. DEPHILIP, PHD AND J. KEVIN MCGRAW, MD

INTRODUCTION

The human spine is a study in contrasts. It provides static support for the head and trunk, while providing a kinetic mechanism for flexible movement. Both of these functions are accomplished while providing essential protection for the enclosed spinal cord, spinal roots, and nerves. Accurate diagnosis of spinal disorders depends on a clear understanding of spinal anatomy, and interventional approaches to the spine will proceed with fewer complications if spinal anatomy is well understood.

This chapter highlights features of anatomy that permit the spine to function normally and that predispose the spine to certain disease processes. It draws attention to recent discoveries *(1)*, often made with modern imaging techniques, that have implications for therapeutic intervention.

SPINAL OSTEOLOGY

The structural unit of the spine is the vertebra. There are 33 vertebrae in the human spine: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal. The 5 sacral vertebrae are fused and form a composite bone, the sacrum, and the 4 coccygeal vertebrae are usually fused to form the coccyx. The sacrum and the coccyx may or may not be fused to each other (Fig. 1).

A TYPICAL VERTEBRA

A typical vertebra consists of a body and an arch. The body is classified as a long bone with a waistlike diaphysis, or shaft, situated between two ends, or epiphyses. The heights of the vertebral bodies increase from the cervical to the lumbar regions, reflecting the fact that the bodies carry the weight of the trunk, upper limbs, and head (Fig. 2).

Adjacent vertebral bodies in the cervical, thoracic, and lumbar regions articulate via intervertebral discs. An exception to this pattern occurs in the cervical spine. The C1 vertebra, the atlas, does not contain a body and articulates with the C2 vertebra, the axis, via bilateral synovial joints between the lateral masses of the atlas and the lateral masses of the axis.

INTERVERTEBRAL DISCS

The intervertebral discs consist of a centrally placed nucleus pulposus and a circumferentially arranged annulus fibrosis. Typically, descriptions of the vertebral bodies emphasize their weight-bearing function, but it should be emphasized that the union between vertebral bodies via the intervertebral discs gives the anterior segment of the spine a great deal of flexibility that is restricted primarily by the joints of the vertebral arch (Fig. 3).

THE VERTEBRAL ARCH

The vertebral arch consists of two pedicles, two laminae, and seven processes. The pedicles project posteriorly from the vertebral body and reach the laminae. There are three processes at the junction of the pedicle and its corresponding lamina. A transverse process projects laterally and acts as a lever and attachment point for intrinsic muscles of the back. A superior articular process projects superiorly and articulates with the inferior articular process of the vertebra above. Similarly, an inferior articular process projects inferiorly and articulates with the superior process of the vertebra below (Fig. 4). The pars interarticularis is the isthmus of bone between the superior and the inferior articular processes and is often the

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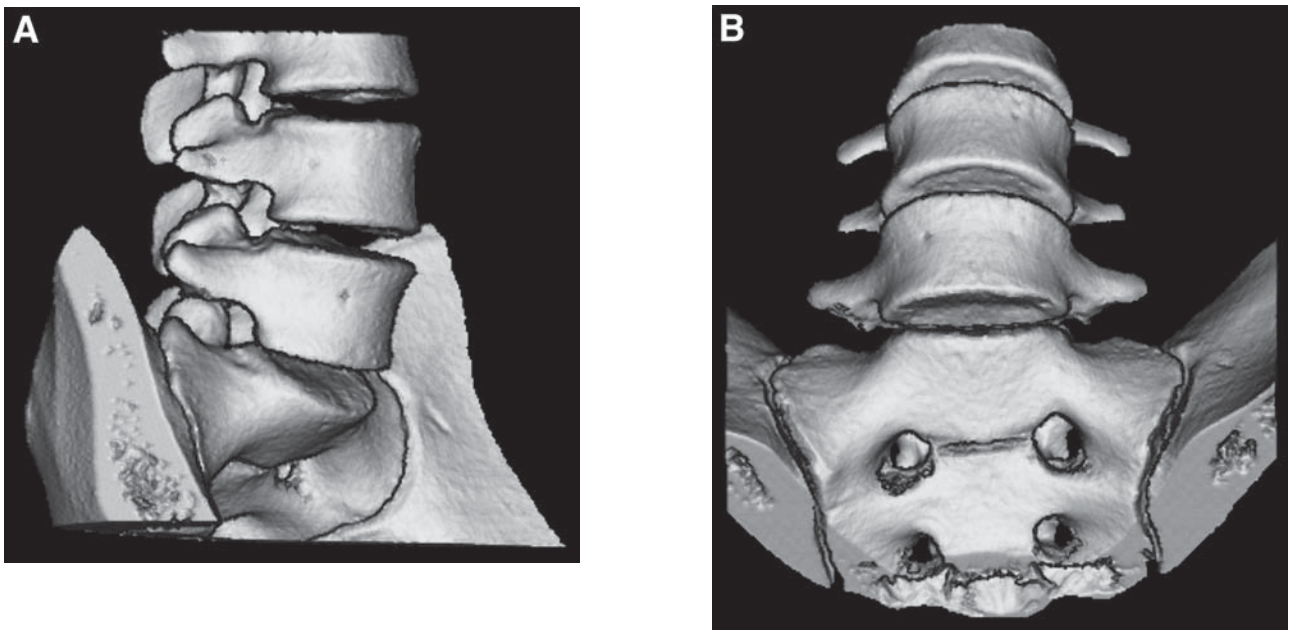


Fig. 1. **(A, B)** CT three-dimensional reconstruction of the lumbar spine and pelvis. (Courtesy of Philips Medical Systems, Bothell, WA)

site of fracture (spondylolysis) produced by stress or trauma. Bilateral fracture of the pars interarticularis allows a vertebral body to slip forward on the vertebra below, a slippage called spondylolisthesis and occurring most commonly at the L5–S1 junction. The laminae meet posteriorly in the midline at the spinous process. The continuous ring of bone formed by the posterior aspect of the vertebral body, the two pedicles, and the two laminae create the vertebral foramen. When the 33 vertebrae are in articulation, the superimposed vertebral foramina form the vertebral canal.

A lateral view of the vertebra reveals a shallow superior intervertebral notch above each pedicle and a deeper inferior articular notch below each pedicle. When two adjacent vertebrae articulate, the superior and inferior notches combine to form the intervertebral foramen (Fig. 5).

REGIONAL DIFFERENCES OF VERTEBRAE

Vertebrae in different regions of the spine have features that distinguish one from another. All cervical vertebrae are distinguished by foramina in their transverse processes that transmit the vertebral artery and associated sympathetic nerve plexus, and the vertebral vein. The spinous processes of C2–C7 are bifid and the transverse processes have anterior and posterior tubercles. The vertebral foramina are large to accommodate the large diameter of the cervical spinal cord and to permit extensive movement. The bodies of cervical vertebrae C3–C7 are longer in the lateral dimension than they are in the anterior–posterior dimension and the superior aspects are concave. This concavity is accentuated by lateral and posterolateral uncinate processes that articulate with a bevel on the body of the vertebra above. The first two cervical vertebrae are unique. The C1 vertebra is a ring of bone containing two lateral masses connected by anterior and posterior arches. The anterior arch displays a tubercle on its anterior aspect for attachment of the anterior longitudinal ligament and the longus capitis muscle. A facet on its posterior aspect articulates with the odontoid process of the axis. The posterior arch displays a posterior tubercle for muscle attachment and grooves on either side for the horizontal portion of the vertebral artery.

The distinguishing feature of the C2 vertebra is its odontoid process, or dens, which is the displaced body of the atlas. Each lateral mass of the axis has a superior articulating surface to receive the inferior articulating surface of the atlas, and an inferior articulating surface to meet the superior articulating process of C3. Its spinous process is large and bifid, being the attachment point for intrinsic muscles of the back, namely the semispinalis cervicis and the inferior oblique muscle of the suboccipital triangle. The spinous process of C7 is the first that can be palpated in the midline of the neck, earning the C7 vertebra the name vertebra prominens.

The bodies of thoracic vertebrae are heart shaped and the laminae are broad and flat. The thoracic spinous processes are long and slender and reach the level of the body of the vertebra below. The thoracic vertebrae have facets on their bodies for articulation with the heads of the ribs and facets on their transverse processes for articulation with the tubercles of the ribs.

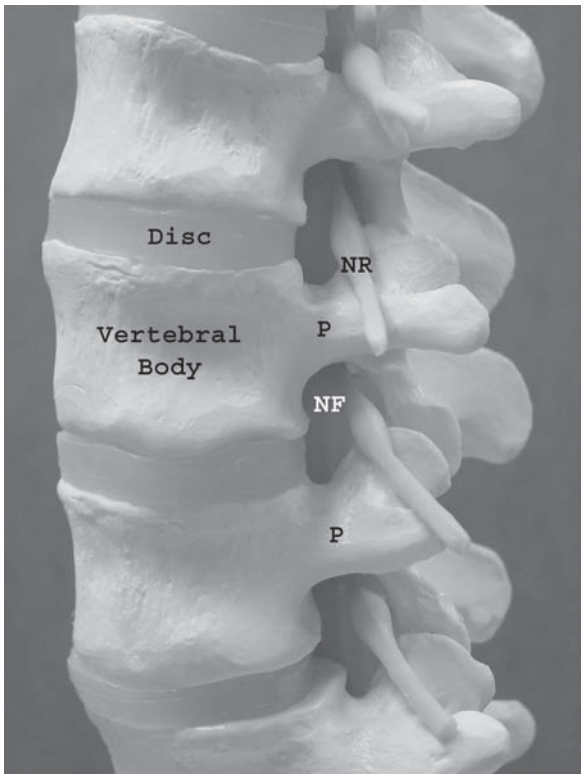


Fig. 2. Spine model showing the vertebral body and intervertebral disc. NF, Neural foramen; P, pedicle; NR, nerve root.

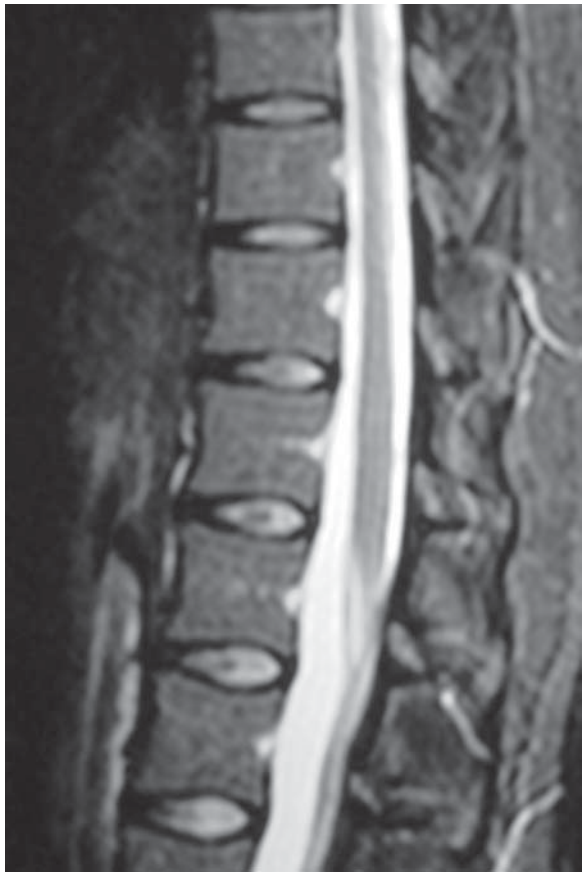


Fig. 3. T2-weighted sagittal MRI showing normal vertebral body signal and normal intervertebral discs.

The lumbar vertebrae lack both foramina in their transverse processes and facets for articulations with the ribs. The lumbar bodies are the largest in the spine and display transverse processes that are long and slender and spinous processes that are stocky and blunt.

SACRUM AND COCCYX

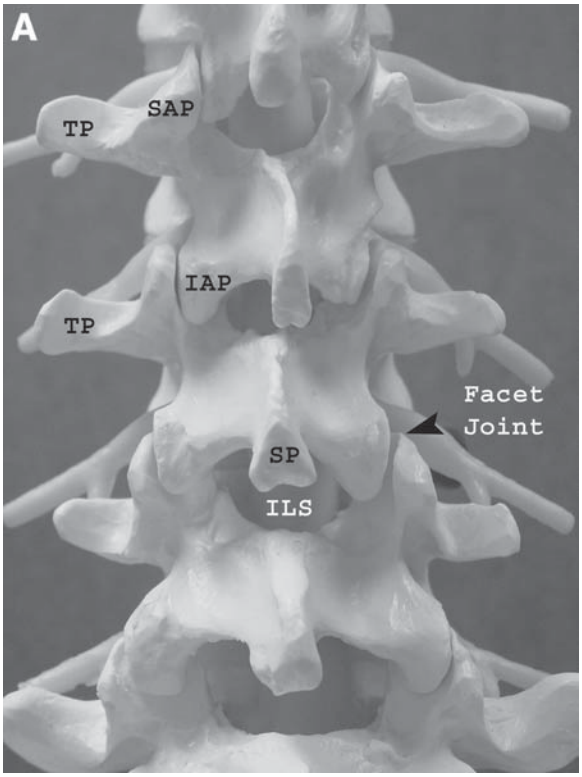
The sacrum is triangular shaped, with its base superior and its apex inferior. Viewed from in front, a median part is separated from two lateral parts by the anterior sacral foramina that transmit the anterior primary rami of spinal nerves. Horizontal ridges on the anterior aspect of the sacrum indicate the fusion sites of the once independent vertebrae. Posteriorly, the sacrum exhibits a midline crest and a median portion of bone separated from lateral parts by the posterior sacral foramina. The first sacral vertebra has superior articulating processes to receive the inferior articulating processes of L5. The sacral canal is the most inferior part of the vertebral canal and ends at the sacral hiatus. The coccyx is usually fused but may contain independent bones. The vertebral canal does not extend into the coccyx (Fig. 6).

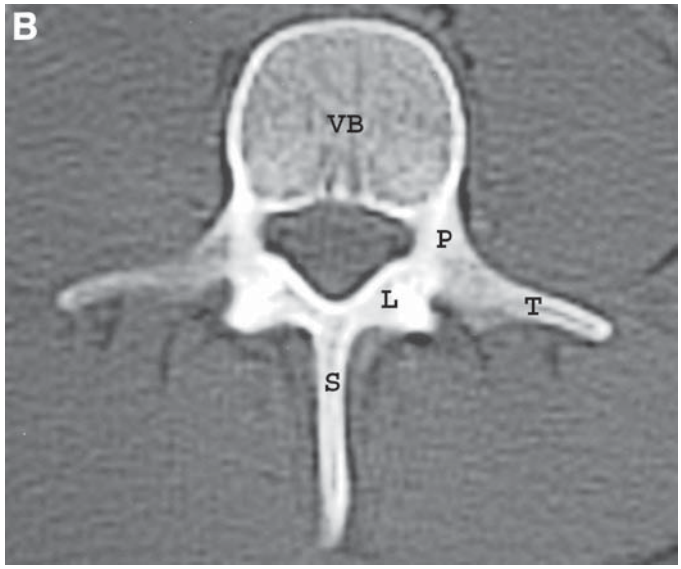
ARTICULATING PROCESSES AND SPINAL MOVEMENT

The orientation of the vertebral articulating processes determines the movements that are permitted in each region of the spine *(2)*. The articulating processes in the cervical region are oriented in nearly a coronal plane, and permit flexion/extension, rotation, and lateral bending. The articulating processes in the thoracic region are arranged on an arc that has its center in the vertebral body. Rotation and lateral bending are permitted. Flexion is prohibited both by the orientation of articulating processes and by attachment of the thoracic vertebrae to the rib cage. Articulating processes in the lumbar region are oriented in the sagittal plane, permitting flexion/extension and prohibiting rotation.

The anterior view of the articulated spine shows the consistent increase in size of the vertebral bodies from superior to inferior. The space between adjacent vertebrae is occupied by the intervertebral discs that collectively contribute approximately one fourth to the height of the spine. The uncovertebral joints are lateral and posterolateral between the C3–C7 vertebral bodies.

The posterior view of the spine demonstrates how the short transverse processes of the cervical vertebrae change dramatically at the C7–T1 junction to the large transverse processes of the thoracic type. The thoracic transverse processes gradually diminish in size from T1 to T12. The lumbar transverse processes are long and surprisingly





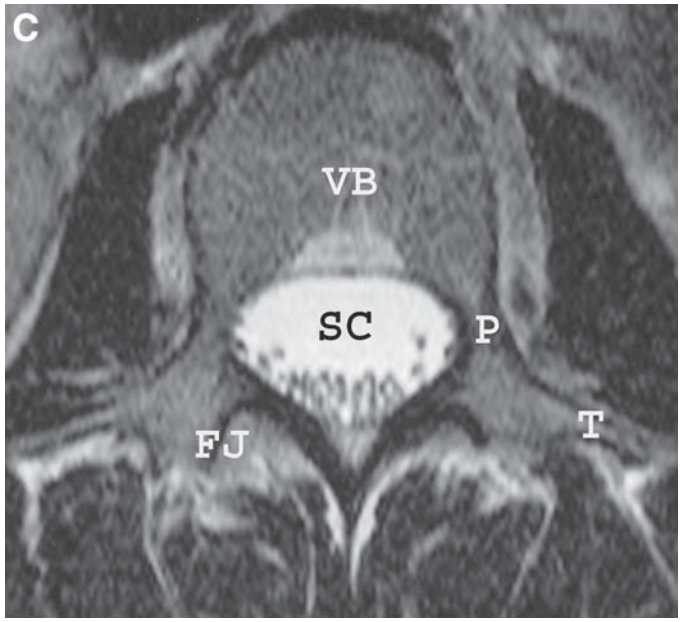


Fig. 4. **(A)** Posterior view of spine. SAP, Superior articular process; IAP, inferior articular process; TP, transverse process; SP, spinous process; ILS, interlaminar space. **(B)** Axial CT through a lumbar vertebral body. VB, Vertebral body; P, pedicle; T, transverse process; L, lamina; S, spinous process. **(C)** Axial T2 MRI through a lumbar vertebral body. VB, Vertebral body; P, pedicle; T, transverse process; FJ, facet joint; SC, spinal canal.

slender and provide attachment points for both flexor and extensor muscle groups. The change is appearance of the spinous processes is dramatic. The bifid spines of cervical vertebrae evolve to the long and sloping spines of thoracic vertebrae. The lumbar spinous processes are flat and blunt. The change in the interlaminal space is also dramatic. The cervical vertebrae are closely packed and have a small interlaminal space. The short intervertebral discs and the downward sloping spines in the thoracic region make the interlaminal space here small. The interlaminal space in the lumbar region is wide and is the optimal site for obtaining spinal fluid and for delivering anesthetics. The termination of the vertebral canal at the sacral hiatus is seen posteriorly.

The fetal spine exhibits a primary kyphotic curvature that is retained in neonates and infants. Secondary lordotic curves develop in the cervical and lumbar regions to support the weight of the head and the erect position of the trunk, respectively. The lateral view of the adult spine demonstrates how the normal curvatures change between adjacent regions. The cervical and lumbar curvatures are concave posteriorly, and the thoracic and sacrococcygeal curvatures are concave anteriorly. Vollmer and Banister observe that the thoracic kyphosis is due to a slight wedging of the vertebrae, with the intervertebral discs being of relatively uniform thickness, and that the cervical and lumbar lordoses are due primarily to the discs having a slightly wedged configuration. One consequence of these arrangements is that pathological changes in thoracic curvature are more likely the result of changes in bone structure, while changes in cervical and lumbar curvatures are more likely due to degenerative changes in the discs *(3)*. Posture has been defined as the position of the erect and static spine and is related to a vertical line of

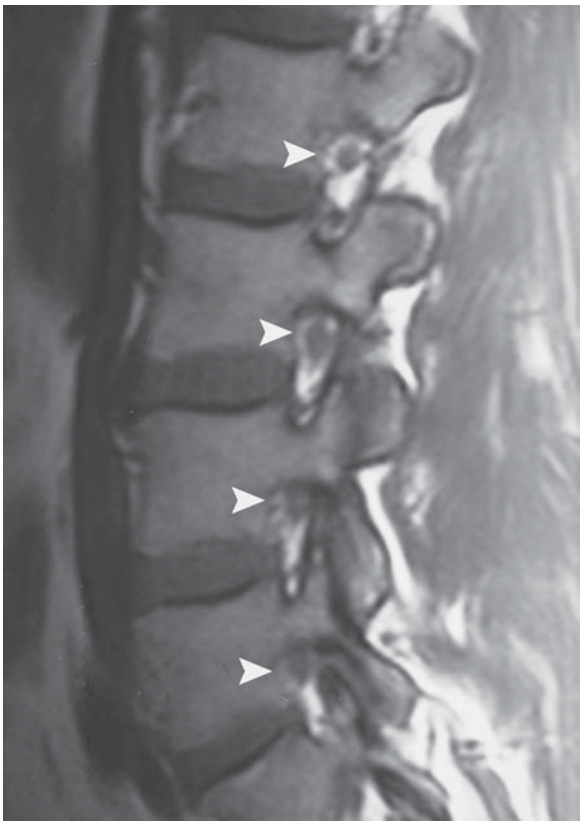


Fig. 5. Sagittal T1 MRI showing the relationship of the nerve roots in the intervertebral foramen.

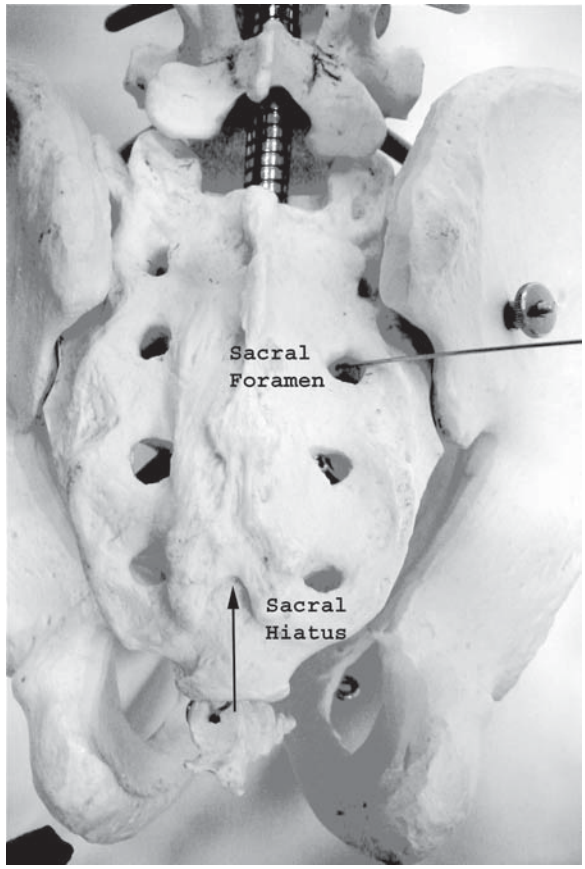


Fig. 6. Model of sacrum showing sacral foramen and sacral hiatus. (Courtesy of Dennis J. Griffin, MD)

gravity. In good posture, the line of gravity passes through the odontoid process, posterior to the bodies of the upper cervical vertebrae, through the center of the C7 vertebra, anterior to the thoracic spine, and through the posterosuperior aspect of the S1 endplate. Deviation of the spine from these relationships with the line of gravity indicates imbalance and can produce pain, muscle fatigue, and gait disturbance *(3)*.

A central concept governing diagnosis and treatment of spinal pathology is that the vertebral canal and the intervertebral foramen are inexpansible. Any encroachment on these spaces, by arthritis, tumor, misalignment, or infection can exert pressure on nervous elements with different degrees of consequence, from paresthesia to paralysis. Furthermore, the site of the symptoms can be far removed from the site of encroachment because of the arrangement of the nerve elements in these spaces and the peripheral distribution of the nerves (Fig. 7).

JOINTS OF THE SPINE

THE CRANIOVERTEBRAL JOINTS

The spine articulates with the skull at the atlantooccipital joint, where the superior surfaces of the lateral masses of the atlas meet the occipital condyles of the skull in a synovial joint. The atlantooccipital joint has the characteristic features of a synovial joint: (1) articulating surfaces covered with hyaline cartilage, (2) a joint space lined with synovial membrane and lubricated with synovial fluid, and (3) a fibrous capsule. Approximately 10° of flexion and 25° of extension are permitted at the atlantooccipital joint *(4)*. In rotation and lateral flexion, the atlas and the skull move as one piece on the axis.

The greatest range of movement in the entire spine occurs as rotation between the atlas and the axis at the atlantoaxial joint. The approximately 70° of rotation permitted at the atlantoaxial joint account for about half of the rotation of the head and atlas on the spine. The remaining half of head rotation occurs between C2 and C7. Four synovial joints accomplish rotation at the atlantoaxial joint. On each side, the inferior articulating surface of the lateral mass of the atlas meets the superior articulating surface of the axis. Because the inferior surface of the atlas is flat and the superior surface of the axis is convex, the atlantoaxial joint permits some flexion (~5°) and some extension (~10°) in addition to rotation. The fibrous capsules of these lateral joints are loose to accommodate wide range of motion. The remaining two synovial joints of the

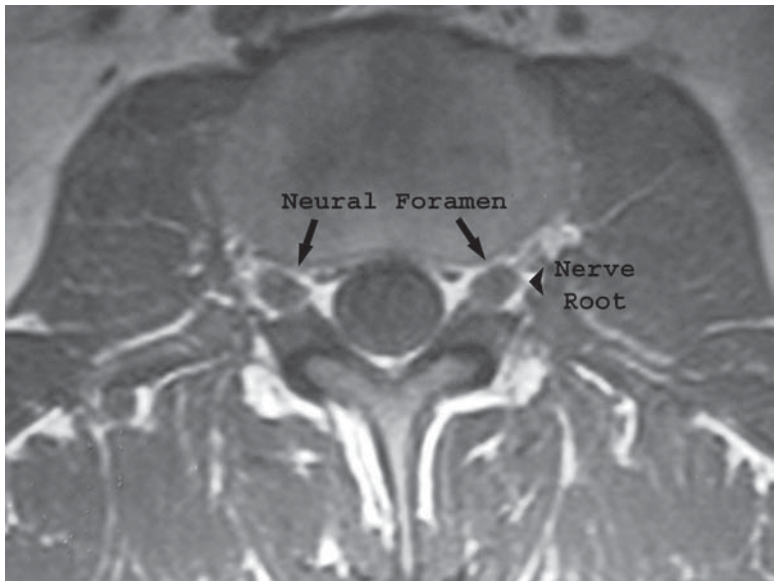


Fig. 7. Axial T1 MRI showing the intervertebral (neural) foramen and nerve roots. It is easy to appreciate how a disc herniation can compress the exiting nerve root as it passes through the narrow confines of the intervertebral (neural) foramen.

atlantoaxial complex lie in the midline. The anterior aspect of the odontoid process articulates with a facet on the posterior aspect of the anterior arch of the atlas. The odontoid is held in place by the transverse ligament of the atlas, and a synovial joint exists here between the posterior aspect of the odontoid and the fibrocartilaginous portion of the transverse ligament. The transverse ligament plays a critical role in holding the odontoid in place and rupture of this ligament has the same effect on stability of the atlantoaxial complex as does fracture of the odontoid process. A superior extension of the transverse ligament connects it to the anterior edge of the foramen magnum, and an inferior extension connects the ligament to the back of the axis. The right and left arms of the transverse ligament and its superior and inferior extensions form the cruciate ligament. The alar ligaments are short, stout, and strong cords that lie anterior to the cruciate ligament and attach the sides of the odontoid process to the medial aspects of the occipital condyles. The alar ligaments help prevent excessive rotation of the head. Finally, the apical dental ligament connects the apex of the odontoid to the anterior margin of the foramen magnum. The apical dental ligament provides little stability and is thought to be a vestige of the notocord.

Two membranes anteriorly and two posteriorly bridge the spaces between the skull, atlas, and the axis. The anterior atlantooccipital membrane connects the upper border of the anterior arch of the atlas with the anterior margin of the foramen magnum. Laterally, this membrane is continuous with the joint capsules of the atlantooccipital joints. The anterior atlantoaxial membrane is strong and connects the anterior arch of the atlas to the front of the body of the axis, between the lateral joints. It is reinforced by the anterior longitudinal ligament.

The posterior atlantooccipital membrane connects the upper border of the posterior arch of the atlas with the posterior margin of the foramen magnum. It reaches the joint capsules of the atlantooccipital joints laterally. The vertebral artery enters the vertebral canal and subarachnoid space through the inferior and lateral aspects of the posterior atlantooccipital membrane. The posterior atlantoaxial membrane is a broad, thin membrane connecting the posterior arch of the atlas with the vertebral arch of the axis. It is in line with the ligamenta flava.

JOINTS BETWEEN VERTEBRAL BODIES

Intervertebral discs join all the adjacent vertebral bodies between C2 and the sacrum. The outer portion of the articular surface of the bodies is a rim of epiphyseal bone, while the central portion of the articular surface is lined with hyaline cartilage. Each intervertebral disc consists of a fibrocartilaginous rim, the annulus fibrosis, and a centrally placed mass of gelatinous material, the nucleus pulposus (Fig. 8). The external fibers of the disc crisscross as they pass from the epiphyseal rim of one body to the next. The criss-crossing pattern of the fibers permits some anterior and posterior displacement and some rotation between one vertebra and the next. All but the most peripheral part of the perimeter of the discs is avascular, and exchange of nutrients and metabolic wastes occurs through the articular hyaline cartilage into the cancellous bone of the vertebral bodies. There is a great deal of interest in determining how nutrition of the intervertebral discs is accomplished, and techniques in magnetic imaging have

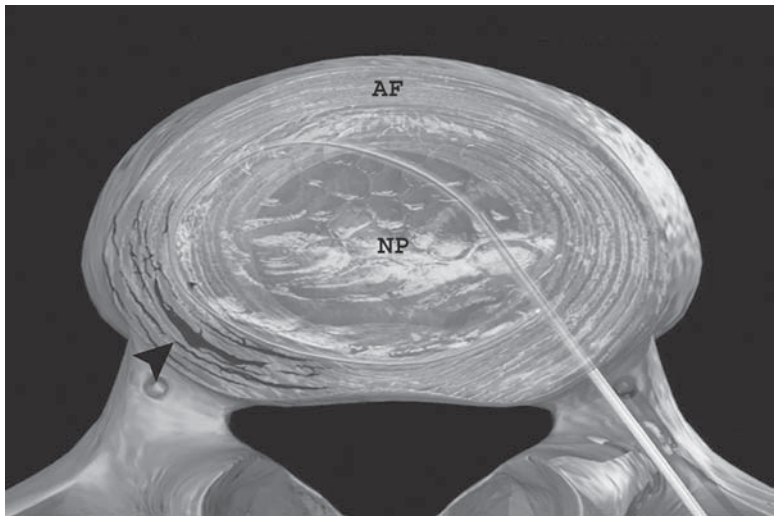


Fig. 8. Diagram of an intradiscal electrothermal therapy (IDET) catheter in a disc. NP, Nucleus pulposus; AF, annulus fibrosis. The *arrowhead* shows an annular tear. (Courtesy of Smith and Nephew, Menlo Park, CA)

been developed to study this process. Using a combination of multiple administration of contrast medium, delayed timing of scanning, and a highly sensitive T1-weighted sequence, it has been possible to visualize solute transport into and within the intervertebral disc *(5)*.

Mercer and Bogduk have described an important difference between the cervical and lumbar annulus fibrosis *(6)*. The cervical annulus fibrosis does not consist of concentric laminae of collagen fibers as it does in the lumbar region. Instead, the cervical annulus forms a thick, crescentic mass of fibers anteriorly that taper laterally toward the uncinate process. The cervical annulus is essentially deficient posterolaterally and is represented posteriorly by only a thin layer of vertically oriented fibers. These findings have implications for understanding cervical disc function, imaging, and pathology.

In the static state, the anterior and posterior longitudinal ligaments reinforce the union of adjacent vertebral bodies and support the intervertebral discs. In the dynamic state, the anterior longitudinal ligament helps prevent hyperextension and the posterior longitudinal ligament helps prevent hyperflexion. The anterior longitudinal ligament is a broad, flat band that extends from the anterior tubercle of the atlas to the pelvic surface of the sacrum. The anterior ligament has a superficial layer of fibers that are long and a deep layer of fibers that extend over only one or two vertebrae. The posterior longitudinal ligament is located within the vertebral canal on the posterior aspect of the vertebral bodies and intervertebral discs. Superiorly, as the tectorial membrane, the posterior longitudinal ligament covers the transverse ligament of the atlas and attaches to the occipital bone. In the thoracic and lumbar regions, the posterior ligament is broader over the intervertebral discs and narrower over the vertebral bodies, giving a serrated appearance to its lateral margins. Inferiorly, the posterior longitudinal ligament is attached within the sacral canal. The deficiency of the posterior longitudinal ligament over the posterolateral aspect of the lumbar intervertebral discs contributes to herniation of the nucleus pulposus in the lumbar region (Fig. 9).

JOINTS OF THE VERTEBRAL ARCH

The joints of the vertebral arch are the paired zygapophyseal joints between opposed superior and inferior articular processes (Greek *zygon*, yoke). They are sometimes referred to as apophyseal joints to indicate that they are outgrowths, or offshoots, of the arch (Greek *apophysis*, an offshoot). Clinically, they are the facet joints (Fig. 10). As synovial joints, they are subject to all of the degenerative changes associated with synovial joints, such as osteoarthritis. The fibrous capsules of the facet joints are sufficiently lax to allow movement of the spine, but they can be easily strained. The laxity of the capsule can allow its fibers to be pinched between the articular surfaces of the facet joint and produce pain. The joint capsules are innervated by twigs from the medial branches of the posterior primary rami of the spinal nerves (Fig. 11).

A series of accessory ligaments fill the gap posterior to the facet joints and between adjacent vertebral arches. The ligamenta flava are elastic ligaments attached to the anterior surface of the laminal arch above and to the posterior surface of the lamina below. The ligamentum flavum on each side meet in the midline posteriorly and are continuous with the interspinous ligament that connects adjacent spinous processes. The superspinous liga-

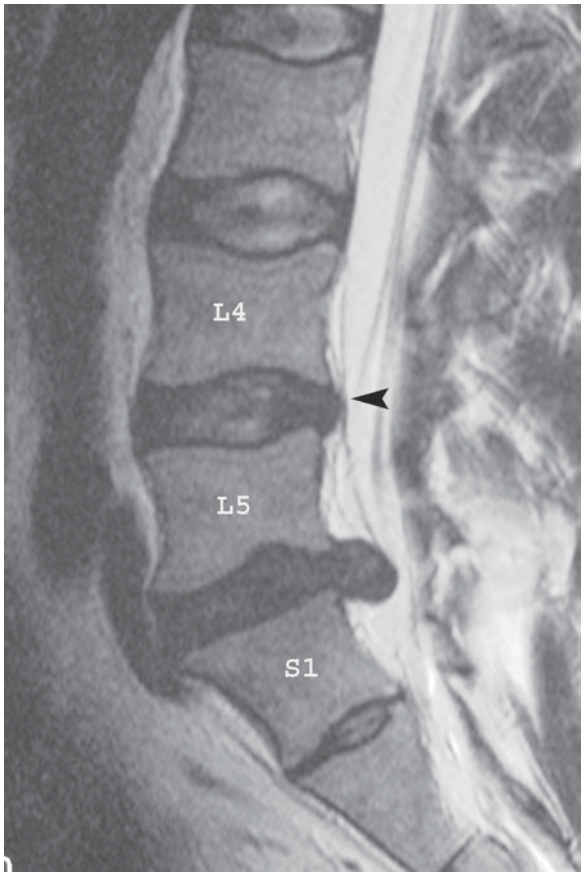


Fig. 9. Sagittal T2 MRI of a large disc herniation at L5–S1. Also notice the disc bulge at L4–L5 (*arrowhead*).

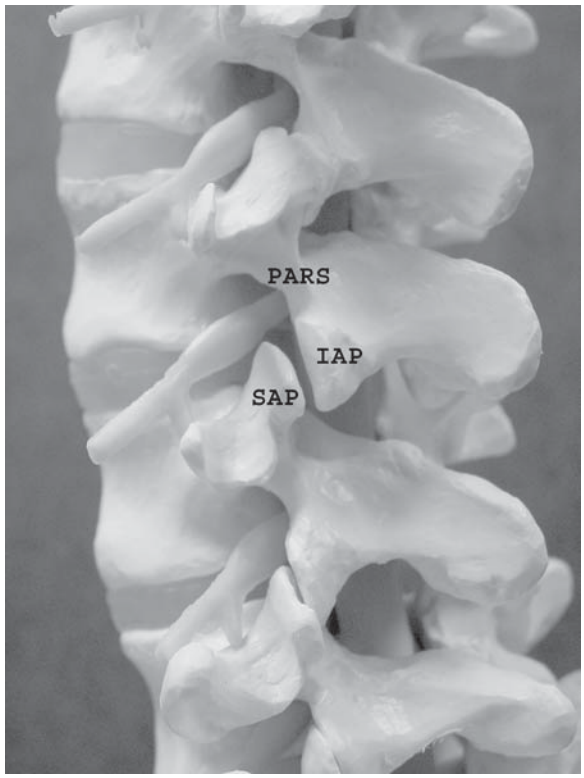


Fig. 10. Spine model showing the formation of the facet joint by the superior articular process (SAP) and inferior articular process (IAP). The pars interarticularis (PARS) is indicated.

ments connect the tips of adjacent spinous processes, and in the cervical region are continuous with the ligamentum nuchae. Laterally, the intertransverse ligaments connect the adjacent transverse processes.

The joints of the vertebral arches form the posterior border of the intervertebral foramen (Fig. 12). Inflammation of the joints and osteophyte formation as a result of inflammation can narrow the foramen and impinge on the spinal nerve. Pain from an affected nerve can be felt locally or along the peripheral distribution of the nerve.

THE UNCOVERTEBRAL JOINTS (OF LUSCHKA)

The uncovertebral joints are unique to the cervical spine and lie at the lateral and posterolateral aspect on the superior surface of the vertebral bodies, C3–C7. The joints are formed by the hooklike uncinate process of the superior aspect of the body below and a corresponding beveled surface on the body above. The joint surfaces are lined with hyaline cartilage. Some consider these joints to be synovial joints, while others feel they develop after degeneration and subsequent fluid accumulation within the substance of intervertebral discs *(7)*. The uncovertebral joints are frequently the sites of osteophyte formation and such bony spurs can encroach upon the anterior aspect of the intervertebral foramen.

THE SACROILIAC JOINTS

The sacroiliac joint connects the auricular surfaces of the sacrum with auricular surfaces of the iliac bones on each side. The auricular surfaces are roughened surfaces that match and interlock to some extent, yet permit limited gliding and rotatory movement. The joint capsule is thin and reinforced by strong, extracapsular ligaments. The ventral and dorsal sacroiliac ligaments and the dorsal interosseous ligaments are particularly strong. The dorsal interosseous ligament occupies the posterior two thirds of the space between the sacropelvic surface of the ilium and the lateral mass of the sacrum. Around the age of 50, the joint cavity disappears and the articulating bones fuse. Downward displacement of the sacrum tends to move the two iliac bones apart and to rotate the inferior aspect of the sacrum and the coccyx posteriorly. The sacrotuberous and the sacrospinous ligaments, which maintain the forward tilt of the lower sacrum and coccyx, oppose this rotation (Fig. 13).

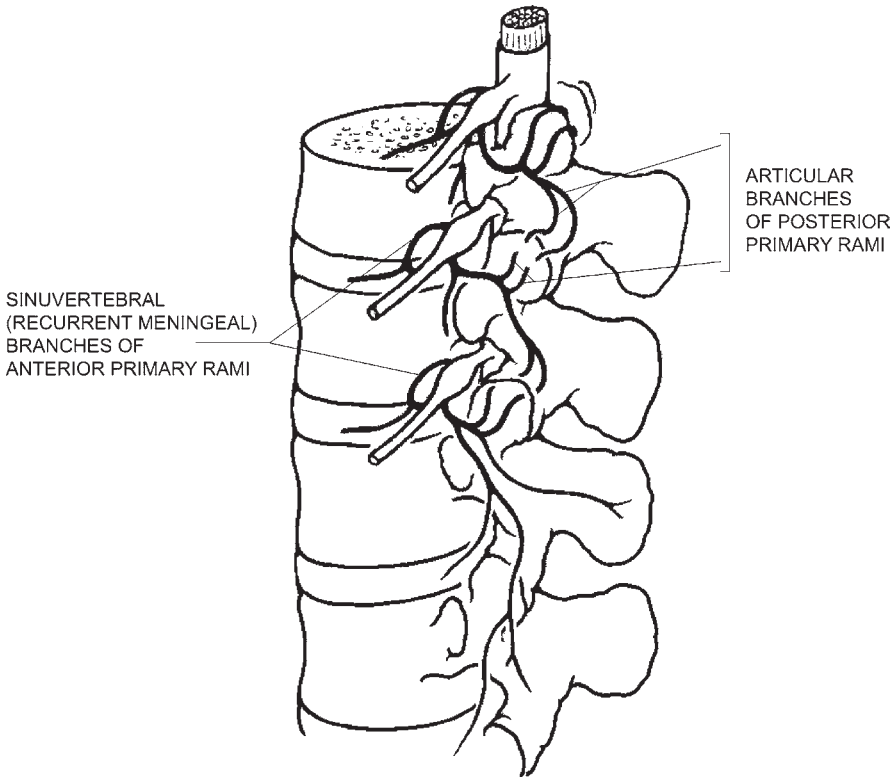


Fig. 11. Posterolateral view of the spine showing the sinuvertebral (recurrent meningeal) branches of the anterior primary rami reentering the intervertebral foramina. Two articular branches of the dorsal primary rami supply each facet joint. (Courtesy of Stephen G. Moon, Columbus, OH)

MUSCULATURE OF THE SPINE

The bones of the spine define its range of motion; the joints and associated ligaments modify this range, but it is the muscles—with the assistance of gravity—that produce movement. The muscles of the spine also help maintain posture; disperse loads applied to the spine and spare the ligaments from injury; and as a result of their sheer bulk, help protect the spine from external forces. Muscles with a direct attachment to the spine are divided into those that attach anteriorly and flex the spine and those that attach posteriorly and extend it.

ANTERIOR MUSCLES OF THE SPINE

The anterior muscles of the spine are less well developed because they are assisted in their primary action of flexion by gravity. In the cervical region, the anterior spinal muscles include the longus colli, longus capitis muscles, and the rectus capitis anterior and lateralis muscles. The lateral attachments of these muscles overlie the transverse processes of cervical vertebrae and must be considered during an anterior approach to the intervertebral discs, the uncovertebral joints, or the vertebral artery in the transverse canal *(8,9)*. As a group, they produce flexion of the head and neck if acting bilaterally, and lateral flexion if acting on one side only. All receive motor innervation from anterior primary rami of cervical spinal nerves.

The longus colli muscles (right and left) each have three parts: a vertical, a superior oblique, and an inferior oblique part. The fibers of the longus colli are arranged symmetrically around the transverse process of C5. The longus capitis muscles (right and left) are slightly anterior and lateral to the superior oblique fibers of the longus colli muscle. The longus capitis muscles arise by thin slips from the transverse processes of C3–C6. The tendons unite and form a distinct band that attaches to the basilar part of the occipital bone, between the anterior edge of the foramen magnum and the pharyngeal tubercle. The rectus capitis anterior and lateralis muscles lie anterior to the anterior atlantooccipital membrane and the atlantooccipital joint capsules, and help fill the gap between the atlas and the occipital bone.

The scalene muscles attach directly to the cervical spine, and when acting from their inferior attachment on the ribs can flex the spine. When the spine is fixed, the scalene muscles raise the ribs in inspiration. These muscles are critical landmarks in the neck. The anterior scalene muscle attaches to the anterior tubercles of the transverse processes of C3–C6. They descend to their attachment on the first rib at the scalene tubercle. The

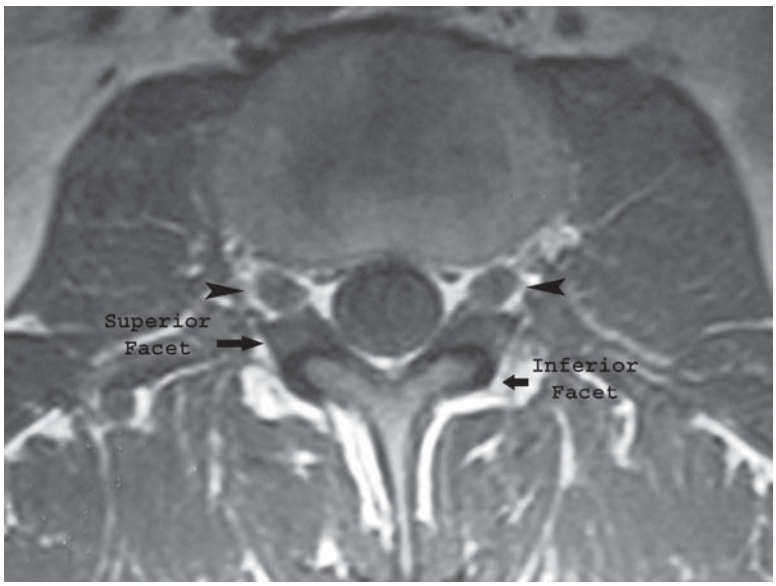


Fig. 12. Axial T1 MRI showing the close proximity of the exiting nerve root (*arrowheads*) to the facet joint. Osteoarthritis or disc herniation can cause narrowing of the neural foramen.

middle scalene muscle is the largest of the three scalene muscles. It attaches to the posterior tubercles of C3–C7 and passes downward to its insertion on the first rib just posterior to the insertion of the anterior scalene muscle. The posterior scalene is the smallest of the three, arises from the posterior tubercles of the transverse processes of C4–C6, and passes inferiorly to the lateral aspect of the second rib. Branches of the anterior primary rami of cervical nerves innervate all the scalene muscles. The phrenic nerve is formed on the surface of the anterior scalene muscle and descends through the superior thoracic aperture on the medial aspect of the anterior scalene. The subclavian vein passes anterior to the anterior scalene muscle, and the subclavian artery and roots of the brachial plexus pass between the anterior and middle scalene muscles. For descriptive purposes, the anterior scalene muscle divides the subclavian artery into three parts, with the vertebral artery, the thyrocervical trunk, and the internal thoracic artery associated with the first part. The costocervical trunk is associated with the second part, and the dorsal scapular artery is associated with the third part.

The anterior flexors of the spine in the lumbar region are the psoas major and minor muscles and the iliacus. These muscles are often described as muscles of the posterior abdominal wall, but they attach directly to the spine and have a direct effect on the position of the spine. The psoas major arises from the sides of the bodies of T12–L4, the intervertebral discs between the bones, and the transverse processes of all lumbar vertebrae. The muscle crosses the pelvic brim under the inguinal ligament and, after passing anterior to the capsule of the hip joint, attaches distally to the lesser trochanter of the femur. The psoas minor arises from the sides of the bodies of T12 and L1 and the intervening disc and attaches distally to the pectin pubis and the iliopubic eminence. The iliacus arises from the inner lip of the iliac crest, the upper two thirds of the iliac fossa, and the superolateral part of the sacrum. Its muscle fibers blend with those of the psoas major to insert on the lesser trochanter. The psoas muscles and the iliacus flex the thigh on the hip, but when the thigh is fixed, flex the trunk on the thigh. These muscles are innervated by the anterior rami of L1–L3.

POSTERIOR MUSCLES OF THE SPINE

The posterior muscles of the spine are well developed because most of the weight of the body lies anterior to the spine and more power is required to produce the primary function of the posterior group, which is extension. The muscles of the posterior group are divided into those that are extrinsic to the back and those that are intrinsic.

The extrinsic muscles of the back developed embryologically on the anterior surface of the body and later migrated to their posterior position. These muscles have carried their motor innervation with them, and thus are innervated by anterior primary rami of spinal nerves, or in one case, by a cranial nerve. In terms of function, the extrinsic muscles are related either to movement of the upper limb (the appendicular group) or to respiration. There are five muscles in the appendicular group: latissimus dorsi, rhomboid major, rhomboid minor, levator scapulae, and trapezius. The first four receive innervation from the anterior primary rami of cervical spinal nerves.

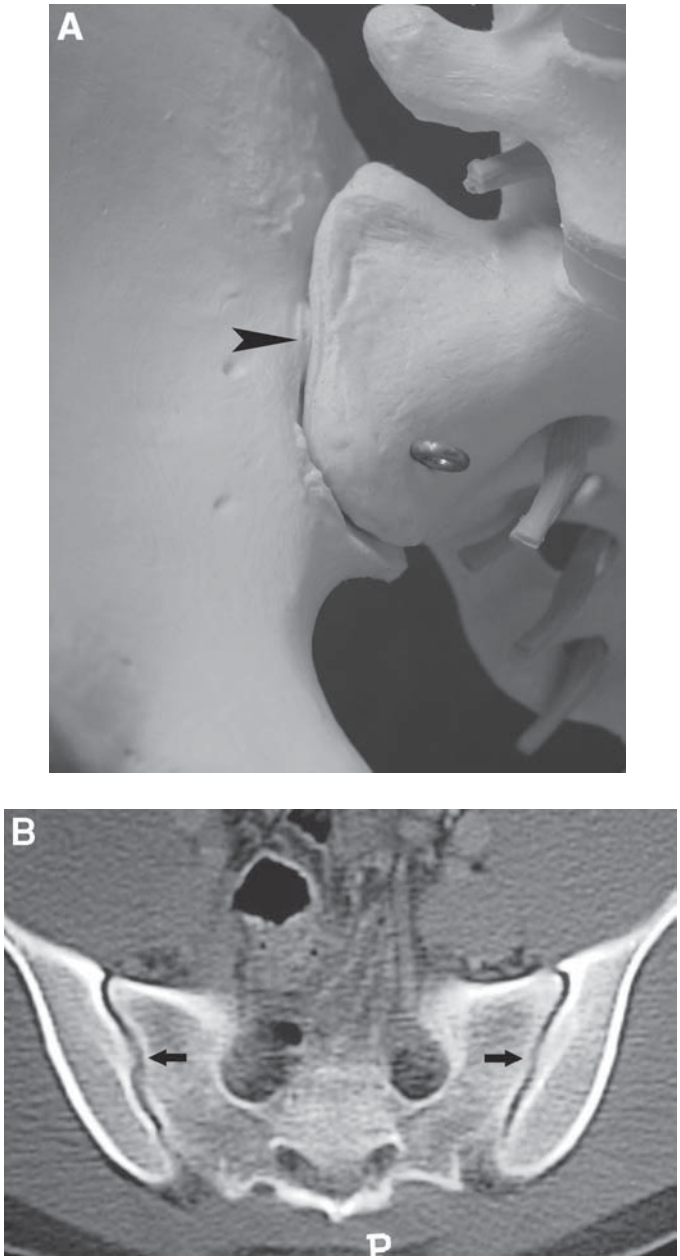


Fig. 13. **(A)** Sacroiliac joint. **(B)** Axial CT showing the sacroiliac joint.

The trapezius receives innervation from cranial nerve XI, the spinal accessory nerve, although it can receive motor innervation from cervical spinal nerves in place of the spinal accessory nerve *(10)*. The respiratory group of extrinsic back muscles includes the serratus posterior superior and inferior. These muscles are usually dismissed as being vestigial and of little functional importance. However, their role as a source of myofascial pain should not be ignored *(11)*.

The intrinsic muscles of the back are also described as the "true" back muscles and all receive motor innervation from posterior primary rami. The intrinsic muscles of the back can be described as belonging to three groups: the splenius group, the erector spinae, and the transversospinalis group.

The splenius group includes two muscles, the splenius capitis and splenius cervicis. The splenius complex lies deep to the trapezius and serratus posterior superior. These muscles arise from the lower half of the ligamentum nuchae and the spinous processes of C7 and the first five thoracic vertebrae. The capitis portion inserts on the mastoid process of the temporal bone and the lateral half of the superior nuchal line. The cervicis portion inserts on the transverse processes of C1–C4. When the splenius capitis and cervicis on one side contract, they move the head and neck to the same side and move the chin upward. Motor innervation is from the posterior rami of C4–C8.

The erector spinae is a composite muscle and the primary extensor of the back. Its origin is a broad tendon that attaches inferiorly to the posterior part of the iliac crest, the posterior of the sacrum, the sacroiliac ligaments, the lower lumbar spinous processes, and the median crest of the sacrum. The erector spinae is covered by fascia that attaches medially at the ligamentum nuchae, the vertebral spinous processes, the supraspinous ligament, and the median sacral crest. Laterally, this fascia attaches to the transverse processes of the cervical and lumbar vertebrae and to the angles of the ribs. That portion of this investing fascia in the thoracic and lumbar regions is the thoracolumbar fascia.

The erector spinae muscles fill the space between the spinous processes in the midline of the back and the angles of the ribs laterally and are described as three columns of muscles with each column named regionally. The lateral column is the iliocostalis and is named regionally—the iliocostalis lumborum, thoracis, and cervicis. The middle column is the longissimus, named regionally—the longissimus thoracis, cervicis, and capitis. The medial column is the spinalis, named regionally—the spinalis thoracis, cervicis, and capitis.

The third group of intrinsic back muscles is the transversospinalis. This group of muscles fills the narrow groove between the transverse and the spinous processes, and their name indicates the inferior to superior direction of the muscle fibers as they course between transverse and spinous processes. Superficial to deep in this groove lie the semispinalis, the multifidus, and the rotators. The essential difference between these three members of the transversospinalis group is the length of their muscle fibers (Fig. 14). The muscle fibers of the semispinalis cross six vertebrae, the fibers of the multifidus cross four vertebrae, and the fibers of the rotators cover two vertebrae (long rotators) or attach to the adjacent vertebra (short rotators). The semispinalis cervicis and capitis are the largest members of the transversospinalis group, and the capitis can be palpated as a large muscle mass attached to

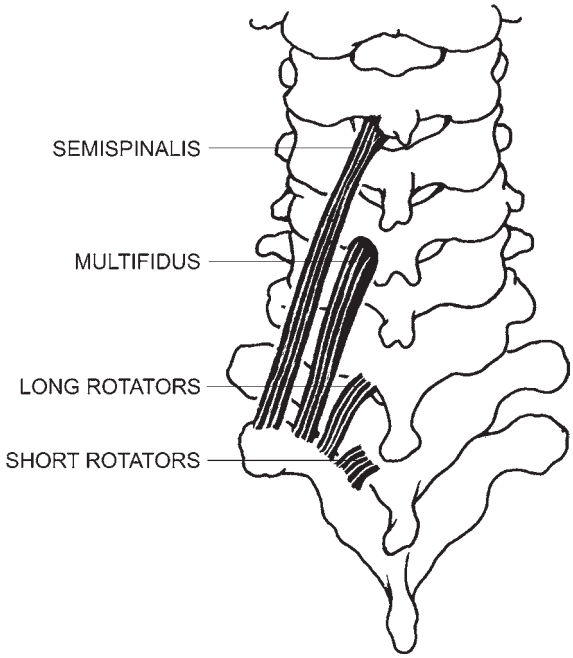


Fig. 14. Muscles of the transversospinalis group. The semispinalis fibers are the most superficial of this group and cross six vertebrae. The multifidus fibers are intermediate and cross four vertebrae. The rotators are deepest and cross two vertebrae (long rotators) or one (short rotators). (Courtesy of Stephen G. Moon.)

the back of the head, between the superior and inferior nuchal lines, just deep to the trapezius.

For completeness, two other muscle groups of the intrinsic back muscles should be mentioned. The interspinalis are muscle fibers that pass between adjacent spinous processes and the intertransversii pass between adjacent transverse process.

It is difficult to see how muscles with very short fibers have sufficient mechanical advantage to be important producers of movement. It has been shown that these shorter muscles have a disproportionately large number of proprioceptor spindle fibers and it has been suggested that they serve as "kinesiological monitors" of position *(12)*.

SUBOCCIPITAL TRIANGLE

The suboccipital triangle contains the horizontal part of the vertebral artery before it pierces the posterior atlantooccipital membrane and enters the subarachnoid space. The triangle is composed of muscles that maintain the posture of the head on the neck and move the head at the atlantooccipital and atlantoaxial joints. These muscles should be considered in the diagnosis of postural problems such as torticollis and the testing of neurological function after a cerebrovascular accident *(13)*.

The suboccipital triangle lies deep to the trapezius and semispinalis capitis muscles. Three muscles form the suboccipital triangle and a fourth is associated with the triangle. All these muscles act to extend the head at the atlantooccipital joint or rotate the head at the atlantoaxial joint. The rectus capitis posterior major is attached to the bifid spinous process of the axis and runs superiorly to insert into the inferior nuchal line. The inferior oblique muscle attaches to the spine of the axis, lateral to the attachment of the rectus major, and inserts on the transverse process of the atlas. The superior oblique muscle attaches on the transverse process of the atlas and inserts superiorly between the superior and inferior nuchal lines. These three muscles define the suboccipital triangle. Medial to the triangle on each side is the rectus capitis posterior minor muscle, which is attached to the posterior tubercle of the atlas and inserts on the medial part of inferior nuchal line. All four muscles receive motor innervation from the posterior primary ramus of C1, the suboccipital nerve.

VERTEBRAL CANAL AND ITS CONTENTS

The spinal cord is the continuation of the medulla oblongata and begins at the vertebral foramen of the atlas. The spinal cord is thin and slender, and almost circular in cross section, being flattened slightly from anterior to posterior. There are 31 pairs of spinal nerves emerging from the spinal cord—8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. Each spinal nerve is composed of an anterior and a posterior root (Fig. 15). Each anterior root contains multiple rootlets that are the peripheral pro-

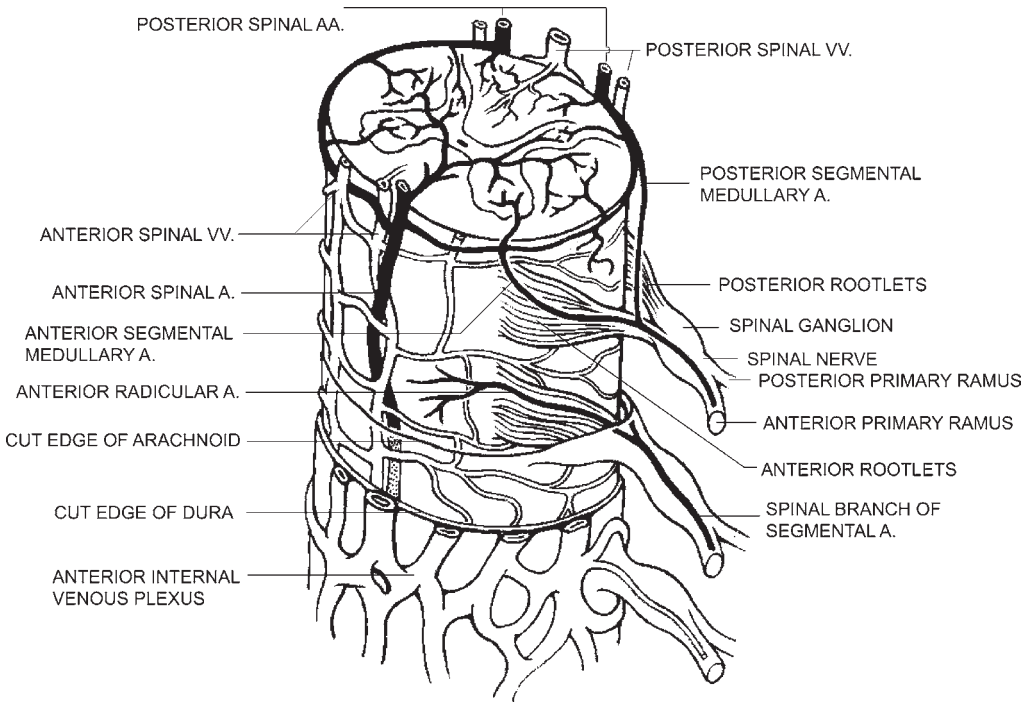


Fig. 15. Meninges and vasculature of the spinal cord. The spinal nerve is short and branches immediately after its formation into anterior and posterior primary rami. The spinal arteries and veins pierce the pia to vascularize the cord. The spinal branches shown are representative of many spinal branches supplied by segmental arteries in the cervical, thoracic, and lumbosacral regions. The internal venous plexus (anterior labeled) lies in the epidural space. (Courtesy of Stephen G. Moon.)

cesses of motor neuron cell bodies located in the anterior gray horn of the cord. Similarly, each posterior root contains multiple rootlets that are the central processes of pseudo-unipolar sensory neurons located in the spinal ganglion. The spinal nerve itself is short, just a few millimeters in length, and divides almost immediately after its formation into its anterior primary ramus and its posterior primary ramus. The spinal nerve, its two primary rami, and all distal branches of the primary rami are composed of both motor and sensory fibers and are mixed nerves.

SPINAL CORD SEGMENTS

While the individual vertebrae give the spine an obvious segmental pattern, the spinal cord itself does not exhibit similarly obvious segmentation. However, the nerve rootlets exiting and entering the cord give rise to a description of spinal cord segments. A spinal cord segment is defined as that region of the cord associated with one pair of spinal ganglia.

During its course through the vertebral canal, the spinal cord exhibits a cervical enlargement corresponding to the fifth cervical to the first thoracic spinal segments. The widest portion of the cervical enlargement is opposite the C6 vertebra (Fig. 16). The cord also exhibits a lumbosacral enlargement corresponding to the first lumbar to the third sacral spinal cord segments. The widest portion of the lumbosacral enlargement is opposite the T12 vertebra (Fig. 17). These enlargements are associated with the large numbers of neurons in the anterior horn of the cord that are responsible for the motor innervation of the upper and lower limbs.

CONUS MEDULLARIS

The inferior, tapering end of the spinal cord is the conus medullaris, and based on studies in cadavers, the termination of the spinal cord is usually described as occurring at the intervertebral disc between the L1 and L2 vertebrae. In a magnetic resonance imaging (MRI) study of living individuals imaged in the supine position, the median level of spinal cord termination was determined to be slightly higher, at the middle one third of the L1 vertebra, with a wide range between the middle one third of T11 and the middle one-third of L3 *(14)*.

THE SPINAL NERVE IN THE INTERVERTEBRAL FORAMEN

The spinal nerve and the proximal parts of its primary rami reside in the intervertebral foramen. Two early branches of the primary rami warrant mention here (Fig. 11). First, the sinuvertebral, or recurrent meningeal nerves, branch from the anterior primary ramus and reen-

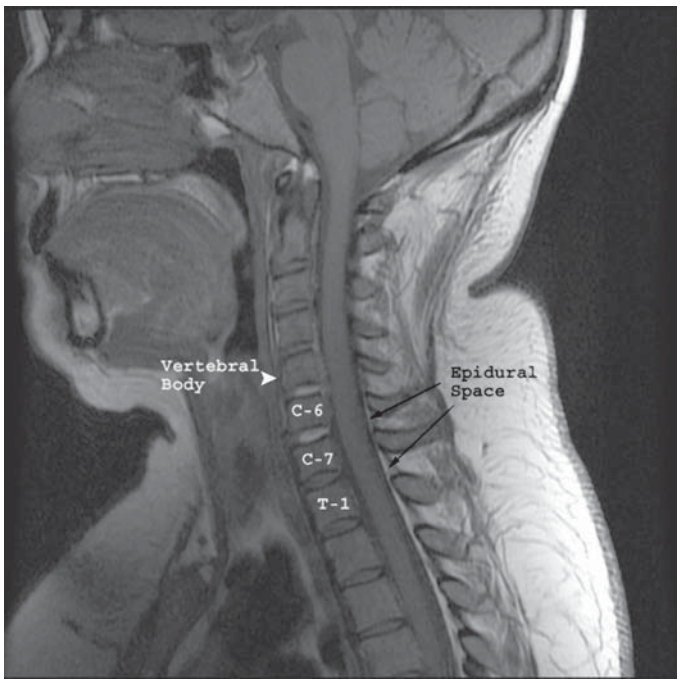


Fig. 16. Sagittal T1 MR through the cervical spine. Notice how the spinal cord becomes slightly larger at C6 and C7.

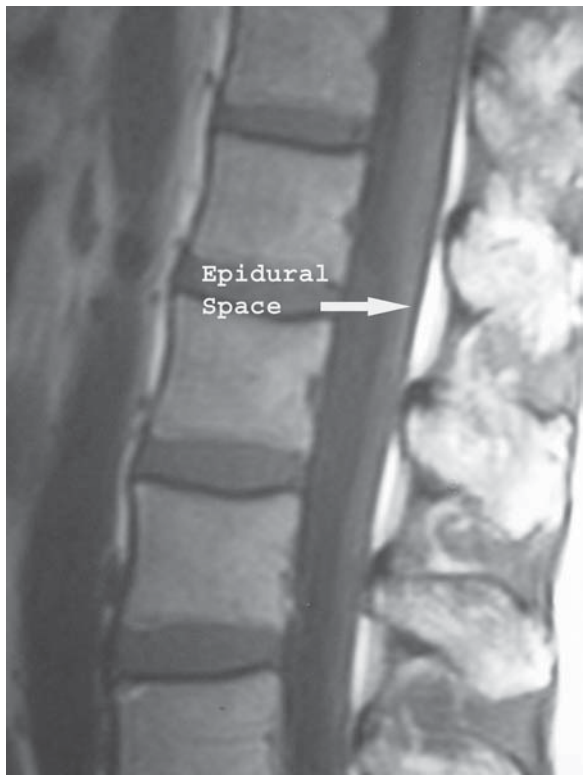


Fig. 17. Sagittal T1 MR of the lumbar spine. The epidural space is shown by the high signal fat within the epidural space.

ter the intervertebral foramen to supply pain and proprioceptive fibers to the posterior longitudinal ligament and the area of the anulus fibrosus associated with this ligament. Second, articular branches of the posterior primary ramus innervate the zygapophyseal joints and convey proprioception and pain. Each zygapophyseal joint is innervated by two articular branches, one branch from the posterior ramus exiting the intervertebral foramen above the joint, and a second branch from the posterior ramus exiting below the joint. To achieve complete anesthesia of a specific zygapophyseal joint, both articular branches must receive anesthetic.

MENINGES

The spinal cord receives additional protection from its enclosure within three layers of membrane, or meninges, and cushioning from the cerebrospinal fluid. The outermost membrane is the dura mater and is attached superiorly to the margins of the foramen magnum, and in living individuals, extends inferiorly to the level of the S2 vertebra *(14)*. The space enclosed by the dura between the foramen magnum and the S2 vertebra is the dural, or thecal sac. A thin prolongation of the dura below S2, the filum terminale externum, extends to the posterior aspect of the sacrum and anchors the dural sac inferiorly. Lateral extensions of the dura surround the spinal nerve and primary rami as they exit the intervertebral canal. The dura is attached to the bony opening of the intervertebral foramen and then becomes continuous with the epineurium of the peripheral nerves. These dural attachments fix the nerves in place and make them vulnerable to compression by a herniated nucleus pulposus or an inflamed zygapophyseal joint.

Deep to the dura mater is the arachnoid mater, a thin, flexible, and elastic membrane that is pressed against the inner aspect of the dura. The arachnoid mater is named for the weblike trabeculations associated with its deep surface. Deep to the arachnoid is the pia mater. The pia is tightly adherent to the surface of the spinal cord and dips into the various fissures to invest the cord completely. Laterally, between the attachments of the anterior and the posterior rootlets, the pia leaves the surface of the cord and extends laterally as the denticulate ligament and attaches to the dura mater. A second extension of the pia, the filum terminale internum, leaves the conus medullaris and descends to the inferior end of the dural sac. Here it picks up investments of arachnoid and dura and as the filum terminale externum, attaches to the posterior aspect of the sacrum.

SPACES WITHIN THE VERTEBRAL CANAL

The concentric arrangement of the meninges creates a number of spaces within the vertebral canal, some that are real and exist normally in life, and some that are potential

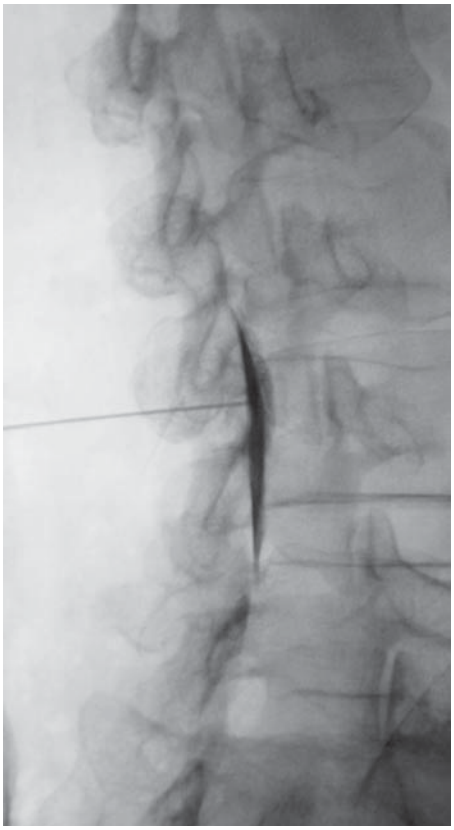


Fig. 18. Image of a lumbar epidurogram confirming needle placement within the epidural space.

and can be opened to fill with fluid during disease processes or therapeutic intervention. Superficial to the dura, between the dura and the inner aspect of the vertebral canal, is the epidural space, filled with fat and the epidural venous plexus (Figs. 16 and 17). Loss of resistance to air or saline is commonly used to indicate successful placement of a needle into the epidural space. The ligamenta flava plays an important role in this loss of resistance, and the anatomic variability of this ligament may contribute to false-positive assessments of needle placement. It has been suggested that epidurography can improve the accuracy of needle placement and medication delivery to targeted areas of spinal pathology *(15)* (Fig. 18).

Deep to the dura, between it and the arachnoid is a potential space, the subdural space. During administration of spinal anesthesia, the needle may push the arachnoid membrane away from the dura, instead of piercing the arachnoid. In this case, the injectate may be delivered to the subdural space and may contribute to the variable success of spinal anesthesia *(16)*. Deep to the meningeal layer of arachnoid, between the arachnoid and the pia, is the subarachnoid space filled with cerebrospinal fluid. Together, the arachnoid and the pia mater are referred to as the leptomeninges.

SPINAL VASCULATURE

The arterial supply and venous drainage of the spinal cord and the vertebral column are provided by a series of longitudinal channels (spinal arteries and spinal veins) that are reinforced by contributions of segmental arteries and drained by segmental veins.

ANTERIOR AND POSTERIOR SPINAL ARTERIES

The unpaired anterior spinal artery occupies the anterior median fissure of the spinal cord and sends branches through the pia to supply the cord (Fig. 15). The anterior spinal artery is formed superiorly within the vertebral canal by anterior contributions from the left and right vertebral arteries just before the latter join to form the basilar artery (Fig. 19). The paired posterior spinal arteries are also formed superiorly in the vertebral canal by posterior branches of either the vertebral arteries or the posteroinferior cerebellar arteries. The posterior spinal arteries are smaller than the anterior spinal artery and take a position along the line of attachment of the posterior rootlets of the spinal nerve.

SEGMENTAL ARTERIES

The segmental arteries that make contributions to the anterior and posterior spinal arteries include (1) the vertebral and ascending cervical arteries in the neck, (2) the costocervical trunk and posterior intercostal arteries in the thorax, and (3) the lumbar, iliolumbar, and lateral sacral arteries in the abdomen and pelvis (Fig. 19). Spinal branches of the segmental arteries enter the intervertebral canal and divide further into two types of branches. Radicular branches distribute with and supply the anterior and posterior rootlets of the spinal nerves (Fig. 15). Segmental medullary branches (anterior and posterior) contribute to and reinforce the anterior and posterior spinal arteries and supply the cord itself. The segmental arteries also provide branches to the vertebral column (not shown in Fig. 15). Postcentral branches of the segmental arteries supply the posterior aspect of the vertebral bodies, and prelaminar branches supply the deep aspect of the vertebral arch.

The artery of Adamkiewicz is a spinal branch that makes a major contribution to the anterior spinal artery by supplying a large portion of the spinal cord including the lumbosacral enlargement (Fig. 19). Accurate localization of the artery is important when planning interventional radiologic treatment, and noninvasive methods of localization are particularly useful in patients with vascular disease. Recently, multidetector row helical computed tomography has been shown to depict the artery of Adamkiewicz in a higher percentage of patients when

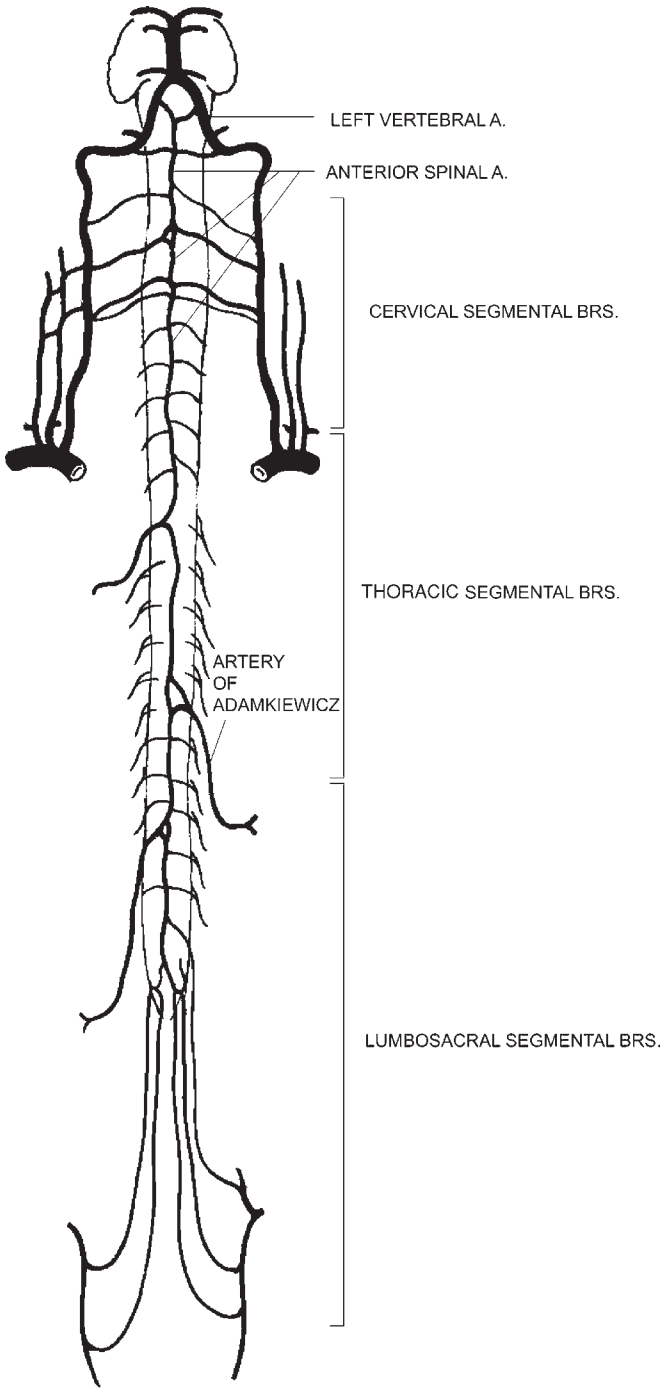


Fig. 19. Formation of the anterior spinal artery and its reinforcement by branches of segmental arteries. The anterior spinal artery is formed superiorly by branches of the right and left vertebral arteries. At many vertebral levels, spinal branches of segmental arteries pass through the intervertebral foramina and reinforce the anterior spinal artery. The relatively constant artery of Adamkiewicz is a spinal branch of thoracic or lumbar segmental arteries. (Courtesy of Stephen G. Moon.)

compared to magnetic resonance imaging *(17)*. Preoperative information on the location of the artery of Adamkiewicz may help reduce the risk of postoperative complications of spinal ischemia.

VERTEBRAL VENOUS PLEXUSES

Venous drainage of the spinal cord and the vertebral column is accomplished by an extensive series of venous plexuses that are found both within and outside the vertebral canal. All parts of these venous plexuses anastomose without valves, making the venous plexuses of the vertebral column a reservoir for blood shifted from the body cavities and a route for metastasis *(18)*. The importance of accurate knowledge of the vertebral plexuses, emphasized by the development of interventional radiology, has prompted examination of these plexuses using modern imaging techniques *(19)*.

The internal venous plexuses are the anterior and posterior internal vertebral venous plexuses. The anterior internal vertebral venous plexus consists of longitudinal and transverse channels and lies in the epidural space in the vicinity of the posterior longitudinal ligament. Indeed, the posterior longitudinal ligament is thought to help compartmentalize the anterior internal vertebral venous plexus *(20)*. The longitudinal channels receive the basivertebral veins, which are endothelial lined sinuses within the vertebral bodies. Superiorly, the anterior internal vertebral venous plexus communicates with the basilar and occipital sinuses, the sigmoid sinuses, and the vein of the hypoglossal canal.

The anterior external vertebral venous plexus is related to the anterior longitudinal ligament. The posterior external vertebral venous plexus is formed by veins in the vicinity of the spinous, transverse, and articular processes of the vertebrae. The anterior and posterior external plexuses communicate with the internal plexuses and all are tributaries to veins corresponding to the spinal branches of the segmental arteries.

The vertebral veins arise in the suboccipital region by the confluence of spinal branches of the segmental veins and muscular veins. The vertebral veins descend through the transverse foramina with the vertebral artery as an accompanying plexus. The vertebral veins receive the segmental and muscular veins at each level in the neck. The vertebral veins exit the foramina at C6 and drain into the right and left brachiocephalic veins.

THE VERTEBRAL ARTERY

The vertebral artery has special importance in discussion of the cervical spine because of its route through the transverse foramina of the cervical vertebrae and its passage through the posterior atlantooccipital membrane. In its position within the transverse foramina, it can be compressed

by a laterally herniated nucleus pulposus *(21)* or by osteophyte formation in the uncovertebral and facet joints *(22)*. It can also be compressed during rotation of the cervical spine while fixed in a calcified posterior atlantooccipital membrane, and thus contribute to bow hunter's stroke *(23)*. Approaches to the vertebral artery are complicated by its variable course through the cervical spine *(24)*.

CONCLUSION

A thorough understanding of the anatomy of the spine is essential to the spinal interventionalist. Anyone who performs interventional spinal procedures must first understand this complex anatomy and relate the two-dimensional images seen with fluoroscopy to the three-dimensional anatomy of the patient. This will lead to fewer complications and greater procedural success.

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2 Computed Tomography of the Spine

STEPHEN FUTTERER, MD

INTRODUCTION

Computed tomography (CT) and magnetic resonance imaging (MRI) have dramatically changed the way that diseases of the spine are diagnosed and treated. Indeed it is difficult to envision the practice of medicine without these advanced imaging techniques, although their widespread use spans only the last 25 yr. These modalities are best regarded as complementary, rather than as redundant, because each gives different and useful information. As an example, consider the evaluation of a patient with acute cervical spine trauma. Plain film radiography is generally the initial step in the evaluation of these patients. However, plain films are limited in their ability to detect nondisplaced fractures, to characterize complex fractures/dislocations optimally, or to evaluate fully injury at the cervicothoracic junction. In the severely injured patient, plain film evaluation is often hindered by difficulties with patient positioning and cooperation. Overlying material, such as a cervical collar or endotracheal tube, obscures bony detail and further limits the examination.

CT is definitely more sensitive to fractures when compared to plain radiographs. CT is also able to depict more precisely the degree of retropulsion and the relative position of the fracture fragments. Recent advances in CT technology include subsecond spiral imaging and multislice acquisition, which have enabled increasingly rapid imaging of larger body segments and with less image degradation. This is perhaps most evident in the improved quality of the postprocessed images. The ability to represent data accurately in multiple planes has significantly improved the diagnostic capability of CT *(1)*. A fracture in the scan plane, such as a subtle vertebral compression fracture, is easily missed on standard axial CT images while plainly visible on the sagittal reformations.

CT does have its limitations. CT is very insensitive in the detection of spinal cord abnormalities and does not play a role in the evaluation of ligamentous injury. While CT can detect an acute traumatic disc extrusion or epidural hematoma, MRI is considered superior. MRI is clearly indicated for the trauma patient with an acute neurologic deficit to assess both for epidural pathology and cord contusion. Short tau inversion recovery (STIR) images on MRI are useful to assess for ligamentous injury in the uncooperative or obtunded patient, for whom flexion and extension views may be unsafe. The sensitivity of this technique for edema is exemplified by the depiction of increased marrow signal in vertebral bodies that have no loss of height or demonstrable fracture by CT. This phenomenon is commonly seen at multiple levels adjacent to an obvious spinal fracture.

CT does have some distinct advantages over MRI. The most obvious are the immediate accessibility (without the need for screening), shorter imaging time, and the far less frequent problem with claustrophobia. The result is fewer studies limited by motion artifact. Monitoring of critically ill patients is also easier in the CT setting. Several specific problems are best evaluated with CT. The high spatial resolution makes CT optimal for detection of acute fractures and pars interarticularis defects *(2)*. CT more accurately reveals the relationship of surgical hardware to the adjacent bony structures as well as the integrity of the surgical construct. CT detection of pathologic mineralization is also superior to MRI, which lacks both sensitivity and specificity. Calcification may not be evident, even in retrospect, on MR images. When seen, it usually is of low signal intensity on all pulse sequences but can cause

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T1 shortening. Furthermore, blood products and gas can mimic mineralization on MRI. The detection and characterization of pathologic mineralization, as well as the distinction from hemorrhage or gas, has important diagnostic and therapeutic implications. Specific examples include the distinction between osteophyte and disc material, the evaluation of tumor matrix (chondroid or osteoid), the detection of ligamentous ossification (e.g., ossification of the posterior longitudinal ligament [OPLL] or diffuse ideopathic skeletal hyperostosis [DISH]), and the identification of mural calcification in a synovial cyst. There are other applications of CT worth noting. Volumetric data acquisition has also enabled its use for surgical planning and stereotactic intraoperative localization. CT also is invaluable in guiding biopsy procedures. Recent advances in slip-ring technology have allowed the development of CT fluoroscopy. This technique gives nearly real-time feedback of needle position and allows for biopsy of smaller lesions and those subject to motion, particularly in the diaphragmatic region.

As initially stated, CT and MRI should be viewed as complementary, with each having its strengths and weaknesses. In addition to it benefits in the trauma setting, MRI has other advantages over CT in evaluation of spine disorders. The higher contrast resolution of MRI makes it more sensitive to infiltrative marrow disorders, leptomeningeal disease, and intrinsic spinal cord pathology (tumors, demyelinating disease, or syrinx). MRI can also provide physiologic data, as with diffusion-weighted imaging and cerebrospinal fluid (CSF) flow techniques. In the current climate of financial austerity, there is a tendency for insurers and referring physicians to take a "single best test" approach. Although it is ideal to seek conclusive diagnostic information using the fewest and least invasive tests available, there are clearly situations that call for multiple modalities to provide a definitive diagnosis and to optimize treatment planning. Spinal disease is quite complex, and the various clinical presentations lack specificity. This makes it difficult to apply rigidly an algorithm for workup and management. Ultimately the approach must be flexible and take into account both the clinical scenario and the findings on initial imaging evaluation.

CT TECHNIQUE

Advances in CT technology have led to a current generation of CT scanners that boast faster acquisition, increased anatomic coverage, and higher spatial resolution. The result has been an increase in productivity as well as improvement in diagnostic accuracy. Rapid, thin section multidetector volumetric acquisition enables a wide array of postprocessing capabilities, such as high-resolution two-dimensional reformation, three-dimensional volume rendering, and surface shading techniques. This has dramatically enhanced the ability of CT, an inherently two-dimensional modality, to depict three-dimensional structures. The gains are perhaps best exemplified by the surge in applications of CT angiography and in the detailed multiplanar reformations in spine imaging. Surgical procedures involving the brain, sinonasal cavity, and spine are increasingly performed with the assistance of stereotactic imaging guidance using CT data. In addition, the advent of CT fluoro-scopy has enabled almost real-time guidance of interventional procedures. To be sure, the future holds new advances, which will further broaden the diagnostic limits of CT.

CT imaging protocols inevitably vary between institutions depending on the specific capabilities of the scanner, physician preferences, and the clinical indications for evaluation of the spine. At our institution, the CT protocols are based on multidetector (MDCT) scanners. The scan parameters for imaging of the cervical, thoracic, and lumbar spine are very similar. The protocol described in the following is representative. CT data are acquired helically in high-speed mode with a slice thickness of 2.5 mm, a rotation time of 1 s, and a table speed of 7.5 mm per rotation. No gantry tilt is used. Tube voltage is 140 kV and the tube current time product is 300 mAs. The base data are then reconstructed with a bone and soft tissue algorithm to 1.25 mm slice thickness at 1.25-mm slice intervals. For image analysis, sagittal and coronal reformations are obtained with a slice thickness of 2.5 mm based on the reconstructed data. The cervical and lumbar spine studies are performed with quiet respiration while the thoracic studies are acquired during suspended respiration. The studies are usually performed without administration of intravenous contrast. Infrequently a patient presents with a clear indication for contrast, such as the evaluation of possible discitis, but for whom MRI is contraindicated (e.g., the presence of a pacemaker).

DEGENERATIVE SPONDYLOSIS

OVERVIEW

By far the most common indication for spine imaging is to evaluate for degenerative spondylosis as a cause of acute or chronic neck pain, back pain, or symptoms of radiculopathy. For the purposes of this chapter, the discussion on degenerative disease is limited to the lumbar spine. There are innumerable articles and texts on the subject and yet there is no consensus as to the appropriate workup and management of these pain syndromes. Complicating the matter is the relatively high incidence of spinal imaging abnormalities in healthy volunteers. A well known study by Jensen et al. evaluated 98 asymptomatic

individuals for abnormalities on lumbar spine MRI. The age of the subjects ranged from 20 to 80 yr and there were nearly equal numbers of men and women. There was a high prevalence of imaging pathology, with only 36% of subjects having a normal disc at all levels. Fifty-two percent of the subjects had a disc bulge at one level or more and 27% had a disc protrusion. Notably disc extrusion was seen in only 1%. Other findings included Schmorl's node (19%), annular tear (14%), and facet arthropathy (8%) *(3)*. Autopsy studies as well as other imaging based studies utilizing myelography, CT, and MRI have found similar results *(4,5)*. This underscores the need for careful correlation of the imaging findings with the clinical presentation, particularly if surgical intervention is considered.

Plain film radiography is often the initial study obtained in the evaluation of symptoms referable to the spine. Radiographs allow for assessment of spine alignment, bone density, vertebral body height, disc height, endplate sclerosis, and osteophyte formation. The advantages of low cost and ready availability of plain radiography are, however, offset by limited soft tissue contrast, structural overlap, and relatively high radiation exposure *(6,7)*. The cross-sectional nature of CT greatly improves the ability to resolve structures of similar density because of the lack of overlap. MRI has the additional advantages over CT of superior contrast resolution, a direct multiplanar imaging capability, and the lack of ionizing radiation. Still there are practical drawbacks to MRI related to availability, expense, length of examination, and patient claustrophobia.

Several published studies have evaluated the relative accuracy of MRI, CT, and CT myelography in the diagnosis of lumbar disc herniation. The results demonstrated that the three examinations were essentially equal in diagnostic ability. Jackson et al. prospectively studied 59 symptomatic patients with low back pain and radiculopathy. Each patient was imaged using all three techniques and every patient underwent surgical exploration (total of 120 disc sites). Accuracy results were as follows: MRI (76.5%), CT myelography (76%), and CT (73.6%). The authors concluded that MRI should be the study of choice in the diagnosis of lumbar disc herniation because of its noninvasive nature and the lack of ionizing radiation *(4)*. Similar results were reported in a cohort of 95 patients by Thornbury et al., who also found no statistical difference in accuracy between the three examinations. They concluded that MRI should replace CT myelography but not CT because the latter is equally accurate but less costly *(5)*. Despite the passage of time, there remains considerable variation in the referral patterns for spine imaging. In some centers, CT myelography surprisingly enjoys continued popularity. Suffice it to say that both CT (with or without myelography) and MRI provide excellent information about spinal anatomy and pathologic derangement, which sometimes is additive. As CT technology continues to improve and with the ever-present issue of cost-effectiveness, it is likely that CT will continue to play a prominent role in the diagnosis of degenerative diseases of the spine.

INTERVERTEBRAL DISC DEGENERATION

CT is relatively limited in the direct evaluation of intervertebral disc pathology. The vacuum disc phenomenon is easily seen on CT although it is a late manifestation of disc degeneration. Loss of disc height can be appreciated on sagittal reformations. CT does readily detect secondary findings of disc degeneration, such as endplate sclerosis or osteophyte formation *(8)*. Clearly MRI affords better delineation of both disc structure and internal derangement. The T2-weighted images alone provide information concerning disc height, disc hydration, the presence or absence of annular tears, and diffuse or focal abnormalities in disc contour *(9)*. As stated earlier, both CT and MRI are accurate in the detection of disc contour abnormalities including diffuse bulge, focal protrusion, and disc extrusion. It could be argued that the diagnostic yield of the additional disc-related findings on MRI is blunted due to their relatively frequent occurrence in the asymptomatic population.

One interesting caveat is the occasionally troublesome appearance of high T2 signal in the disc space in an otherwise degenerative appearing spine. In extreme cases, the findings can be easily confused with discitis, in that the adjacent marrow may demonstrate edema and the disc and endplates may enhance following gadolinium administration. As always, the imaging findings must be put into clinical context. However, it is not unusual for a patient with discitis, particularly if elderly, to have scant clinical evidence of infection. There are several possible explanations for fluid in the disc space in the setting of disc degeneration without infection. The first relates to the vacuum phenomenon. It is theorized that during the course of the MRI examination, gas within a vacuum disc can be replaced by fluid, resulting in high T2 signal within the disc space. Schweitzer and El-Noueam noted the presence of fluid signal within the disc space on T2-weighted MR images in 12 of 100 (12%) patients known to have the vacuum disc phenomenon. In the other 88 subjects, the gas cleft was of low signal intensity on both T1- and T2-weighted images *(10)*. The fluid usually takes a fusiform or linear shape and has a central location within the disc, much like the corresponding gas cleft on plain radiographs *(10)*. Plain films and/or CT will usually confirm the presence of gas in such cases. Awareness of the variable appearance of the vacuum disc on MRI will help avert unnecessary investigations for infectious discitis (Fig. 1). There are other less common disease processes that can

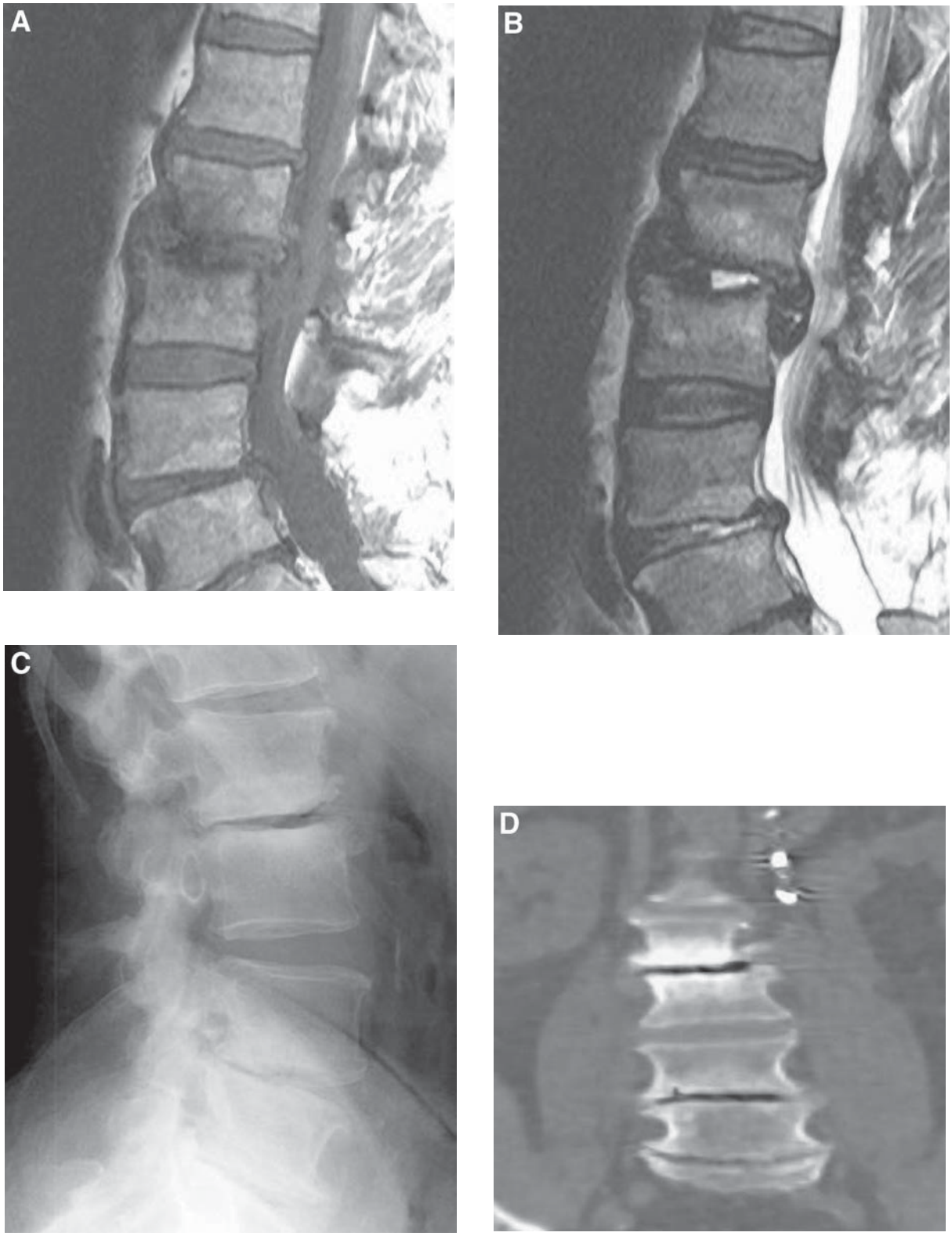

Fig. 1. Sagittal T1- **(A)** and sagittal T2-weighted images **(B)** demonstrate endplate edema and fluid in the disc space at L2–3, findings usually associated with discitis. Note the relative preservation of the vertebral endplates and the similar changes at L4–5. A large disc extrusion is also present at L2–3. **(C)** Lateral radiograph reveals degenerative endplate sclerosis, osteophytes, and an intervertebral vacuum disc at L2–3, which virtually excludes the presence of discitis. **(D)** Coronal CT reformation is derived from a routine abdominal CT performed for an unrelated reason. It shows the remarkable resolution that is attainable with MPRs, even from a nondedicated exam. Also note the vacuum cleft at the L4–5 space.

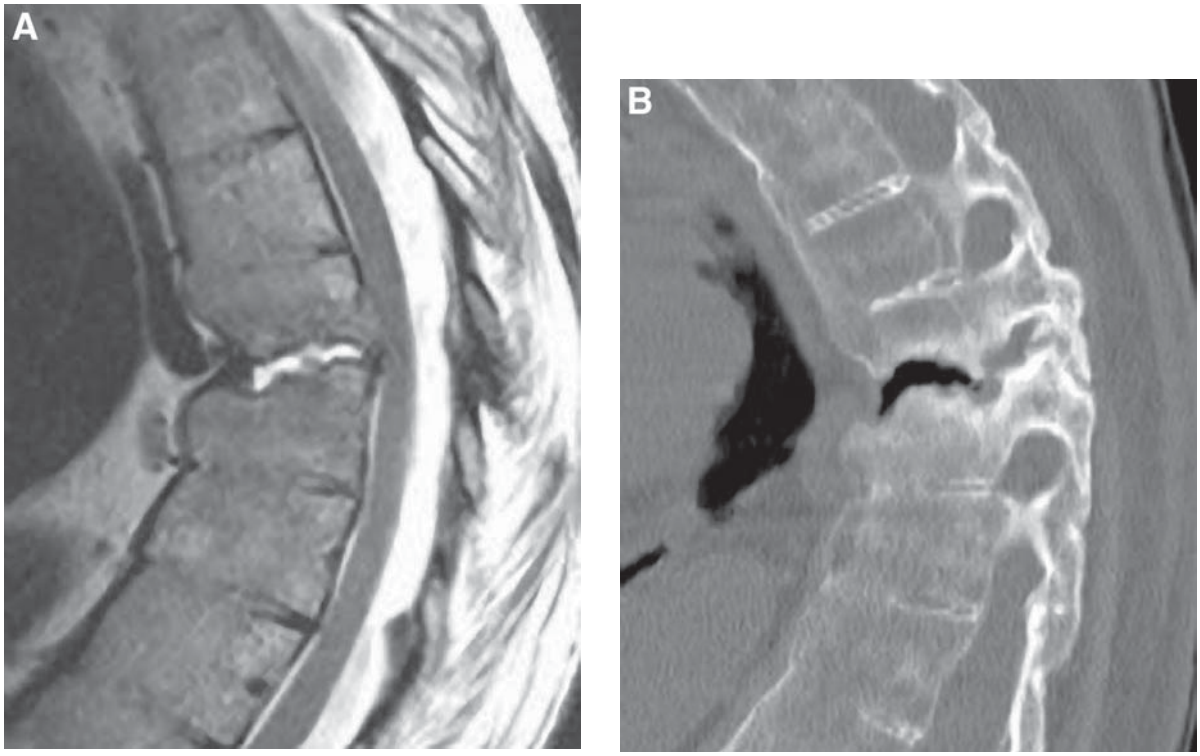

Fig. 2. (A) Sagittal T2-weighted image demonstrates fluid in the expected location of the T8–9 disc space with associated endplate erosion. This appearance could be misconstrued as indicative of discitis. **(B)** Sagittal CT reformation more clearly shows the bony fusion characteristic of ankylosing spondylitis, which in this case is complicated by fracture and pseudoarthrosis. Patients with DISH are at risk for similar injuries. Note again the association of a vacuum cleft with high T2 signal on MR.

also present with high T2 signal in the disc space. One such scenario occurs when there is complete loss of disc height at a given disc level associated with segmental instability, which results in a pseudoarthrosis of the adjoining endplates. The result is similar to the Baastrup's phenomenon, in which fluid is noted at the friction point between adjacent spinous processes. Other causes of pseudoarthrosis, such as when an unstable fracture complicates ankylosing spondylitis or spinal fusion, can also simulate infectious discitis (Fig. 2). Additional rare mimics include neuropathic (Charcot) spine and dialysis-related spondyloarthropathy *(11)*. In some cases, disc biopsy is needed to exclude infection, which can be performed using either fluoroscopic or CT guidance.

Although unrelated, a vacuum cleft also occurs within a collapsed vertebral body in the setting of avascular necrosis (Kummell's disease) (Fig. 3). It is worth mentioning in the context of the vacuum disc phenomenon because of the similar imaging findings. The intravertebral vacuum cleft (within the vertebral body) is virtually always an indicator of benign disease, and its recognition should prevent unnecessary workup and intervention driven by a suspicion of underlying malignancy or infection. On plain radiographs and CT, the collapsed vertebral body is noted to contain a horizontal linear band of gaslike radiolucency. This phenomenon is dynamic, however, and it is dependent on both patient position and the time spent in that position. Malghem et al. found that on serial T2-weighted MR images (over an approx 1-h period), the cleft gradually changed from a signal void (gas) to a band of high signal intensity, suggesting that the gas had been replaced with fluid. Furthermore, the vacuum cleft was most visible on supine and extension stress radiographs and was shown to disappear on standing and flexion views. The authors stressed that when a band of high T2 signal is observed within a collapsed vertebral body, the presence of a vacuum cleft should be confirmed with the appropriate radiographic views or repeat T2-weighted images after prolonged sitting or standing *(12)*.

FACET JOINT DEGENERATION

Low back pain is extremely common and is one of the leading causes of disability in North America. It is the second leading cause of physician visits in the United States. In a substantial percentage of cases in the adult population, there is at least some minor abnormality of disc, endplate, or facet joints. However, the correlation between the specific symptoms and diagnostic testing is often less than gratifying, even when the imaging findings are quite striking. The explanation for this lack of correlation relates, in part, to the numerous potential etiologies for such pain syndromes. Causes include annular tear,

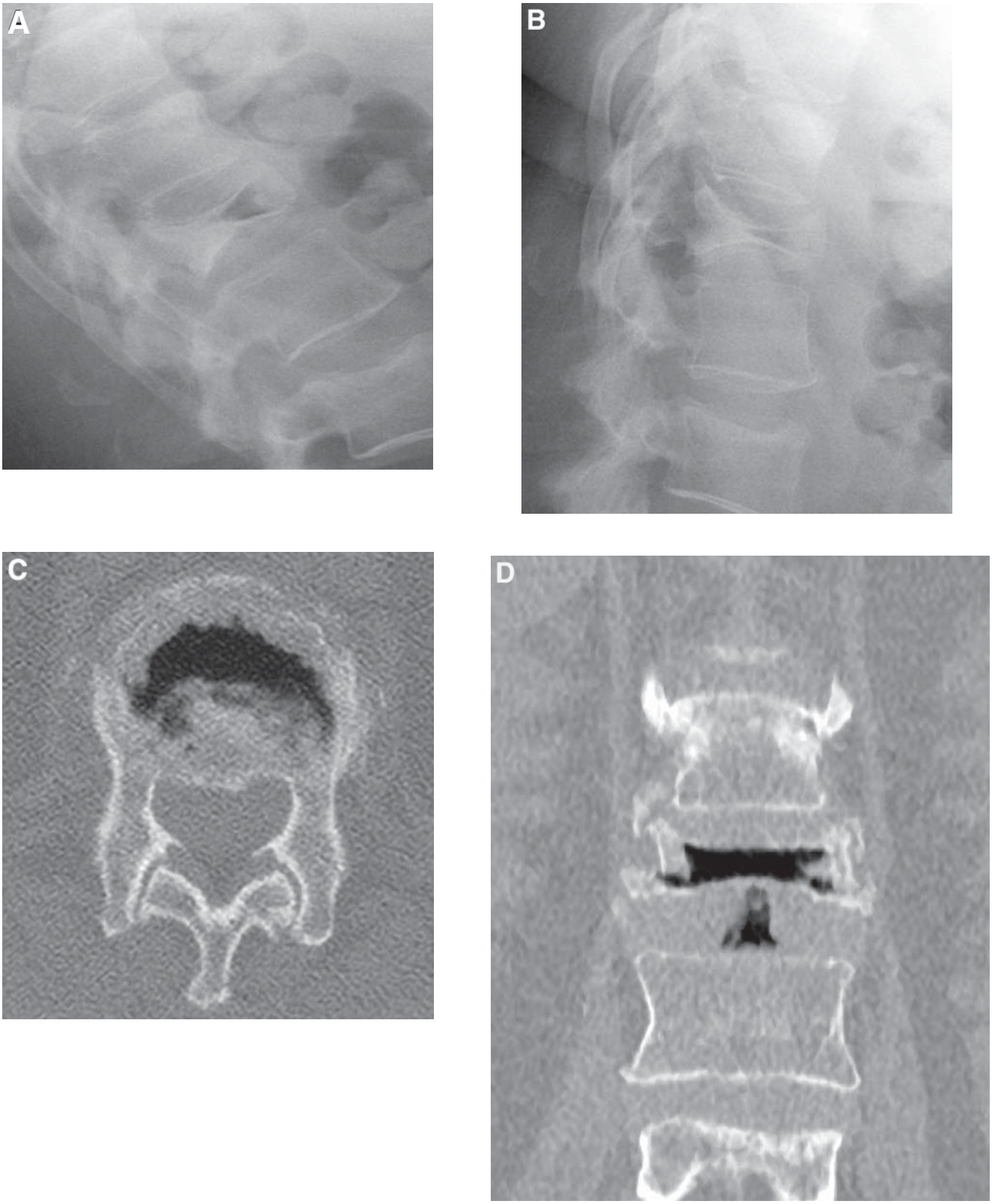

Fig. 3. (A,B) Plain radiographs obtained in extension and flexion reveal vertebral collapse and an intravertebral vacuum cleft, which are characteristic of Kummell's disease (vertebral avascular necrosis). Note the positional change of vertebral height and size of the the vacuum cleft. Axial CT **(C)** and coronal CT reformation **(D)** confirm the presence of intravertebral gas. Note also that the axial CT image more accurately quantifies the degree of retropulsion as compared with the plain radiographs. **(E)** Sagittal STIR demonstrates high T2 signal fluid that has

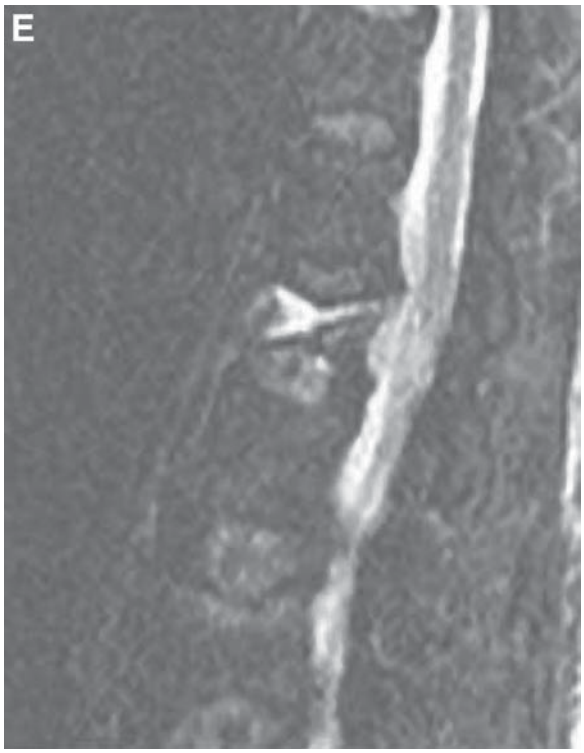

Fig. 3. (*continued*)
replaced the gas within a vertebral vacuum cleft due to prolonged supine positioning. This MR appearance should prompt correlation with plain radiographs or CT to confirm the diagnosis of Kummell's disease.

disc protrusion/extrusion (which may have both a mechanical and chemical irritation effect), spinal stenosis, facet arthropathy, osteophytic nerve root compression, spondylolysis (with or without spondylolisthesis), vertebral compression fracture, sacral insufficiency fracture, discitis/osteomyelitis, spinal tumor (either primary or metastatic), arachnoiditis, and postoperative scar. The clinical differential diagnosis may also include causes of back pain unrelated to the spine, such as abdominal aortic aneurysm, retroperitoneal lymphadenopathy, or renal colic. A detailed discussion of the neurophysiologic basis of back pain and radiculopathy is beyond the scope of this text. The reader is referred to an excellent review of the complex relationship between the somatic and autonomic nervous system and the nature of referred pain by Jinkins et al. *(13)*.

Facet arthropathy is one of the many causes of back pain with or without radiculopathy. Facet disease degeneration can result in nerve root compression due to stenosis of the central spinal canal, lateral recess, or neural foramen. This may result from osteophyte formation, hypertrophy/redundancy of the ligamentum flavum, or the formation of a synovial cyst (Fig. 4). Again the precise mechanism of pain development is not well understood, but it is likely related to both mechanical and inflammatory factors. Support for an inflammatory component lies in the relief of symptoms with injection of corticosteroid and local anesthetic into the facet joint. In this way, a facet joint injection acts as both a diagnostic test and a therapeutic intervention. Similarly, a synovial cyst may be aspirated under image guidance and may even resolve with injection of the adjacent joint.

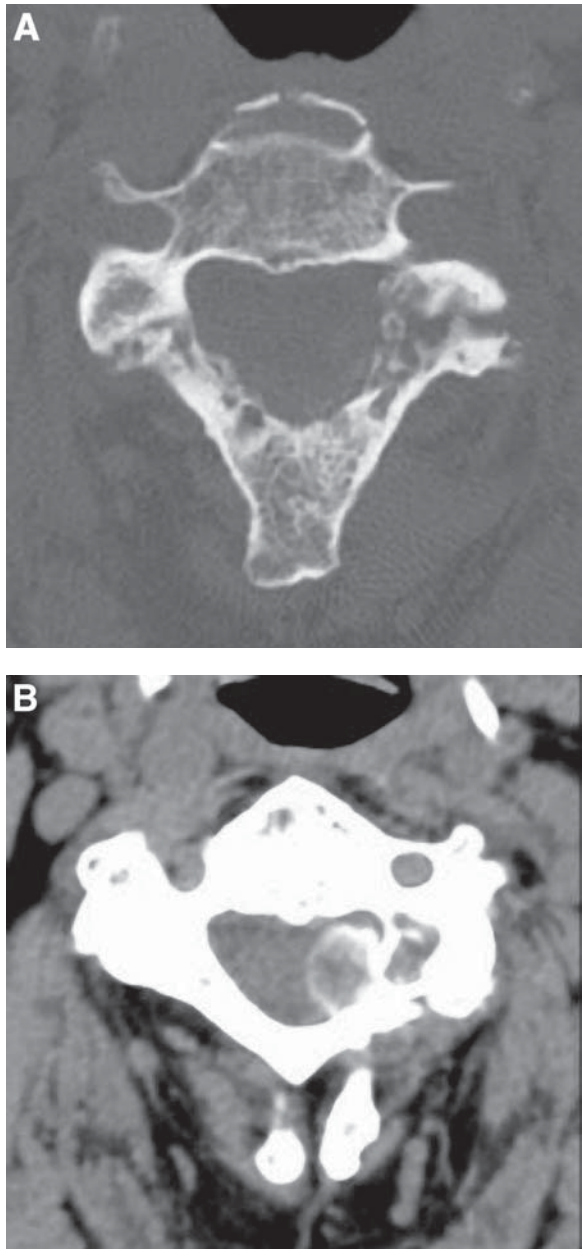

Fig. 4. (A) Axial CT filmed on bone windows demonstrates prominent left-sided facet joint degeneration at C2–3. **(B)** Soft tissue windows is just caudal to image **(A)** at the C3 level. It reveals an extradural mass with mural calcification that causes moderate spinal canal stenosis. The findings are typical for a synovial cyst. This case was confirmed surgically.

One advantage of CT over MRI is the ability readily to distinguish soft tissue structures from bone or osteophyte. CT accurately characterizes facet joint degeneration with

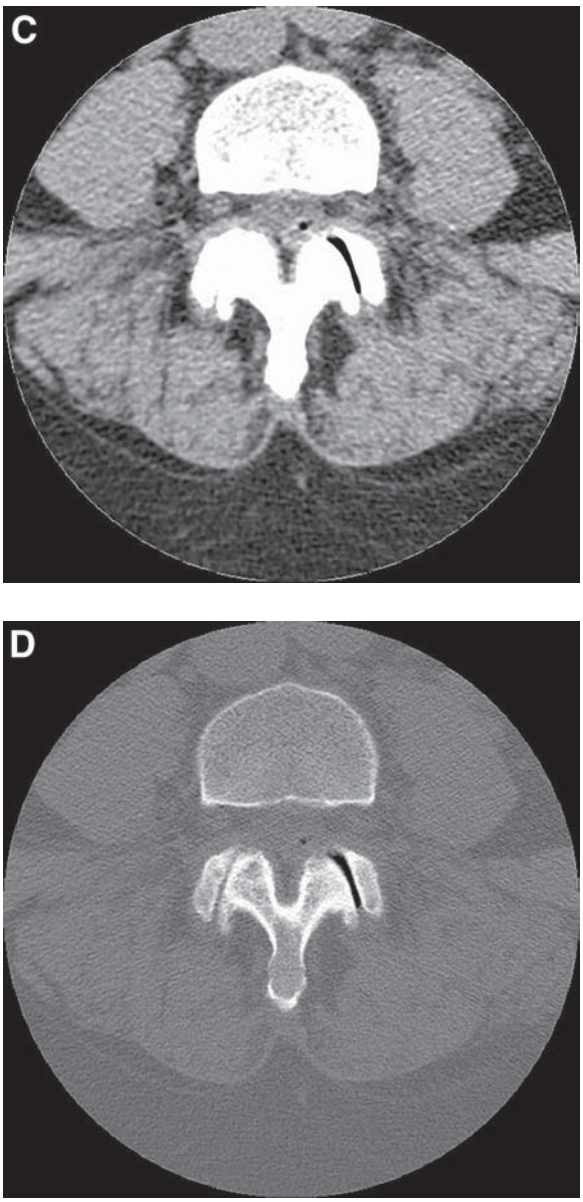

Fig. 4. (*continued*)
(C, D) Axial CT scans from a different patient demonstrate gas within a synovial cyst, indicating communication with the adjacent facet joint.

its accompanying joint misalignment, bony overgrowth, sclerosis, and subchondral cyst formation. CT also readily detects soft tissue mineralization, which can be found in the ligamentum flavum, posterior longitudinal ligament, the wall of a synovial cyst, or in the thecal sac in the rare case of arachnoiditis ossificans. Sagittal reformations are very useful in the assessment of neural foraminal stenosis. CT accurately characterizes spondylolisthesis, which may be secondary to facet joint degeneration or spondylolysis. The ability to detect central canal and lateral recess stenosis is comparable to that of MRI. The high spatial resolution also extends to evaluation of surgical hardware. CT, often following an initial plain film evaluation, is the preferred method for evaluating the integrity of a surgical construct, which may be diminished by hardware malposition or fracture *(14)*.

SPINAL CANAL STENOSIS

Central spinal canal stenosis may be developmental, acquired, or a combination of the two. Developmental stenosis is relatively uncommon and is estimated to account for approx 15% of all cases of spinal stenosis. It may be idiopathic or related to a more generalized disorder affecting the skeletal system, as in the case of the mucopolysaccharidoses or Down's syndrome. The idiopathic variant may selectively involve the lumbar region or may be generalized. It results from the formation of short pedicles with a resulting decrease in the cross-sectional diameter of the central canal. In isolation, this abnormality is generally not symptomatic but renders the patient more susceptible to relatively mild derangements of the disc or posterior elements. Acquired central spinal stenosis may be caused by various abnormalities related to degeneration of the intervertebral disc (vertebral osteophyte, circumferential disc bulge, focal disc protrusion or extrusion), facet joints (osteophyte, synovial cyst, or spondylolisthesis), and hypertrophy of the ligamentum flavum. Clinical presentation is nonspecific and includes back pain and radiculopathy that despite impressive imaging findings may be asymptomatic. The clinical consequence of more severe stenosis is a syndrome of neurogenic or spinal claudication, related to compression of the nerve roots of the cauda equina. The symptoms are typically bilateral and include back pain, sciatica, lower extremity parasthesias, and motor weakness, which tend to be exacerbated on standing or walking and improved with lying flat or sitting, particularly with flexion. The straight leg raise sign is frequently absent and sensory changes are often nondermatomal owing to the typically diffuse nature of disease. Bowel, bladder, and sexual dysfunction are late manifestations. Axial T2-weighted MR images are the best noninvasive way to evaluate the degree of central canal stenosis. CT and CT myelography are comparable techniques *(14)*.

SYNOVIAL CYSTS

Juxtaarticular or synovial cysts are synovium-lined cystic masses that arise adjacent to degenerated facet joints and usually communicate with the joint space. Synovial cysts are most common in the middle and lower lumbar regions, with cervical lesions being relatively uncommon. The result is an extradural mass that lies posterior or posterolateral to the thecal sac within the spinal canal. Cyst contents are variable and include serous fluid, more viscous gelatinous material, hemorrhage, or gas.

This accounts for the varied appearance of synovial cysts on imaging studies. On CT, cysts range from hypodense to hyperdense (the latter indicating hemorrhage or protein-rich fluid), and the cyst wall may be calcified (Fig. 4). The lesions may be difficult to detect on CT or, when of soft tissue attenuation, may be misinterpreted as a free disc fragment. The MR appearance on T2-weighted images is usually characteristic, with a low signal intensity rim and high signal centrally. A fluid level may be present within the cyst cavity. The capsule may enhance following contrast administration. On injection of the adjacent facet joint, the cyst will often fill with contrast, indicating communication with the joint space. For that reason, one of the management strategies for symptomatic synovial cysts is corticosteroid injection into the affected joint. Others have advocated percutaneous drainage under image guidance, with or without the instillation of steroids. Surgical removal via laminectomy is generally reserved for large lesions with significant mass effect.

PARS INTERARTICULARIS DEFECTS (SPONDYLOLYSIS)

Spondylolysis represents a unilateral or bilateral defect in the pars interarticularis of the vertebra. Alignment may be normal or there may be accompanying spondylolisthesis. The etiology of spondylolysis has long been debated. Current consensus would favor that the lesion is an acquired fatigue fracture secondary to repetitive stress rather than congenital. The recognized spike in incidence in school-age children would support that perception. It is thought to be present in as many as 3–7% of the population, with a male predominance. The lower lumbar region is most commonly affected with involvement at the L5 level in two thirds of cases. The incidence decreases at each ascending level in the lumbar spine. Involvement of the cervical spine is uncommon.

When plain radiography is used, pars defects are most clearly visible on oblique projections. A radiolucent cleft is identified through the neck of the "Scottie dog," which describes the appearance of the pedicle, facet joint, and lamina in that imaging plane. Plain films may be nondiagnostic owing to poor technique, improper positioning, or if there is superimposed facet osteophyte and sclerosis. CT is more definitive and will clearly demonstrate a break through the region of the pars interarticularis (Fig. 5). In the axial plane, contiguous images will fail to demonstrate a complete ring at the affected level. The appearance on sagittal reformations mimics that of the oblique radiograph. In the unusual situation of a unilateral pars defect, hypertrophy and sclerosis of the contralateral pedicle and lamina will be seen, related to asymmetric loading stress. The findings may lead to an erroneous diagnosis of osteoid osteoma. Similar changes can result from congenital absence of a pedicle, lamina, or articular facet. MRI is frequently diagnostic in the setting of pars defects, with CT being confirmatory in equivocal cases. All of the standard imaging modalities will depict spondylolisthesis associated with spondylolysis, although CT and MRI have the added advantage of quantifying the degree of secondary central canal and neural foraminal stenosis. Increased activity on bone scan in the region of the spondylolysis has been correlated with clinical activity.

SPINAL TRAUMA

The balance between the use of plain film radiography and CT in the evaluation of acutely injured patient continues to evolve. The debate over the appropriate triage algorithm considers such factors as time, cost, and diagnostic accuracy. In reality, other factors such as clinical judgment, regional practice variations, and the possibility of litigation also affect the utilization of resources. The issue boils down to two considerations. First, who should be imaged? Second, how should they be imaged? A complete discussion of all of these issues is beyond the scope of this chapter, but a few background points are worth noting. The National Emergency X-Radiography Utilization Study (NEXUS) was a large, multicenter prospective study that evaluated 34,069 patients with neck trauma in an attempt to determine criteria for classifying patients with an extremely low likelihood of clinically significant injury. The goal was to define a subset of patients for whom imaging would not be necessary. Five criteria had to be satisfied in order to be considered for the low probability category. These consisted of the absence of midline cervical tenderness, the lack of a focal neurologic deficit, a normal level of consciousness, the absence of intoxication, and the lack of a distracting painful injury. This clinical tool identified 99% (missing 8 of 818 fractures) of the clinically significant injuries. Further investigation revealed that only two of the eight missed fractures were believed to be clinically significant, and in one of those two the criteria had not been correctly applied. Their conclusion was that clinical indicators accurately predict the likelihood of significant cervical spine injury *(15)*. The result would be improved diagnostic yield and cost-effectiveness for imaging studies.

As to the question of how best to image the patient suspected of cervical injury, there is to date no consensus. There appears to be a trend toward the use of CT earlier in the investigation, usually following a series of plain radiographs including anteroposterior, lateral, and odontoid views. In the severely injured patient, obtaining adequate plain films is difficult and time consuming, often requiring multiple repeat images. This can lead to a costly delay in the management of other potentially life-

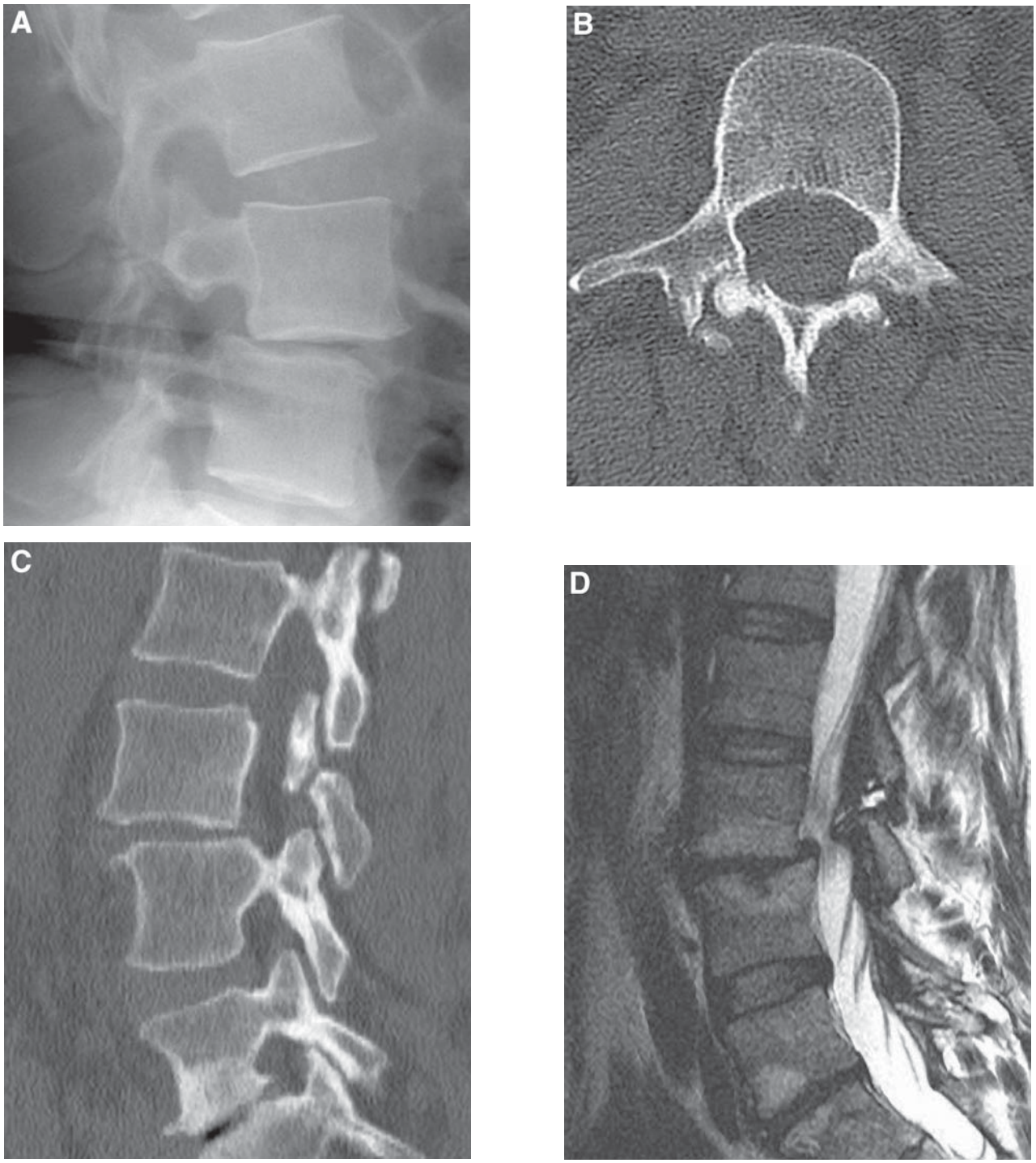

Fig. 5. Lateral radiograph **(A)** and axial CT **(B)** reveal obvious interruption of the pars interarticularis at L3 bilaterally. There is associated disc degeneration at L3–4 with grade 1 spondylolisthesis. **(C)** Sagittal CT reformation again demonstrates the spondylolysis. The actual bony defect may be difficult to detect on MR images, as in this case. **(D)** Sagittal T2 shows reactive edema, which is indirect evidence of instability at that level.

threatening injuries. The cervicothoracic junction is often poorly imaged in the severe trauma patient. The odontoid process is frequently obscured by overlapping bony structures or by the presence of an endotracheal tube. This has led some to advocate the use of CT to clear the cervical spine routinely in the setting of an inadequate initial plain film evaluation (Fig. 6) *(1)*. Others have further proposed that CT should be the initial study in severely injured patients who have already been triaged to CT for evaluation of other critical injuries, such as to the head or viscera *(16)*. Several studies support this proposal. Blacksin and Lee studied routine use of CT of the craniocervical junc-

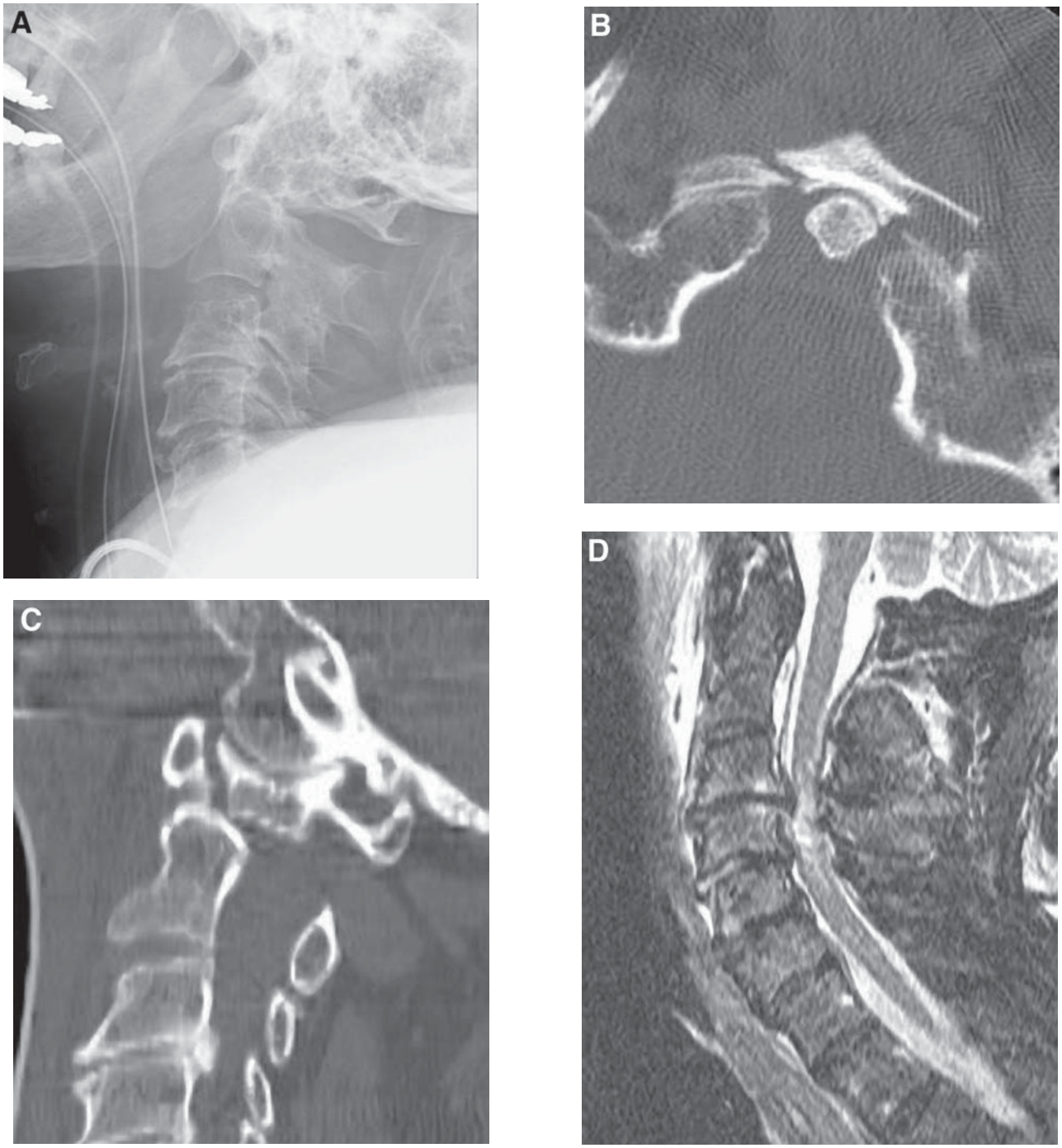

Fig. 6. (A) Lateral radiograph was obtained following trauma in a patient with acute quadriparesis. The endotracheal tube precluded obtaining a satisfactory odontoid view. The lateral view was initially interpreted as showing no fracture. Axial CT **(B)** and sagittal CT reformation **(C)** demonstrate minimally displaced fractures of the anterior arch of C1, which extended into the C1 lateral mass bilaterally. **(D)** Sagittal STIR reveals spinal cord edema at the C3–4 level, which is not directly related to the fractures. The likely mechanism is a hyperextension injury in the setting of degenerative spinal stenosis. Note the dorsal osteophyte complex at C3–4 on the sagittal CT image. This example underscores the complementary nature of CT and MRI in the trauma setting.

tion in 100 patients at high risk for cervical spine injury. They found eight fractures (8%) that were not directly identified on plain radiographs although prevertebral soft tissue swelling was seen in three of those patients *(17)*. Berne et al. studied 58 patients with severe, blunt trauma who had multiple injuries and were clinically unevaluable for cervical spine injury (due to head injury, shock, intoxication, pharmacologic sedation, or paralysis). All patients were evaluated with standard cervical spine radiographs and all underwent complete cervical spine helical CT studies. Twenty patients (34.4%) had cervical spine fractures. Plain radiography failed to detect eight fractures, three of

which were deemed unstable. Two fractures were missed on CT although both were considered stable. The authors concluded that a protocol of initial complete cervical spine CT combined with cervical radiography would lead to more rapid and accurate diagnosis of cervical fractures in high-risk patients *(1)*. Undoubtedly, management algorithms will continue to be modified and imaging protocols will vary between institutions. Other factors such as expense and scanner availability will inevitably factor into the equation. As CT technology continues to improve and scan times decrease, the use of CT in the evaluation of cervical spine injury will likely increase.

Careful attention to technique is critical to maximize both sensitivity and specificity of spine CT in the setting of trauma. Thin-section helical axial CT images are acquired through the region of interest with both sagittal and coronal reformations performed in all cases. The latter are critical to the evaluation of fractures in the axial plane, such as a nondisplaced odontoid fracture. Compression fractures may also be quite subtle on axial images but are readily seen on sagittal reformations. The sagittal plane is also best for characterizing abnormalities of alignment, particularly of the facet joints. Such reformatted images easily distinguish a high riding facet from one that is either perched or completely jumped. Facet fractures are best confirmed in the axial plane since those images have the highest spatial resolution. At our institution, helical (MDCT) 2.5-mm axial unenhanced CT images are obtained from the skull base through the upper thoracic spine. The base data are then reconstructed to 1.25 mm slice thickness at 1.25-mm intervals and then reformatted as 2.5-mm slices in the sagittal and coronal planes. The images are reconstructed in both soft tissue and bone algorithm.

Image interpretation should utilize both bone and soft tissue windows. Close inspection of the latter may reveal a disc extrusion or epidural hematoma, which may be unsuspected in a severely injured patient. Such a finding should prompt evaluation with MRI to confirm the abnormality and to assess for accompanying spinal cord injury, which is not possible on CT. MRI has the added advantage of detecting ligamentous injury in the acute phase without the need for flexion and extension of a potentially unstable spine. The sensitivity of MRI for soft tissue injury diminishes with time, and thus flexion–extension views are still of use in looking for delayed instability. They are also indicated in the acute setting for cooperative patients who have been cleared of fracture by previous imaging.

The principles for imaging the thoracic and lumbar spine are the same as in the cervical spine. Generally speaking, the force required to produce a fracture in the thoracic region is higher than in the cervical or lumbar spine because of the stabilizing effect of the thoracic cage. For that reason, thoracic spine injuries are less common but tend to be more severe. There is a high incidence of associated neurologic deficit, occurring in approx 50% of cases. Comorbid visceral injury is another important factor in these patients. Thoracic spine fractures may be associated with cardiac contusion, pulmonary contusion or laceration, tracheobronchial rupture, pneumothorax, and aortic rupture. With lumbar fractures, potential concurrent injury to the solid organs or hollow viscera in the abdomen necessitates efficient evaluation of the spine. The obvious goal of imaging is accurate and rapid diagnosis while allowing for continued monitoring and resuscitation efforts. Although it is beyond the scope of this chapter to examine these visceral injuries, suffice to say that CT plays a vital and ever increasing role in their evaluation.

The mechanism of injury to the thoracolumbar spine is usually related to axial loading and flexion and results in a predictable array of fracture patterns, including compression fracture, burst fracture, flexion–distraction (Chance fracture), and fracture–dislocation. Over the years, many schemes have been proposed for the classification of injuries to the thoracic and lumbar spine. One of the most commonly utilized is the three-column system devised by Denis, who divided the spine into anterior, middle, and posterior components in an attempt to categorize fractures on the basis of mechanism and to make predictions regarding vertebral stability. The anterior column consists of the anterior longitudinal ligament, the ventral half of the vertebral body, and the corresponding intervertebral disc. The middle column is composed of the posterior half of the vertebral body, the corresponding disc segment, and the posterior longitudinal ligament. The posterior column is made up of the bony posterior elements and the supporting ligaments, including the ligamentum flavum and interspinous ligaments. Denis asserted that spinal instability would ensue if any two of these columns were disrupted *(18)*. Simple compression fractures, because they involve only the anterior column, are considered stable. Burst-type fractures, which by definition involve the middle column, are by this system always classified as unstable (Fig. 7). Fracture–dislocation (dislocation is usually anterior or lateral) and flexion–distraction injuries involve all three columns and are obviously unstable *(18)*. Regardless of the classification system used, imaging remains the fundamental basis for the diagnosis and thus the management of patients with spinal injury.

With few exceptions, the modality initially employed in the investigation of spinal trauma is plain film radiography. It has the advantages of rapid acquisition and low cost, and it also provides an easy basis for comparison in

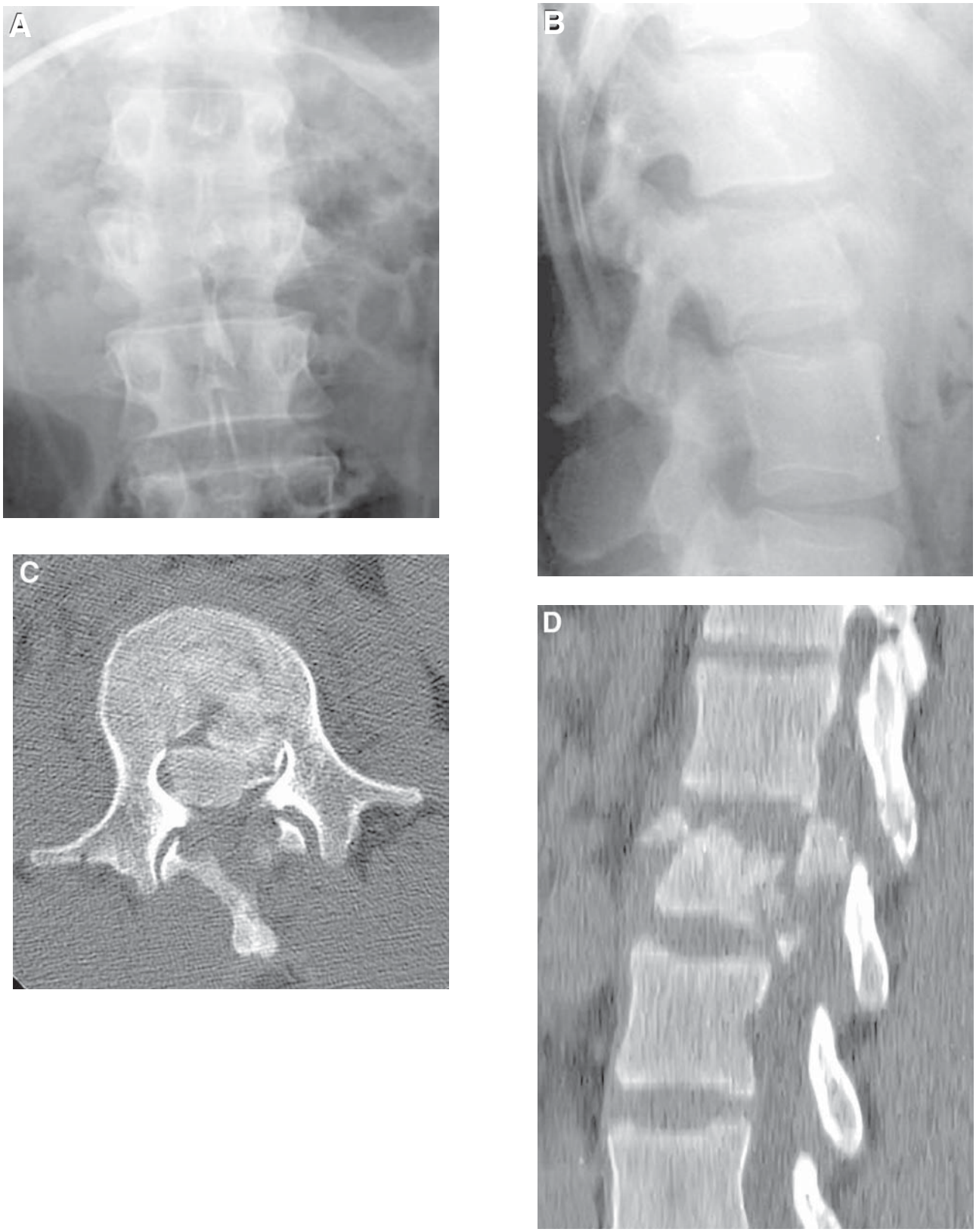

Fig. 7. (A, B) AP and lateral radiographs demonstrate the classic findings of a burst fracture at the L2 level. There is vertebral collapse, retropulsion, and widening of the interpedicular distance. Axial CT **(C)** and sagittal CT reformation **(D)** show to better advantage the distribution of fracture fragments and the degree of retropulsion. **(E)** Sagittal STIR reveals ligamentous disruption posteriorly. Notice also edema

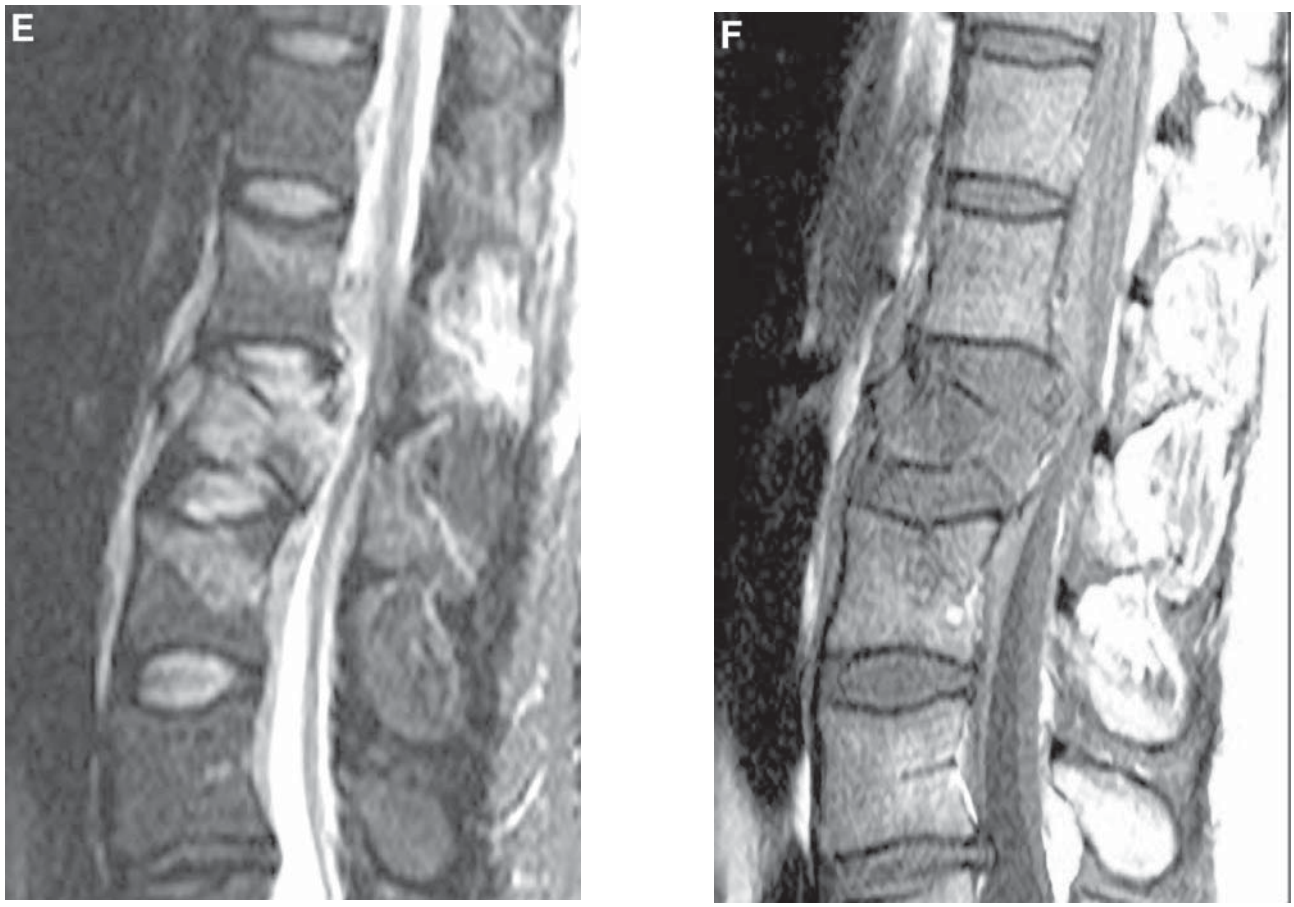

Fig. 7. (*continued*)
in the adjacent L1 and L3 vertebral bodies despite a normal appearance on CT. This points to the sensitivity of STIR images in detecting marrow and soft tissue edema. **(F)** Sagittal T1 reveals a moderate ventral epidural hematoma.

the anticipation of serial exams *(6)*. There are, however, limitations. Because of the overlapping soft tissues of the shoulder girdle, the upper thoracic spine is often poorly evaluated on plain X-ray images. Respiratory motion, external radiopaque material overlying the spine, and localized differences in beam penetration (most commonly related to the diaphragm) often result in suboptimal radiographs in the severely injured patient. Even high-quality images fail to detect subtle fractures and tend to underestimate the degree of retropulsion. Taking the case of a fracture–dislocation, CT more accurately depicts the extent of the fractures (especially with regard to the posterior elements), the relationship of the bone fragments, and the degree of retropulsion. The sagittal and coronal reformations clearly demonstrate loss of vertebral body height, vertebral subluxation, and abnormal alignment of the facet joints. This has obvious implications in terms of fracture classification and the assessment of stability. MRI adds important information for patients with complex spine fractures and those with neurologic deficits. Spinal cord contusion, epidural hematoma, disc extrusion, and ligamentous disruption are all best evaluated with MRI. This modality also is ideal for detecting delayed complications of spinal trauma such as myelomalacia, cord atrophy, and syrinx formation.

SPINE TUMORS

Primary tumors of the spine are far less common than spinal involvement with metastatic disease, multiple myeloma, or lymphoproliferative disorders. The presence of multiple lesions suggests the latter diagnoses although some primary lesions can also be multiple, as with multifocal hemangiomas or enostoses, which might create diagnostic confusion. Because of higher contrast resolution, spinal involvement with disseminated malignancy (metastic disease or multiple myeloma) is best investigated with MRI. Most lesions in this setting will be of low signal intensity on T1-weighted images and high signal intensity on T2 and STIR images. Purely sclerotic lesions can be problematic on MRI because of a lack of increased T2 signal. In this setting, the areas of sclerosis may be more conspicuous on CT. Until recently, it was not practical to study the entire spine with CT. The ability of bone

scan and MRI to image the spine effectively still today relegates CT to an adjunctive role. CT does have its uses, however. It can distinguish an atypical hemangioma (those that lack T1 shortening precontrast) from a malignant lesion seen on MRI (*see* later). CT also plays an obvious role in the evaluation of patients for whom MRI is contraindicated, albeit with some loss of sensitivity *(19)*.

With localized disease of the spine, both benign and malignant primary spinal tumors enter the differential diagnosis. This covers a broad spectrum of lesions ranging from a benign enostosis (bone island) to a highly aggressive sarcoma. In such cases, CT can add valuable information about the etiology and biological activity of the lesion. For example, an expansile lesion with multiple cystic areas that contain fluid–fluid levels is characteristic of an aneurysmal bone cyst. The presence of mineralized matrix would suggest a tumor of osteoid or cartilagenous origin (osteosarcoma or chondrosarcoma). Indicators of a more aggressive lesion include poorly defined margins (wide zone of transition), bone destruction, associated soft tissue mass, and invasion of adjacent structures *(19,20)*.

BENIGN TUMORS

On the benign end of the tumor spectrum, there are several lesions whose appearance is usually diagnostic, including enostosis, osteoid osteoma, hemangioma, and osteochondroma. Enostoses, or bone islands, are benign incidental lesions detected on imaging, which occasionally are mistaken for sclerotic metastases. They are classically round to oval in shape, sharply defined, and have characteristic spiculated margins. Most lesions do not demonstrate activity on bone scintigraphy although giant bone islands (>2 cm) may show increased uptake. On rare occasions, interval growth will prompt biopsy to prove its benign etiology.

Osteoid osteoma is a lesion of young patients, usually between the ages of 10 and 20 yr, with a male predominance (3:1). It should be noted that only 10% of osteoid osteomas involve the axial skeleton. The classic clinical history in such cases is painful scoliosis, but it may also present with localized pain, radiculopathy, or gait disturbance. The pain tends to be worse at night and is typically relieved with aspirin or nonsteroidal antiinflammatory drugs (NSAIDs). Spinal lesions tend to involve the posterior elements (75%) and involvement of the lumbar spine is most frequent (59%), followed by the cervical (27%), thoracic (12%), and sacral (2%) regions. On CT, the lesion is round to oval with a central radiolucent nidus that is surrounded by a variable extent of reactive sclerosis. The central nidus is usually <1.5 cm in diameter and may contain a focus of calcification. Although the lesion may heal spontaneously, complete surgical resection of the nidus is often needed for cure. CT-guided percutaneous excision or ablation of the nidus has also been described *(19)*.

A vertebral hemangioma is a very common incidental finding on spine imaging studies (Fig. 8). On MRI, the lesions are usually of high signal intensity on both T1- and T2-weighted images with a subtly variegated internal architecture. Hemangiomas are most frequently found in the vertebral body although extension into the pedicles and laminae is well described. Isolated involvement of the posterior elements is uncommon. Rarely there is a soft tissue component with extension into the paraspinal soft tissues or spinal canal. The CT appearance is virtually pathognomonic and is characterized by a geographic zone of radiolucency that contains an internal scaffold of coarse vertical trabeculae, the so-called "corduroy" pattern. CT is very useful for confirming the diagnosis of hemangioma when the MRI appearance is atypical.

Spinal osteochondromas are uncommon tumors that can be seen sporadically as solitary lesions or in the setting of hereditary multiple exostoses. Patients are young, usually in the third or fourth decade, and there is a male predominance. Any part of the spine may be affected but the cervical region is most often involved. Myelopathy is a frequent presenting manifestation although trauma may uncover an otherwise asymptomatic lesion. Osteochondromas that project anteriorly may cause dysphagia, vocal cord dysfunction, or vascular compromise. The lesion may be sessile or pedunculated. As with exostoses in the appendicular skeleton, the characteristic finding is lesion continuity with the underlying vertebral cortex and marrow, which is well depicted by CT. Both CT and MRI are well suited to demonstrate the degree of accompanying spinal canal stenosis or mass effect on paravertebral structures. Osteochondromas rarely undergo malignant transformation into a secondary chondrosarcoma *(19)*.

There are three primary spinal tumors that are considered pathologically benign but that may have aggressive clinical features on the basis of size and an expansile growth pattern. These are the aneurysmal bone cyst, osteoblastoma, and giant cell tumor. All three lesions tend to occur in younger patients. Although histologically benign, these tumors have substantial recurrence rates if not completely resected. Complete resection of large lesions is often impossible in the spine as a result of the associated morbidity.

Aneurysmal bone cyst (ABC) in the spine most often involves the thoracic region. Involvement of the sacrum, unlike giant cell tumor, is rare. Pathologically, the lesion is characterized by multiple blood-filled cystic spaces. On CT and MRI, a multicystic mass with expansile remodeling is found with characteristic fluid–fluid levels, indi-

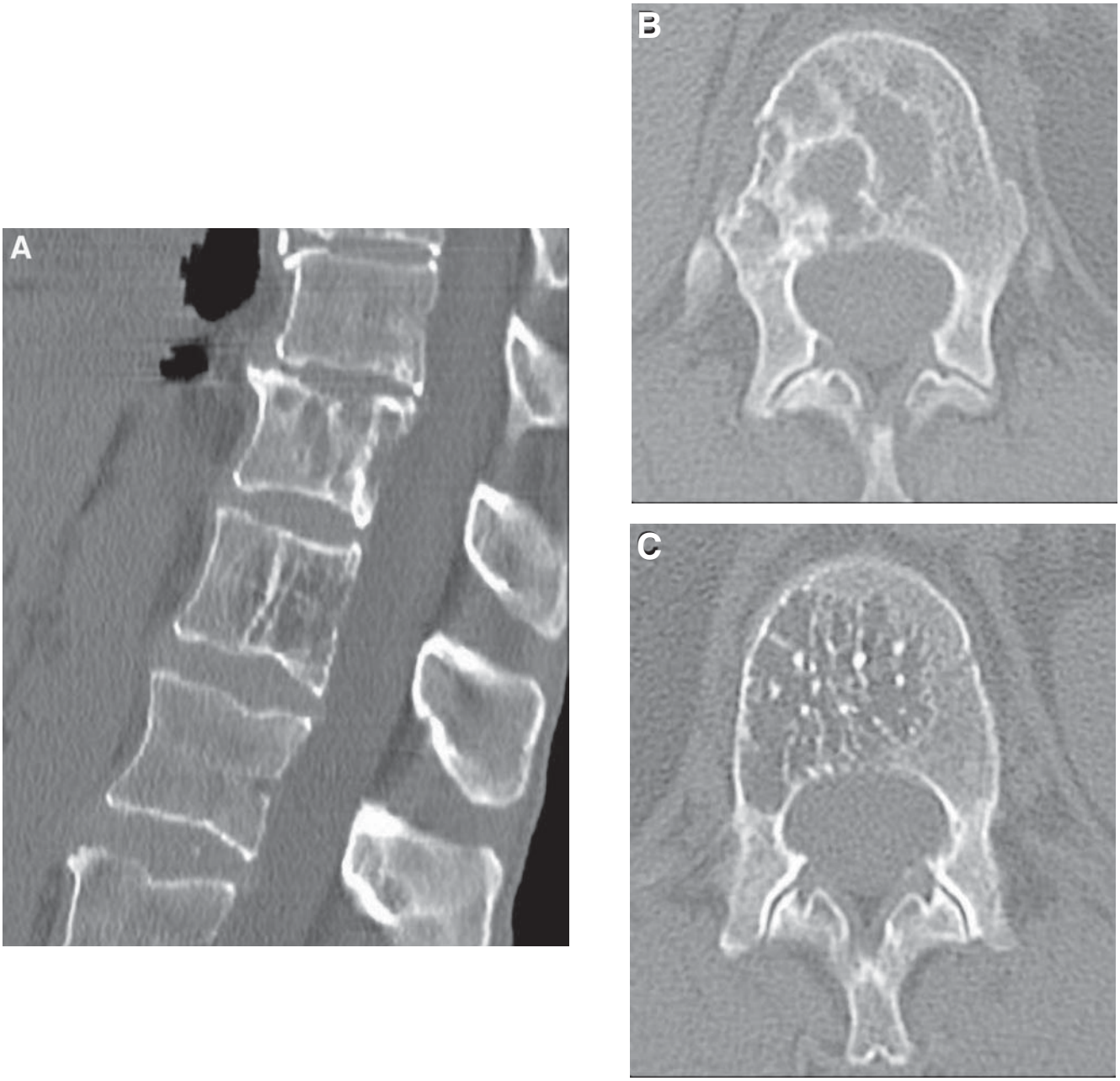

Fig. 8. (A) Sagittal CT reformation reveals predominately osteolytic foci involving both the L1 and L2 vertebrae in a patient with suspected metastatic breast carcinoma. **(B)** Axial CT at the L1 level shows irregular areas of lytic bone destruction with a small break in the cortex laterally. This proved to be metastatic disease. **(C)** Axial CT at the L2 level demonstrates the classic "corduroy" appearance of a vertebral hemangioma. Note the prominent vertically oriented trabeculae on both the axial and sagittal images.

cating the presence of hemorrhage. A thin outer rim of preserved periosteum is typical although it may be interrupted. The lesion is usually centered on the posterior elements although involvement of the vertebral body is common (75–90%). Direct extension to involve adjacent ribs and vertebral bodies has been described (Fig. 9). ABCs are vascular lesions and embolization can be performed as a primary treatment or preoperatively to minimize blood loss at surgery. ABCs are also radiosensitive *(19)*.

Like ABC, osteoblastoma of the spine most often localizes to the posterior elements with extension into the vertebral body being fairly common (42%). Smaller lesions have an appearance very similar to osteoid osteoma with a central lucent region surrounded by reactive sclerosis. With this type of osteoblastoma, the only distinction from osteoid osteoma is based on size (>1.5 cm). At the other end of the spectrum is an aggressive, expansile mass with bone destruction, paraspinal soft tissue infiltration, and multifocal mineralization that may resemble chondroid

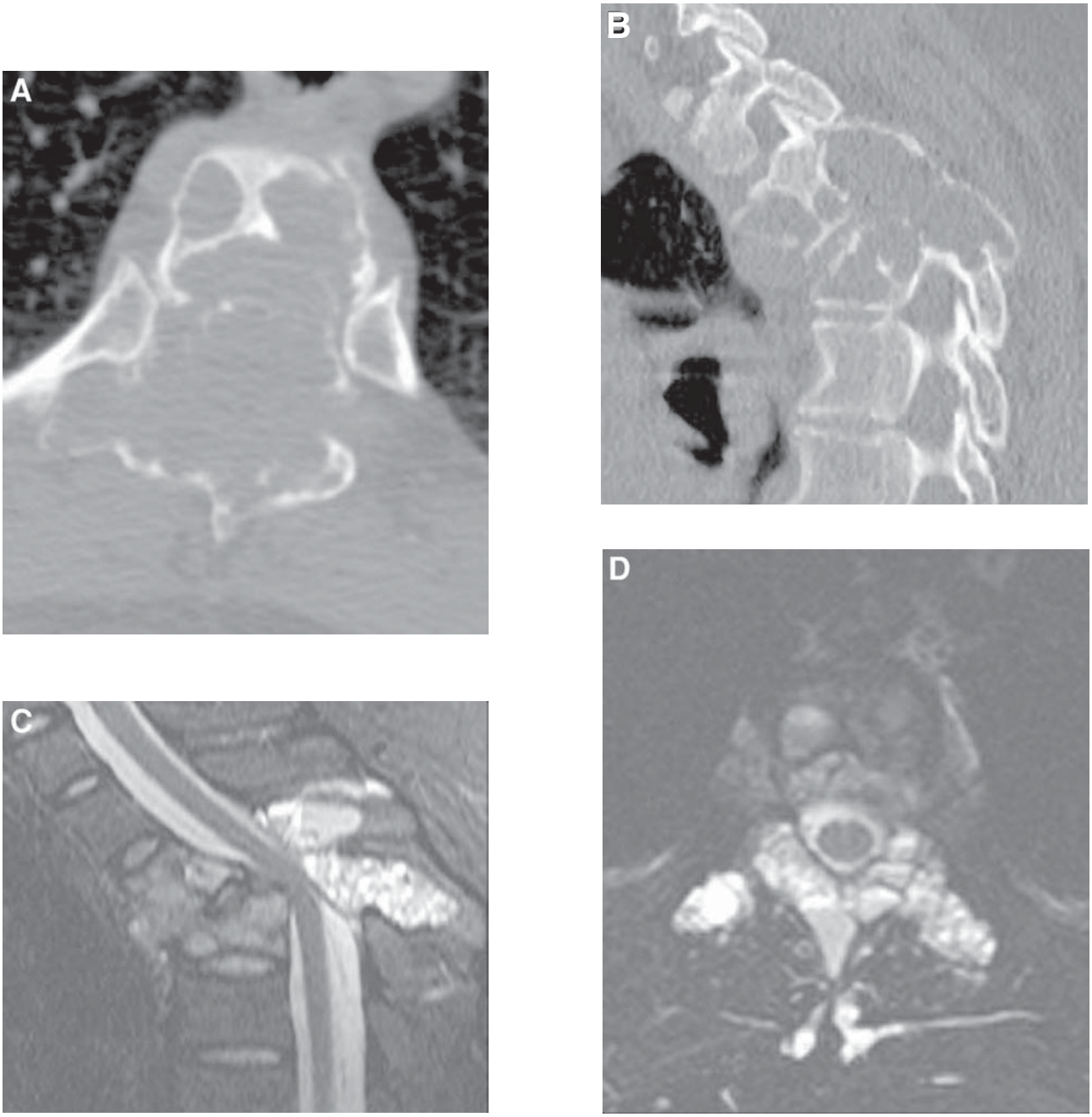

Fig. 9. Axial CT **(A)** and sagittal CT reformation **(B)** demonstrate expansile, destructive lytic lesions involving both the T2 and T3 vertebral levels. There is involvement of the anterior and posterior elements with vertebral collapse and accompanying kyphosis. Differential considerations would include primary and secondary spinal malignancies (metastatic disease, multiple myeloma, or lymphoma) as well as benign aggressive lesions such as aneurysmal bone cyst (ABC) or osteoblastoma. **(C, D)** Sagittal and axial STIR demonstrate a characteristic multiloculated, cystic appearance with fluid–fluid levels (indicating hemorrhage). Although not entirely specific, this pattern strongly suggests the diagnosis of ABC, which was confirmed surgically.

matrix (rings and arcs). Treatment is surgical resection. The recurrence rate for the aggressive form is approx 50% vs 10–15% for the more indolent subtype. Malignant transformation is rare but has been reported.

Giant cell tumors (GCTs) differ from the other two lesions in that the most arise in the sacrum. In addition, involvement of the spine usually localizes to the vertebral body rather than the posterior elements. Necrosis and hemorrhage within a GCT may create an appearance similar to an ABC. Unlike GCTs of the long bones, lesions of the sacrum and spine have a tendency to spread across natural boundaries, such as the intervertebral disc space and sacroiliac joint. This finding may lead to a misdiagnosis of infection. Treatment for GCTs is surgical resec-

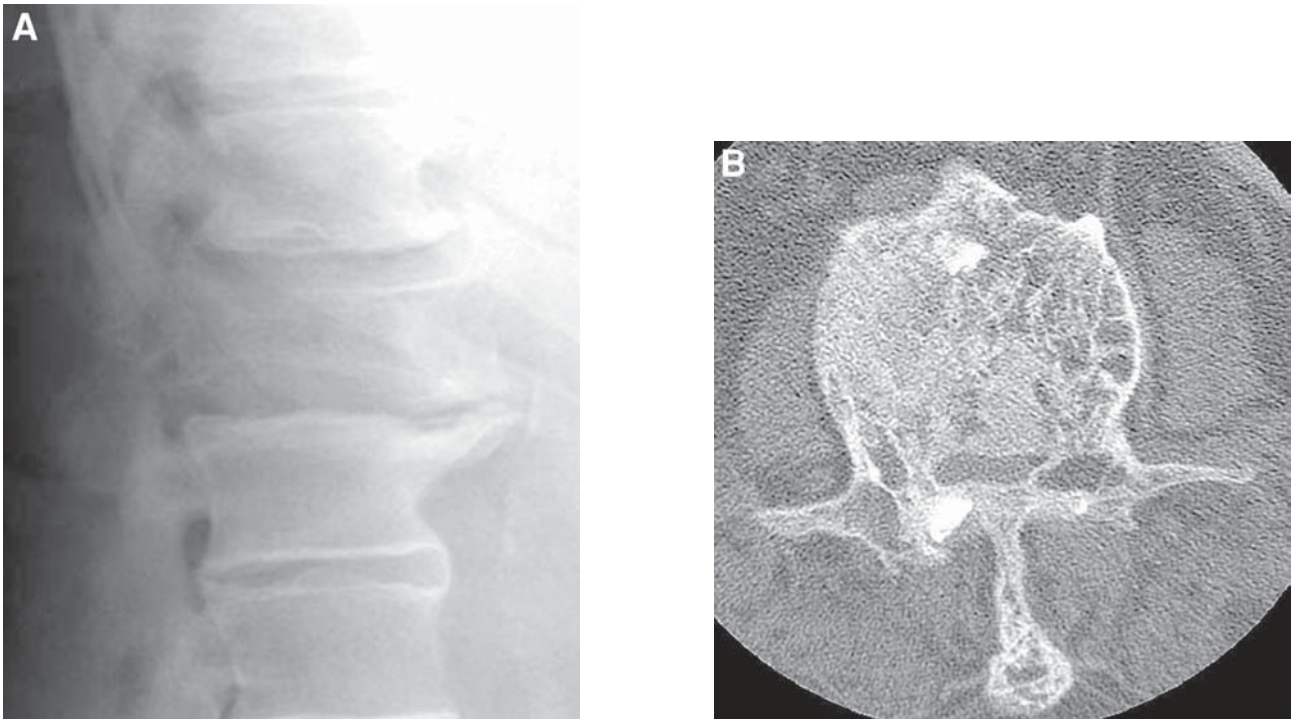

Fig. 10. Lateral radiograph **(A)** displays a relatively lucent appearance of the L2 vertebral body with loss of height and some widening in the anteroposterior dimension. Axial CT **(B)** shows the characteristic features of Paget's disease with a coarse trabecular pattern and osseous expansion, which results in severe spinal canal stenosis.

tion. Incompletely resected tumors are treated with radiation. The prognosis of GCT of the spine is less favorable than for the other benign tumors. Recurrence is expected in 40–60% of cases. Malignant transformation of GCTs is described in 10–15% of cases although there is speculation that the majority of these may actually represent radiation–induced sarcomas *(19)*.

MALIGNANT TUMORS

Nonlymphoproliferative primary malignant tumors of the spine in adults include chordoma, chondrosarcoma, and osteosarcoma. In the pediatric population, Ewing's sarcoma and primitive neuroectodermal (PNET) tumors predominate, although with these tumors metastatic disease to the spine is more common than a primary lesion. All of these tumors share an aggressive imaging appearance with frequent bone destruction, paraspinal soft tissue mass, and invasion of adjacent structures, most notably the spinal canal. Large size at presentation often precludes complete surgical resection and patients usually succumb to their disease *(19)*.

Chordoma is a tumor of notochordal remnants that can arise anywhere between the skull base and the coccyx. It is the most common malignant primary spinal tumor in adults, excluding lymphoproliferative disorders. In descending order of frequency, chordomas arise from the sacrococcygeal region (50%), clivus (30–35%), and the remaining spinal regions (15%). Of the latter, the cervical region is most often involved (particularly C2), followed by the lumbar spine. The imaging hallmark is an enhancing, destructive midline mass that demonstrates very high signal intensity on T2-weighted images. Amorphous calcification is frequently seen on CT, particularly in the sacrococcygeal lesions. This pattern is suggestive of the diagnosis but overlaps the appearance of chondrosarcoma, a tumor that also has a predilection for the skull base and the sacrum/pelvis. Not suprisingly, the variant chondroid chordoma shares several histopathologic features with chondosarcoma. Prognosis depends on the extent of resection. Tumors in the saccro-coccygeal region tend to fare better, with a mean survival in the 8- to 10-yr range.

The second most common primary malignancy of the spine is chondrosarcoma. Most lesions arise *de novo*, with only a small percentage resulting from malignant transformation of an osteochondroma. The thoracic spine is the most common location for spinal chondrosarcoma. As stated previously, the imaging appearance is very similar to that of a chordoma. Mineralization with chondroid matrix is typically evident on CT. The tumors are usually low grade and pulmonary metastases, frequently seen with peripheral lesions, are relatively uncommon. Mean survival is approx 6 yr.

Osteosarcomas of the spine are rare. The mean age at onset is in the fourth decade, about 10 yr older than for

conventional osteosarcoma of the extremities. These tumors show variable differentiation and can produce osseous matrix, chondroid martix, or may be entirely lytic. This results in a variety of imaging appearances although densely mineralized matrix is the norm. Osteosarcoma is also one of the causes of a so-called "ivory vertebral body." Secondary osteosarcomas may result from prior radiation therapy (latency period 5–20 yr) or underlying Paget's disease (Fig. 10). Prognosis of spinal osteosarcoma is extremely poor, with death usually occurring in less than 1 yr.

CONCLUSION

In this chapter, I have tried to present an overview of the many uses of CT in the evaluation of spine disorders. Wherever possible, I have compared the strengths and weaknesses of CT and MRI. There are some instances in which these modalities should be viewed as complementary rather than competing because each provides important and significantly different information. It is clear that advances in CT technology have led to a resurgence of CT imaging applications including detailed two- and three-dimensional representations of the spine, CT angiography, CT brain perfusion mapping, stereotactic surgical guidance, and near real-time guidance of interventional procedures. Information that was once the domain of conventional angiography or MRI is now attainable with CT, which has the inherent advantages of wide availability, rapid acquisition, and relatively low cost. Further increases in speed and image quality are forthcoming as multislice volumetric CT scanners continue to improve. This will lead to novel CT applications as well as even greater productivity. CT, it seems, is here to stay. As my friend and fellow radiologist Dr. John Nicotra once said, "CT is good at showing you stuff." To me, that says it all.

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3 Magnetic Resonance Imaging of the Spine

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MRI APPEARANCE OF THE NORMAL SPINE

T1- and T2-weighted images are routinely performed in the evaluation of the spine. With T1-weighting, the intervertebral disc demonstrates fairly homogeneous signal intensity that is slightly less than that of the vertebral body red marrow. Epidural fat can be distinguished by its relatively bright appearance or high signal intensity *(1)*. Nerve tissue, on the other hand, is of low intensity (dark appearance) but may still be differentiated from cerebrospinal fluid (CSF), which appears black with an even lower signal. The thin lines of low signal intensity along the superior and inferior borders of vertebral bodies represent the cortical endplates and have been confirmed by correlation with cadaveric specimens *(2)*.

In contrast to the homogeneous appearance of discs on T1-weighted images, T2-weighting shows a high signal inner portion surrounded by a low signal outer area *(1)*. The high signal corresponds to the water-rich nucleus pulposus and inner fibers of the annulus fibrosus, which cannot be distinguished with magnetic resonance imaging (MRI). The peripheral low signal areas represent the outer fibers of the annulus *(2)*. CSF has fairly high signal intensity with this sequence, which can be distinguished from the low signal nerve tissue *(1)* (Fig. 1).

After the age of 30, intranuclear clefts can be observed as horizontal areas of hypointensity (dark areas) in the nucleus. These are normal changes of aging and represent the appearance of fibrous tissue *(3,4)*. Interestingly, this MRI finding does not distinctly correlate with an anatomic structure in cadaveric studies *(2)*.

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Visualization of the intervertebral foramina and their contents should be performed with both axial and sagittal cuts to ensure adequate delineation of discs, foramina, and nerve roots *(1,5)*. Epidural fat in the neural foramina, which has relatively high signal intensity with T2-weighting, can be differentiated from the very high signal CSF and low intensity nerve tissue, which appears as a filling defect within the CSF *(1)*.

DISC HERNIATION

Findings of disc disease on MRI examination must be carefully correlated with clinical symptoms *(6)*. Jensen et al. performed lumbar spine MRI on 98 patients without back pain and found a 64% prevalence of either a bulge, protrusion, or extrusion *(7)*. Thirty-eight percent had abnormalities at more than one level. A similar study noted extrusions in 24% of asymptomatic people *(8)*. Furthermore, discogenic pain, caused by a small annular tear with an inflammatory reaction, can often produce severe discomfort. This pain may be present even in patients without significant morphologic changes on imaging *(9)*.

The word "herniation" is a generic term for a focal and abnormal extension of the intervertebral disc beyond the margins of the endplates of neighboring vertebral bodies. Protrusions, extrusions, and sequestered discs represent the three types of herniations. A bulge is also an abnormal extension but is by definition not focal. The lumbar levels account for the highest number of herniations, followed by the cervical spine, and more rarely the thoracic spine. Roughly 92% of lumbar disc herniations are found at the L4–5 and L5–S1 levels *(10)*.

A bulge is a symmetric distention of the annulus fibrosus beyond the vertebral body endplates around its entire circumference *(3,10)*. These may exist in either

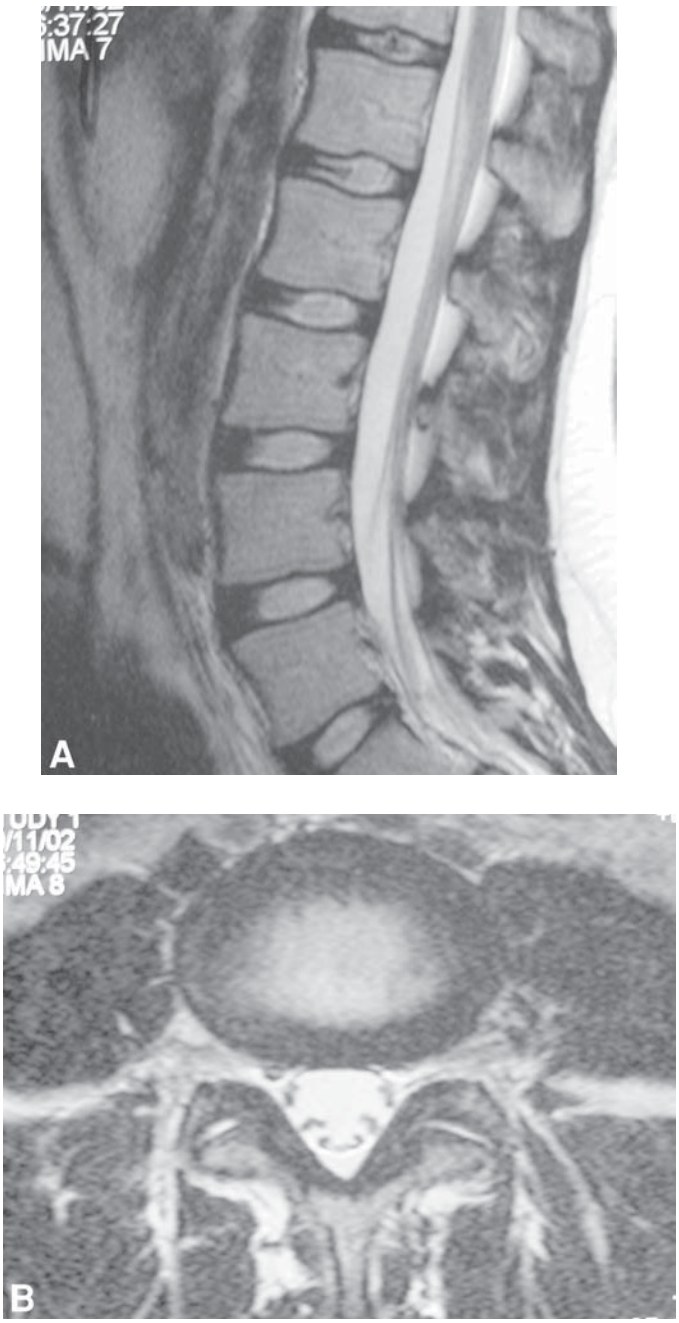


Fig 1. Normal lumbar spine. Sagittal T2-weighted **(A)** and axial T2-weighted. **(B)** images show the high signal central nucleus pulposus of the disc surrounded by the low signal outer fibers of the annulus. In addition, the high signal CSF can be distinguished from the low signal nerves.

degenerated or nondegenerated discs *(3)*. Although some believe that the annu-lus fibrosus is intact with disc bulges, a cadaver study reported by Yu et al. showed that 84% of adult discs with radial tears had bulges >2.5 mm beyond the vertebral endplates *(11)*. Similarly, in all but a single case, discs with bulges >2.5 mm contained either a radial tear or complete disruption of the annulus. In a separate MRI investigation of annular tears, 14 of 16 discs with radial tears seen on T1-weighted contrast enhanced images had a disc bulge *(12)*. Masaryk et al., however, state that bulging discs are the result of disc degeneration with an intact annulus, and the T2-weighted images show the low intensity Sharpey's fibers to be intact *(13)*.

In either case, loss of disc height is present owing to the peripheral extension of the disc substance. Bulges may encroach on the spinal canal and clinically mimic a central herniation (see later for definition of central herniation) or, alternatively, may affect the contents of intervertebral foramina and result in foraminal nerve impingement *(10)*. These are best imaged using both sagittal and axial images to compare the diameter of the disc with those of the neighboring levels. Tears of the annulus may or may not be discernible on imaging.

A protrusion is a focal herniation of the nucleus pulposus through an incomplete rent in the annulus fibrosus. Nuclear material passes between layers of annulus fibrosus and forces the outer layers of the annulus to extend outward *(3)*. Because of the intact annulus, protrusions cannot migrate cranially or caudally to a significant extent.

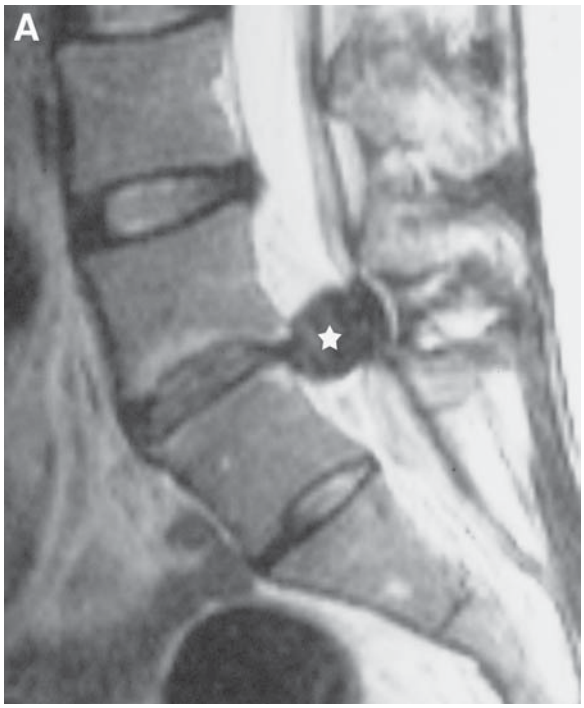
On MRI, the protrusion is connected to the body of the disc by a pedicle of high signal on T2-weighted imaging. The actual material in the protrusion may have variable signal intensity with respect to the main body of the disc. The outer fibers of the annulus may be visible as a low signal line abutting the thecal sac or epidural fat *(13)*.

An extrusion consists of nucleus pulposus that has escaped the confines of the annulus *(6,10)*. These can be classified further as subligamentous or transligamentous, based on whether they remain confined anterior or have penetrated posterior to the posterior longitudinal ligament (PLL) *(3)*. Extrusions may also migrate cranially and/or caudally to variable extents (Fig. 2).

On T2-weighted imaging, the extrusion is also connected to the disc by a hyperintense stalk. The extrusion itself is usually of high signal intensity as well and can be readily distinguished from the low intensity signal of the outer fibers of the annulus *(13)*. The distinction between a protrusion and extrusion on MRI is less important than possible symptoms attributable to the particular lesion.

A sequestered disc, or free fragment, is an extrusion that has lost its attachment to its parent disc *(3,6,10)* (Fig. 3). The free fragment may be found on either side of the PLL and at a range of distances from the disc of origin. Most often, they are situated anterior to the dural sac, but more rarely may be found posterior to the dura or even inside.

Sequestered discs are best demonstrated on sagittal images, especially when the fragment has migrated significantly from the parent disc *(13,14)*. T1-weighted imaging shows isointensity with the parent disc, and post-contrast



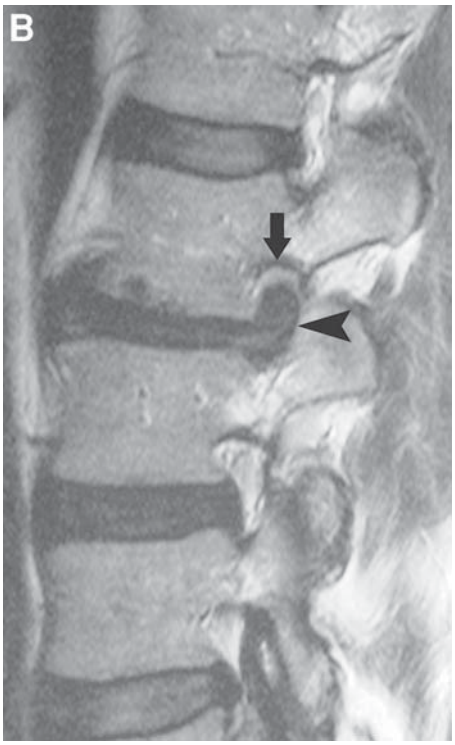


Fig. 2. Disc extrusions. Sagittal T2-weighted image **(A)** demonstrates a large disc extrusion (*star*) that extends to the posterior aspect of the canal. Sagittal T2-weighted image **(B)** in a different patient demonstrates a superiorly migrating neural foraminal disc extrusion (*arrowhead*) which compresses the exiting nerve root (*arrow*).

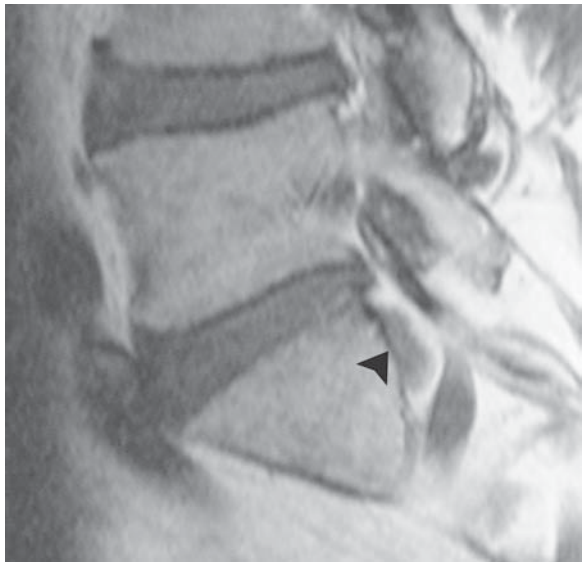


Fig. 3. Sequestered disc fragment. Sagittal image shows an inferiorly migrated free disc fragment (*arrowhead*) posterior to the S1 vertebral body and just superior to the exiting S1 nerve root.

images reveal a peripheral rim of enhancement *(3,13)*. The discs of origin commonly demonstrate loss of signal intensity on T2-weighting, signifying degenerative changes that predispose to disc disease *(13)*. Sequestered discs are a clinically significant finding, as they can have a major impact upon the management of the patient *(13)*.

MRI is fairly reliable at differentiating between the types of disc herniation. In a prospective study comparing surgical findings with MRI, Kim et al. reported an overall accuracy of 80.6% of MRI in distinguishing between protrusions, subligamentous and transligamentous extrusions, and sequestered discs *(15)*. Distinguishing between subligamentous and transligamentous extrusions was best performed with T2-weighted imaging, in which the disruption of the PLL, represented by the hypointense line immediately posterior to the vertebral bodies, could be identified *(15)*. The authors reported an accuracy of 75% when using this criterion. Gadolinium enhancement was particularly helpful for identifying sequestered discs, demonstrating an anterior rim of enhancement and clearly demarcating the lack of connection with the parent disc.

The orientation of a herniation with respect to the central canal is critical in determining which nerve roots will most likely be affected. A central herniation has most of its substance in the midline, with lesser amounts to either side. A central/right paracentral or central/left paracentral herniation has the major portion between the intervertebral foramen and the midline of the central spinal canal but does not extend into the intervertebral foramen. Lateral herniations occur beyond the central spinal canal and usually affect the intervertebral foramina. These herniations may extend more anteriorly, beyond the intervertebral foramen *(5,16,17)*.

A central or paracentral L4–5 disc extrusion will most likely impinge upon the L5 nerve root as it first descends

in the central spinal canal in close proximity to the dorsal aspect of the L4–5 disc and then traverses the lateral recess en route to the L5–S1 intervertebral foramen. It does not regularly affect the L4 nerve root, as this descends inferolaterally through the lateral recess at a level superior to that of the L4–5 disc before reaching the L4–5 intervertebral foramen. In addition, the disc is located at the level of the caudal half of the intervertebral foramen. A lateral extrusion into the intervertebral foramen at the same level, however, will likely affect the L4 nerve root, while a paracentral or central extrusion migrating cranially may also reach the descending fibers of the L4 nerve root *(5)*. Thus, vertical migration of an extrusion or sequestered disc may have significant clinical consequences *(16)*.

MR examinations evaluate intervertebral disc degeneration. Because degenerated discs demonstrate decreased T2 signal intensity of the nucleus pulposus when compared to normal discs and CSF, this finding on sagittal examination may serve as a guide in choosing the levels for axial imaging *(1,18)*. Indeed, axial imaging is critical for evaluating certain types of pathology, such as a lateral herniation, that are more difficult to detect on sagittal images *(5)*.

DEGENERATIVE CHANGES

The intervertebral disc and two facet joints between vertebra may be considered as a series of "three-joint complexes." The functioning of these joints at a given level is so closely related that degenerative damage to one joint will inexorably affect the other two *(19,20)*. With advanced degeneration and restriction of movement at one level, nearby levels experience abnormal forces and, thus, accelerated degeneration. When multilevel degenerative changes are encountered, these findings are likely the result of pathology originating from a single level *(20)*.

The initial injury may lie with disc degeneration and loss of disc height, which leads to laxity and inward buckling of the ligamentum flavum *(21,22)*. The resultant minute degrees of instability lead to abnormal stresses in the facet joints and their eventual degeneration, with continuation of disc damage *(21)*.

DISC DEGENERATION

A series of biochemical changes takes place as an intervertebral disc ages. The disc gradually loses its water-binding capacity, leading to dehydration of the nucleus pulposus. Concomitantly, the fibrocartilage content of the nucleus increases, which leads to a less pliable core. Eventually, the nucleus becomes virtually indistinguishable from the inner annulus and loses its ability to distribute forces correctly *(3,6)*. These changes, in turn, require the annulus to assume unnatural forces that lead to tears in the annulus as well as traction spurs. These spurs form at the junction between the outer fibers of the annulus and their insertion into the vertebral bodies *(6)*. These changes are associated with loss of disc height, causing axially directed compressive forces to be disproportionately distributed to the facet joints *(6)*.

With these degenerative changes, the inner disc area of high signal intensity on T2-weighting slowly loses intensity *(1)*. This corresponds to the loss of water from the nucleus and to the changes in biochemical consistency and structure as described in the preceding. In the later stages of degeneration, the signal intensity of the nucleus pulposus and inner annulus approximate that of the outer annulus, signifying the loss of water content and conversion to a dehydrated collagenous structure *(1,3)*. Thus, differences between normal and degenerated discs are more easily appreciated on T2-weighted images, where water, or lack thereof, is more easily seen *(1)*.

The hallmark in disc degeneration is the development of a radial tear of the annulus fibrosus, with resultant loss of fluid and fibrocartilage from the nucleus pulposus *(4)*. Radial tears are almost always present in discs showing both early and severe degeneration and create a possible route for disc herniation *(3,4,23)*. They are oriented perpendicularly to the lamellar fibers of the annulus *(3)*. The most severely degenerated discs are associated with complete radial tears, those extending from the nucleus through the outer fibers of the annulus. In contradistinction, normal discs show an almost complete absence of radial tears.

Radial tears can be identified on MRI as a consequence of the pathologic changes *(3)*. The substance of a tear has a greater degree of hydration than the surrounding annulus, accounting for the hyperintense signal on T2. Owing to collagen fibers replacing much of the substance of the nucleus pulposus, many degenerated discs with radial tears will demonstrate decreased signal intensity on T2-weighed images *(12,23)*. Contrast-enhanced T1 images demonstrate foci of enhancement from neovascularity present as a part of the healing process *(3,12)* (Fig. 4).

As a disc suffers degenerative changes, a disc bulge may occur concomitantly with loss of height. This combination acts synergistically to narrow the intervertebral foramina. Loss of height causes a reduction in the craniocaudal dimension of a foramen, while the bulge may reduce its anteroposterior dimension. In addition, loss of height may lead to laxity and increased width of the ligaments about the spine *(19)*.

As degeneration progresses, instability may lead to negative pressures inside of an intervertebral disc, caus-

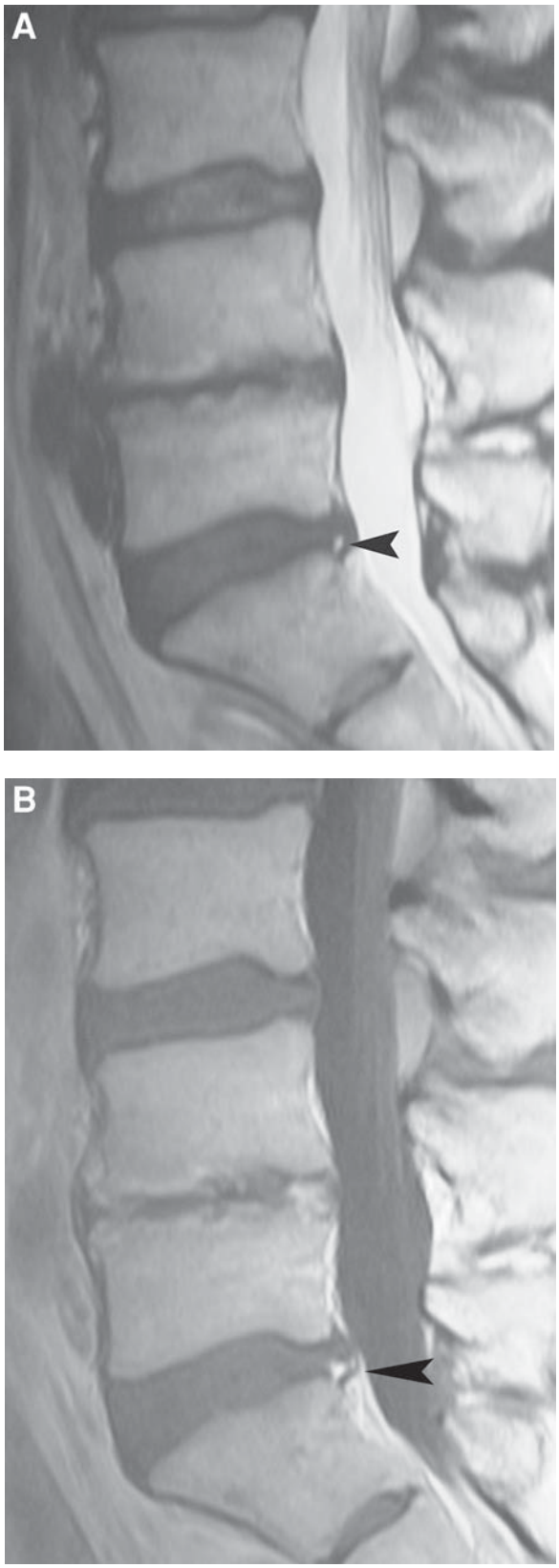


Fig. 4. Disc bulge with an annular fissure. Sagittal T2-weighted **(A)** image shows an L5–S1 disc bulge with a high signal annular fissure (*arrowhead*) that enhances (*arrowhead*) on the sagittal T1-weighted post contrast **(B)** image due to vascularized granulation tissue.

ing gaseous conversion of interstitial nitrogen. This vacuum disc phenomenon is observed more frequently in the lumbar spine, and is seen as a signal void on MRI. These can often be visualized on plain films as gas pockets. On T2-weighted images, vacuum discs can paradoxically be seen as areas of high signal intensity consistent with fluid, because shifts in intradiscal pressures may cause fluid filling of the cleft when the patient is in the supine position *(19,24)*.

FACET JOINT DEGENERATION

Although the primary lesion lies with disc degeneration, facet joint damage follows closely. Degenerative changes of the facet joints show synovitis as their earliest feature. This is seen on MRI as high signal intensity in the intraarticular space consistent with fluid on T2-weighting *(25)*. This progresses to joint space narrowing and articular cartilage damage in a variety of forms, ranging from total loss to chondromalacia in the form of fibrillation, fragmentation, and loose bodies. Joint capsule laxity ensues, owing to the cartilaginous changes and chronic joint effusions that distend the capsule *(20)*. Ligamentum flavum hypertrophy, articular process overgrowth, and osteophytosis are found in later stages *(25)*. The net result is instability at the facet joints with possible anterior or posterior subluxation.

Osteophytosis of the articular processes may encroach on different areas of the spinal canal. Because of the anterolateral location of the superior articular process of the inferior vertebra, osteophytes may grow anteromedially to narrow the lateral recess of the spinal canal. The posteromedially located inferior articular processes may form osteophytes that directly impinge upon the central canal *(20)*.

With facet joint degeneration, synovial cysts may develop. Oftentimes, they are found at the medial aspect of the facet joint and protrude into the spinal canal. They may also encroach on intervertebral foramina and affect the exiting spinal nerves *(20)* (Fig. 5). These cysts are believed to originate from degenerative changes that cause chronic joint effusions with proliferation and expansion of the joint capsule. They are most common in the lumbar spine and are rarely bilateral *(26)*. Because they are fluid filled, they are seen as high signal masses on T2-weighted images. This is in distinction to fibrous and chondromatous masses that can be found in the same area, which possess low signal intensity *(20)*. Enhancement may be seen in the cyst wall with post-contrast imaging.

STAGES OF DEGENERATION IN THE THREE-JOINT COMPLEX

Degenerative changes in the three-joint complex progress through three clinical stages. The stage of dysfunction is characterized by very minimal damage to joints

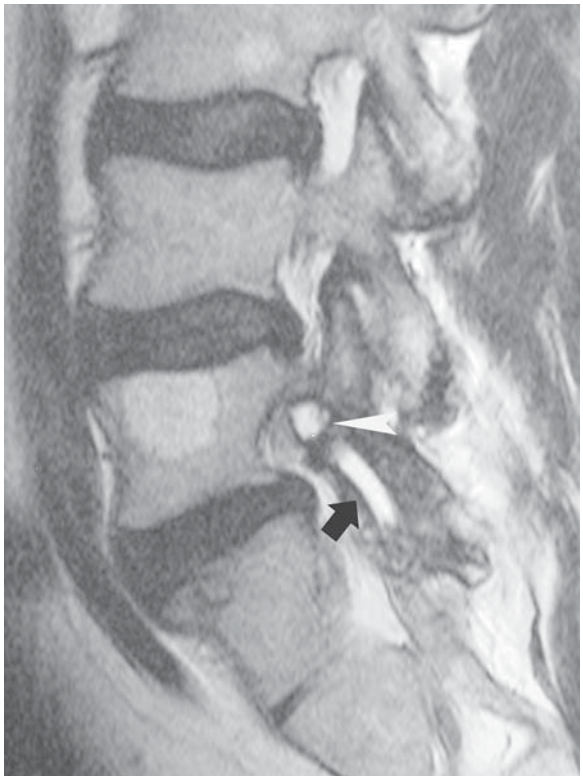


Fig. 5. Synovial cyst. Sagittal T2-weighted image demonstrates a synovial cyst (*white arrowhead*) extending into the L5–S1 neural foramen from the adjacent fluid filled (*black arrow*) facet. The cyst abuts the exiting L5 nerve root. Incidentally noted is an L5 vertebral body hemangioma.

that is difficult to detect objectively. Similarly, the patient's symptoms are not yet severe. The stage of instability is defined by the presence of abnormal movement of the vertebrae. Clinical symptomatology and radiologic findings are apparent, which may include spondylolisthesis and position-dependent lateral stenosis. Eventually, with the progression of osteophytosis and degenerative changes, movement of the vertebrae is limited, resulting in the stage of stabilization. Dynamic stenosis encountered before give way to fixed lesions, and patients may report some degree of improvement as a result of the stability *(20)*. Thus, the finding of spondylolisthesis on imaging may not necessarily indicate instability, as stabilization may have already taken place *(24)*.

REACTIVE MARROW CHANGES

Disc degeneration may lead to changes of the vertebral body marrow, through abnormal forces exerted upon the vertebral body endplates. These reactive endplate changes have been grouped into three types discernible on MRI *(20)*. Type I changes consist histologically of fibrovascular tissue replacement of normal cellular marrow. These changes are seen as low signal intensity on T1 and high signal intensity on T2. Although they may resemble osteomyelitis, the lack of high signal in the disc on T2-weighted images can differentiate them from infection *(27)* (Fig. 6).

Type II change represents areas of fatty replacement of bone marrow. Accordingly, both T1- and T2-weighted images are of relatively high signal intensity, consistent with fat (Fig. 6). No significant amount of post-contrast enhancement is observed. Unlike type I changes, this stage usually does not revert and can proceed to type III *(19,27)*.

The final stage consists of sclerotic changes and hyperostosis. There is a deficiency of normal marrow. These type III changes are seen as low signal intensity on both T1- and T2-weighted images *(19)*.

SPONDYLOLISTHESIS

Spondylolisthesis is essentially a "slipping" of one vertebral body on another. This situation may exist in one of two conditions. Degenerative spondylolisthesis occurs as a consequence of facet joint subluxation and degenerative disc disease with an intact vertebral arch *(20,25)*. Spondylolisthesis with spondylolysis, however, is caused by bilateral pars defects, producing a discontinuity between the vertebral body and the elements posterior to the pars defect. The spondylolisthesis is described by the movement of the superior vertebral body with respect to the inferior vertebral body *(24)*. Thus, the forward slipping of L4 on L5, the most common location for degenerative spondylolisthesis, is described as an anterior spondylolisthesis, or anterolisthesis, of L4.

DEGENERATIVE SPONDYLOLISTHESIS

In degenerative spondylolisthesis, damage to each element of the three-joint complex causes instability between adjacent vertebra. Central to this condition is injury to the facet joint (Fig. 7). A symmetric anterolisthesis may result in stenosis of both the central canal and lateral recesses. The neural arch of the upper vertebra and the posterosuperior aspect of the lower vertebral body combine to narrow the spinal canal, while the inferior articular processes of the superior vertebra encroach upon the lateral recesses *(20)*. In the case of a retrolisthesis, central canal stenosis would be found between the post-eroinferior portion of the upper vertebral body and the lamina of the lower vertebrae. Central stenosis is not as common with retrolisthesis as anterolisthesis owing to a decreased degree of instability in this condition *(24)*. A degenerative retrolisthesis may also result in intervertebral foramen stenosis at the affected level, as the space between the posterior aspect of the superior vertebral body and the superior articular process of the inferior vertebrae is pathologically narrowed *(26)*.

These alterations may affect the facet joints at a given level unevenly. In this case, rotational movement may be

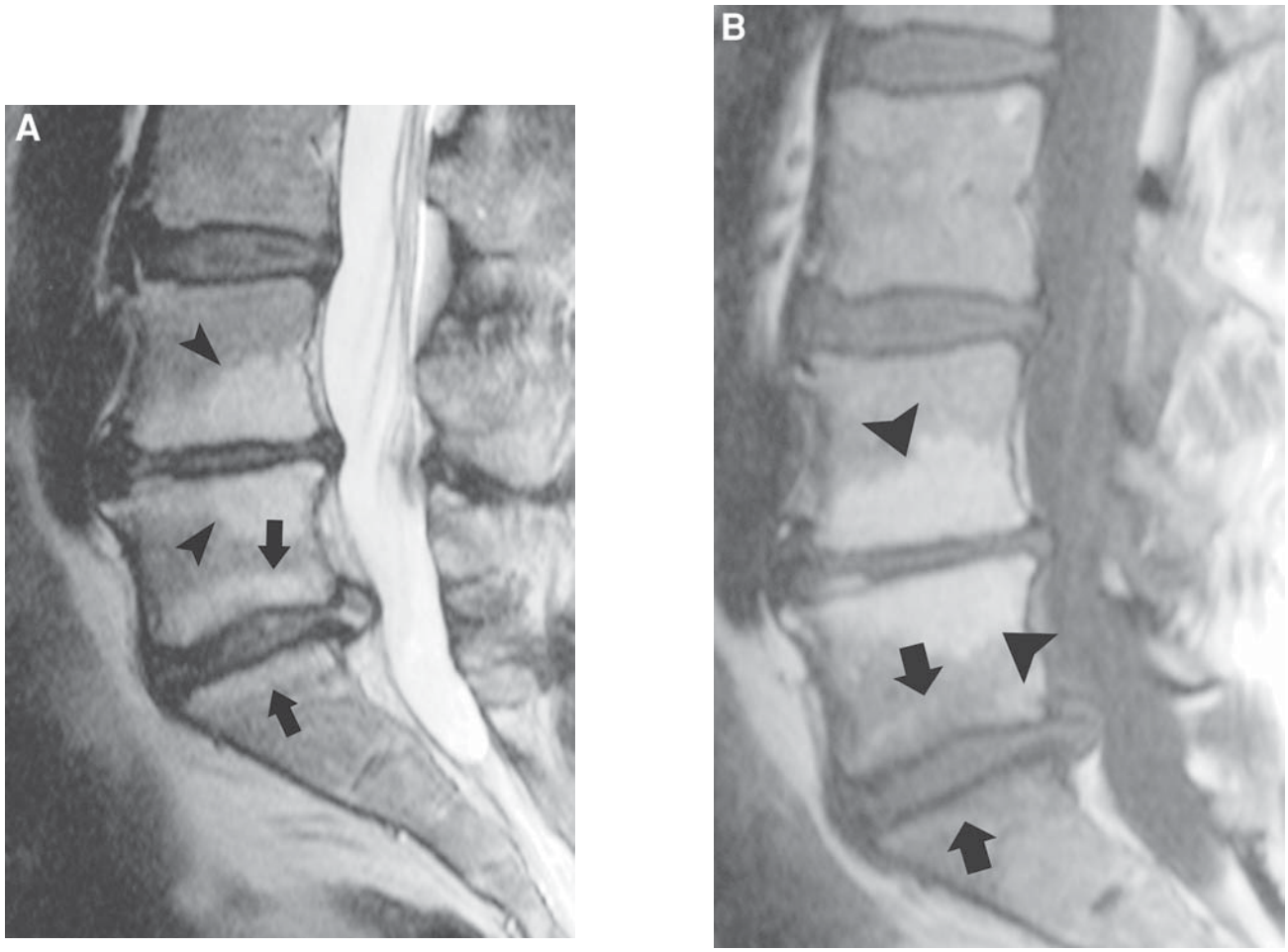


Fig. 6. Reactive marrow changes. Sagittal T2-weighted image **(A)** and sagittal T1-weighted image **(B)** demonstrate type I reactive marrow changes at the L5–S1 level with areas of increased T2 (*arrows*) and decreased T1 signal (*arrows*). Type II changes are present at the L4–5 level with increased T1 and T2 signal (*arrowheads*).

possible, with the approximate center of rotation located at the facet joint less affected by the degenerative process *(20)*. With asymmetric anterior spondylolisthesis, the lateral recess is constricted on the side with greater movement, with a lesser degree of the central stenosis. A disc herniation involving the foramen is often found at the same level ipsilateral to the side of lateral recess stenosis in these cases, likely as a result of the shear forces placed upon the disc. This completes the triad of rotatory spondylolisthesis: asymmetric spondylolisthesis, unilateral lateral recess stenosis, and a foraminal disc herniation *(24)*. Facet joint synovial cysts are also common findings in degenerative spondylolisthesis and can contribute to stenosis *(24)*.

SPONDYLOLISTHESIS WITH SPONDYLOLYSIS

Spondylolysis, or fracture, of the pars interarticularis is a cause of spondylolisthesis distinct from degenerative changes. The fracture, also known as a pars defect, is usually oriented perpendicular to the articular process. Bilateral pars defects lead to a discontinuity between the anterior and posterior portions of the ring of a vertebra, and anterior translational movement of the vertebral body is no longer impeded by the facet joints. Spondylolysis is the most common cause of spondylolisthesis in patients younger than 50 yr of age and is believed to result from repetitive stresses and minor trauma with formation of fatigue fractures.

Sagittal images taken through the medial aspect of the pedicles and facet joints best demonstrate the normal anatomy. The superior facet has a triangular shape, and the remainder of the pars interarticularis can be seen extending in an inferoposterior direction to the inferior facet joint. A single sagittal image, however, cannot image all lumbar facet joints owing to the increasing diameter of the spinal canal inferiorly. More laterally, only facet joints may be seen without the more medially located pars. This should not be mistaken for a pars defect. On axial images, the pars interarticularis is seen slightly superior to the level of the intervertebral foramina. If the images are taken

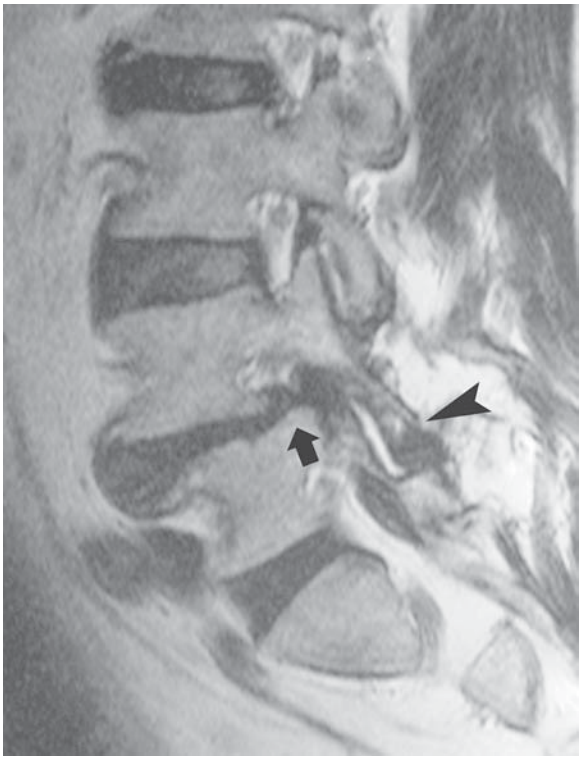


Fig. 7. Degenerative spondylolisthesis. Sagittal T2-weighted image shows degenerative anterior spondylolisthesis of L4 on L5 (*arrow*) with related degenerative changes and fluid in the facets (*arrowhead*).

perpendicular to the posterior vertebral body, the entire vertebral arch may be demonstrated *(28)*.

Imaging spondylolysis is best performed with sagittal images. Discontinuity in the cortical bone is better demonstrated on T1 and proton density weighted images than with T2-weighting, as these allow a greater discrimination between cortical and medullary bone. The defect is seen as a perpendicular lesion with respect to the orientation of the articular processes *(28)*. T2-weighted images may show increased signal intensity from the region of the pedicle and superior articular process, signifying marrow edema in the acute setting *(25)*. In addition, type II marrow changes may be found in roughly 40% of pedicles next to a pars defect *(25)*. Midsagittal images illustrate the degree of spondylolisthesis *(25)*. Axial views may also demonstrate the defect, but facet joints may be mistaken for a pars defect *(28)*.

Anterior spondylolisthesis with spondylolysis may complicate a bilateral pars defect. The width of the pars defect in this case is typically >5 mm and the central canal may actually increase in anteroposterior dimension due to the immobility of the posterior fragment and anterior subluxation of the vertebral body *(28,29)*.

In addition to spondylolisthesis, sequelae of spondylolysis include acceleration of degenerative changes and stenosis. Intervertebral foraminal stenosis at adjacent levels is a fairly common finding but is usually more severe at the inferior level *(28)*. With L5–S1 spondylolytic anterolisthesis, lateral disc herniations are a frequent finding, and the L5 spinal nerves in the intervertebral foramen may show signs of impingement from both foraminal stenosis and the herniation *(25)*.

SPINAL STENOSIS

Spinal stenosis refers to impingement upon neural tissue in the central spinal canal, intervertebral foramina, or lateral recesses. These conditions may result from developmental anomalies, one or any combination of the degenerative changes detailed in the preceding, or a number of other conditions *(19)*. The term stenosis, however, should be reserved for patients with clinical findings consistent with such a diagnosis. Findings on imaging without clinical correlation should be referred to as narrowed *(30,31)*.

Developmental stenosis accounts for a minority of cases in roughly a 1:10 ratio with respect to degenerative causes, and can be grouped into those due to hereditary–idiopathic spinal stenosis and those related to disorders of skeletal growth, such as the mucopolysaccharidoses, Down's syndrome, and achondroplasia, among others *(30)*. These stenoses result from a hypoplastic vertebral arch with short, thick pedicles. In addition, the distance between pedicles at a given level may also be reduced, resulting in a horizontally narrowed central spinal canal *(32)*. These patients are usually asymptomatic until degenerative changes act synergistically to produce symptoms *(26)*.

Dural sac encroachment comprises the principal lesion in central stenosis and is distinguished by elimination of bordering epidural fat or impingement upon the thecal sac *(22)* (Fig. 8). This can lead to compressive myelomalacia, which gives an array of MRI findings. In the early stages, myelomalacia is seen as an area of high signal on T2-weighted imaging that is believed to represent edema and microvascular stasis. Unenhanced T1-weighted images are essentially normal. Post-contrast images, however, may demonstrate enhancement due to disruption of the blood–brain barrier. With progression, T2-weighting continues to show high signal, while T1-weighted images begin to lose signal intensity. These finding represent gliosis and cystic necrosis. Ultimately, atrophy and syrinx formation can be observed if the insult is not removed *(19)*.

Lateral recess stenosis often occurs in conjunction with central stenosis but may be seen alone. As the nerve root descends at an angle through the lateral recess, it is critical to remember that lateral recess pathology at a given lumbar level often affects a nerve root that will exit more

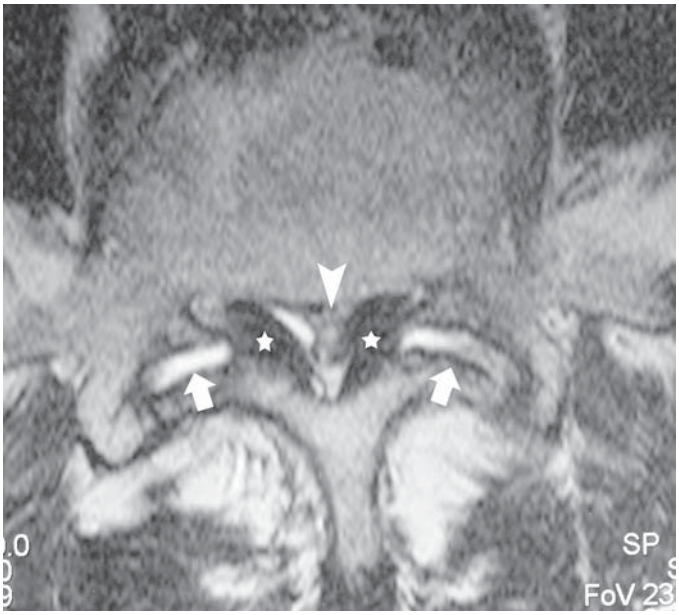


Fig. 8. Central canal and lateral recess narrowing. Axial T2-weighted image shows significant narrowing of the central canal (*arrowhead*) and lateral recesses which is in part due to ligamentum flavum hypertrophy (*stars*) and in part due to facet hypertrophy with additional fluid present in the facets (*arrows*).

inferiorly. Axial cuts with both T2-weighting and postcontrast T1 images can demonstrate the stenosis *(26)*.

Degenerative changes may result in stenosis of the intervertebral foramina by the mechanisms described in the preceding. These effects are best visualized on parasagittal images that demonstrate the foramina in cross-section. Findings consistent with foraminal stenosis include differing amounts of displacement and/or obliteration of the hyperintense fat within the foramen *(26)*. However, axial images should also be obtained.

Nonspecific degenerative changes may cause intervertebral foramen narrowing. With loss of disc height, there is reduction in the craniocaudal dimension of the foramen. This forces the superior articular process of the inferior vertebral body into the inferior aspect of the notch of the superior pedicle, resulting in osteophyte formation. The situation is exacerbated further by laxity in the annulus fibrosus and ligamentum flavum and additional osteophytosis of the vertebral bodies. These factors act in concert to cause a stenotic intervertebral foramen *(26)*.

EFFECT OF POSITION ON STENOSIS

When the spine moves from flexion to extension, there is a significant reduction in room available to the cauda equina on the order of 16% *(31)*. Extension also constricts the posteriorly situated intervertebral foramina and contributes to a thickening of the ligamentum flavum *(31)*. A similar degree of decrease can be seen with a change from an axial tensile force of 250 Newtons to a compressive force of 250 Newtons *(31)*. To account for these changes, dynamic plain films may be indicated when degeneration and instability are suspected as a cause of symptomatology to ensure that lesions are not missed in the supine position assumed by patients during MRI *(22)*.

OTHER CAUSES OF SPINAL STENOSIS

After surgical manipulation of the spine, stenosis may result from a variety of causes, including instability with spondylolisthesis, scar tissue formation, and excessive bony growth. Trauma may also lead to stenosis from fracture of bone or acute damage to intervertebral discs. Malignancies, whether metastatic or primary, are an important cause of neural compromise *(31)*. Ossification or calcification of the ligamentum flavum or posterior longitudinal ligament may also cause stenosis. Epidural lipomatosis may be seen in patients on chronic corticosteroids and those with Cushing's syndrome *(32)*. Other more rare causes include fluorosis and Paget's disease of bone *(31)*.

JUVENILE DISCOGENIC DISEASE

Also known as thoracolumbar Scheuermann's disease, this entity affects relatively young patients in their late teens to early 30s with low back pain referable to degenerative disc disease *(25)*. Imaging reveals loss of intervertebral disc height, vertebral endplate irregularities and Schmorl's nodes at the thoracolumbar levels, associated with degenerative disc disease at the lower lumbar levels. Although its etiology is unclear, some have theorized an inherent defect of the disc and endplate leading to these premature degenerative changes *(33)*. Others believe that excessive mechanical forces are to blame, as this disorder was almost an order of magnitude more common in children raised in the country *(34,35)*.

Schmorl's nodes represent intradiscal herniations of nucleus pulposus through a disruption in the superior or inferior cartilaginous endplates *(36)*. MRI usually demonstrates the nodes to be contiguous with the nucleus pulposus of origin and of the same signal intensity on both T1 and T2. However, in a minority of cases, the signal intensity can differ significantly *(37)*.

DISCITIS AND OSTEOMYELITIS

MRI plays a pivotal role in the evaluation of infectious spondylitis particularly because the diagnosis is often a difficult one to make clinically. Patients with spinal infections present with nonspecific symptoms such as malaise, focal tenderness, radiculopathy, and back pain *(38–40)*. These symptoms may be attributable to other etiologies

such as degenerative disorders, spinal stenosis, and neoplasms. In fact, back pain (the most common symptom in patients with infectious spondylitis *[40,41]*) is also the second leading cause of physician visits affecting 5% of the population annually *(42,43)*. Physicians therefore often rely on imaging modalities and on laboratory tests such as elevated erythrocyte sedimentation rate (ESR), white blood cell (WBC) count, or C-reactive protein *(40)*. In a group of patients with pyogenic vertebral osteomyelitis evaluated by Caragee, 30% of immunocom-promised and 44% of immunocompetant patients had abnormal WBC counts while 89% of immunocompromised and 100% of immunocompetant patients had elevated ESR *(44)*. It is important to note that WBC count and ESR can be normal in patients with chronic or partially treated infections *(40)*. C-reactive protein is also accurate in identifying underlying infection *(40)*.

MRI has been shown to be a highly accurate imaging modality in the diagnosis of infectious spondylitis with a reported sensitivity of 96%, specificity of 92%, and accuracy of 94% *(45)*. This accuracy, along with the superior spatial resolution of MRI in assessing the extent of soft tissue and bone involvement and its ability in detecting early changes of infection have made it the imaging modality of choice in the evaluation of infectious spondylitis.

Spinal infections most commonly result from hematogenous spread although they may also occur by traumatic or iatrogenic inoculation (during an invasive procedure) or uncommonly by extension from an adjacent infection *(39,40,46)*. The hematogenous route typically originates from a genitourinary, gastrointestinal, skin, or respiratory source. Diabetics, intravenous drug abusers, and patients with chronic diseases such as sickle-cell anemia and acquired immunodeficiency syndrome (AIDS) particularly are prone to developing infections *(38,40)*. Bacteria are the most common causes of spinal infections, with *Staphylococcus aureus* identified in 55–80% of cases *(40,45,46)*. Parasitic and fungal infections are uncommon while viral infections are seen in greater frequency in AIDS patients *(40)*.

The typical appearance and distribution of osteomyelitis and discitis is directly related to the vertebral arterial supply. Although retrograde venous infection of the spine through the inferior vena cava and Batson's plexus has been documented, arterial spread is the typical route of hematogenous infection *(39,40,46–48)*. The vertebral bodies have a complex arterial supply with lumbar arteries and intercostal arteries terminating in multiple metaphyseal end arterioles adjacent to the subchondral endplates *(39,48)*. Septic emboli lodge in end-arterioles producing infarctions susceptible to infection. This accounts for adult spinal infections often originating in the endplates. The infection then spreads to the adjacent disc or vertebral bodies through arteries that traverse the discs *(39)*.

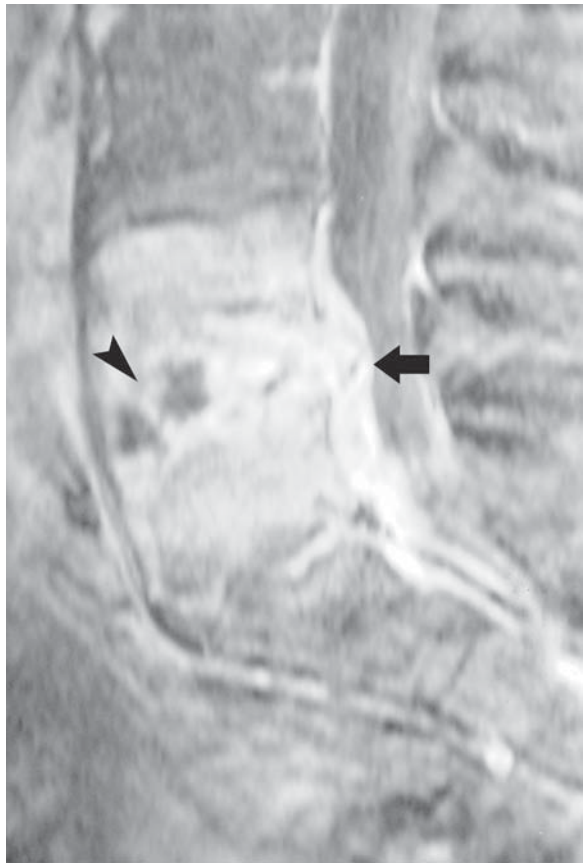


Fig. 9. Discitis and osteomyelitis. Sagittal postcontrast T1-weighted fat suppressed image shows a peripherally enhancing L4–5 disc abscess (*arrowhead*) with adjacent enhancement of the infected L4 and L5 vertebral bodies and erosion of the adjacent endplates. Enhancing ventral epidural tissue (*arrow*) represents epidural phlegmon.

Children have a rich network of collateral vessels which decreases the risk of embolic induced infarctions. These arteriole anastamoses atrophy by age 15 *(47,49)*. In addition, unlike adults, children have a direct arterial supply to the intervertebral disc which is the most common site of pediatric spinal infection *(39)*.

MRI FINDINGS

The earliest MRI changes in osteomyelitis are a result of the increased water accumulation (edema) which causes a decrease in T1 signal and an increase in T2, T2 fat-saturated, or short tau inversion recovery (STIR) signal in the vertebral metaphysis *(39,40,45,50)*. Lesions are more conspicuous on STIR and T2 fat-saturated images than on conventional T2-weighted images because the suppressed/dark background fat signal of the former pro-

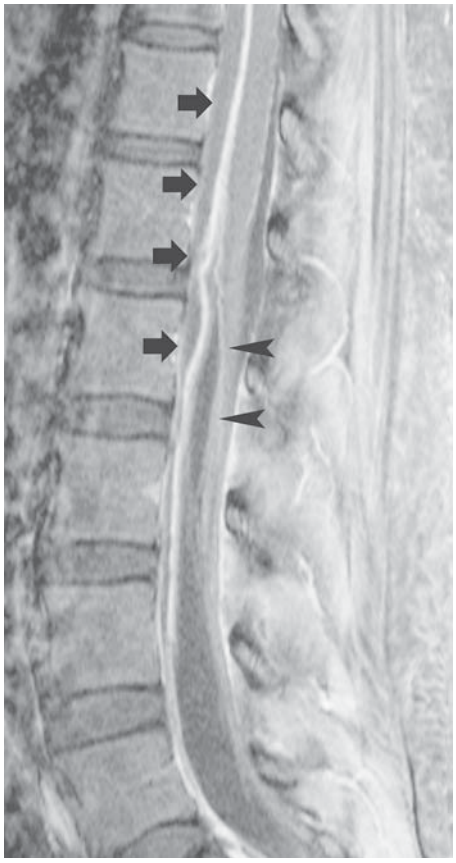


Fig. 10. Epidural abscess and leptomeningitis. Sagittal postcontrast T1-weighted image reveals a peripherally enhancing ventral epidural abscess (*arrows*) with additional enhancing tissue surrounding the spinal cord and nerve roots.

vides a greater contrast with the increased/bright signal of the infection *(51)*.

In a group of 37 patients with disc space infection studied by Dagirmanjian et al., 95% of the levels exhibited eroded endplates on T1-weighted images, 95% had hypointense T1 vertebral body signal, and 95% had increased T2 disc signal while 85% of the levels had all three of these findings. In addition, 94% of the patients had disc and vertebral body enhancement *(52)* (Fig. 9). These MRI imaging characteristics are the most reliable indications of infection. Increased T2 vertebral body signal has been shown to be a less sensitive sign and was present in only 56% of the levels in Dagirmanjian's group *(52)*.

Gadolinium administration plays a pivotal role in the evaluation of spinal infections. It is often needed to diagnose leptomeningitis where post-contrast images show enhancement of the dura and/or nerve root sheath. The enhancement may be linear, nodular, or diffuse *(50,53)*. Gadolinium is also needed to differentiate between peripheral ring enhancing epidural/paravertebral abscesses and homogeneously enhancing phlegmon *(50,54,55)* (Figs. 10 and 11).

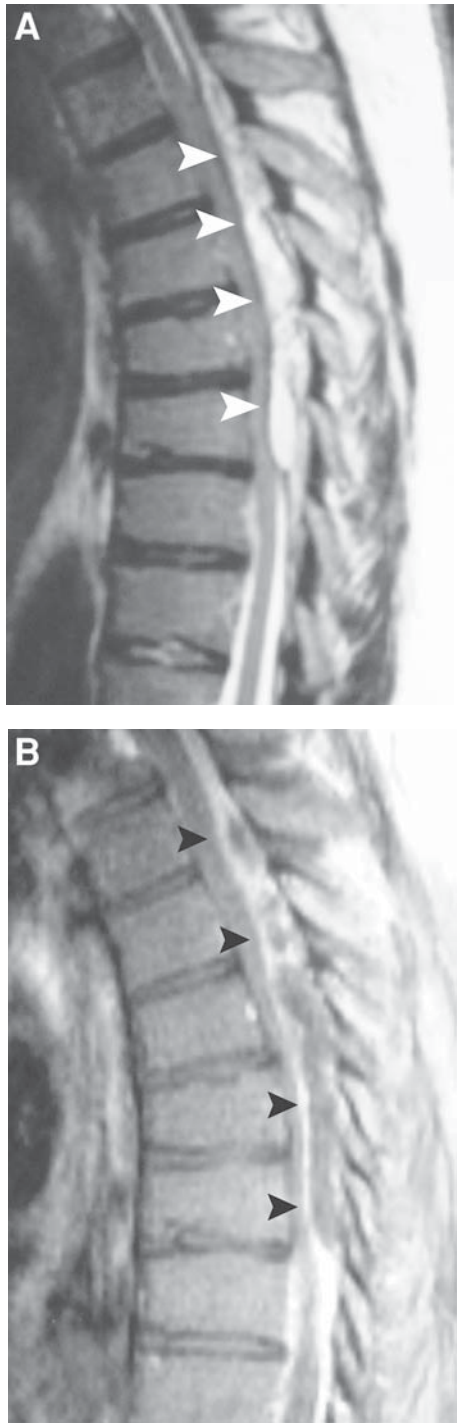


Fig. 11. Epidural abscess. Sagittal T2-weighted **(A)** and sagittal postcontrast T1-weighted **(B)** images show a dorsal epidural abscess that anteriorly displaces and compresses the spinal cord. The abscess is centrally bright (*white arrowheads*) on the T2-weighted image and peripherally enhancing (*black arrowheads*) on the T1-weighted post-contrast image.

Gadolinium is essential in evaluating for resolution of the infection. The first MR indication of resolution (early healing) is a decrease in the amount of soft tissue enhancement or abnormal soft tissue *(56)*. These findings are indicative of healing regardless of whether there

is improving or worsening bone/disc changes. Late healing has a high peripheral T1 signal, which extends centrally with decreasing gadolinium enhancement (reliable sign). These findings may be due to a healing edge with fat deposition. An increase in enhancement does not necessarily mean treatment failure, as some patients with clinical improvement will initially have increasing or persistent gadolinium enhancement before showing decreased enhancement. The lack of gadolinium enhancement indicates that there is no longer active inflammation *(56)*. The use of fat saturation following the administration of gadolinium increases the conspicuity of marrow involvement.

Differentiating pyogenic infections from granulomatous infections such as tuberculosis and *Brucella* is often difficult on MRI although there are certain findings that when present are more suggestive of one type of infection *(44)*. Pyogenic infections tend to result in loss of disc height which is thought to be due to the release of proteolytic enzymes that digest the nucleus pulposus *(49)*. Nonpyogenic organisms, such as *Mycobacterium tuberculosis*, usually do not affect the discs because they do not release the proteolytic enzymes *(39,46,49,50,57)*. Disc space narrowing can, however, occur secondary to bone destruction which results in disc herniation into the vertebral body *(49)*.

Tuberculosis often involves the middle column which is hypothesized to be secondary to the high blood flow to the posterior aspect of the vertebral body. This provides the mycobacterium the high concentration of oxygen it needs to survive. In addition, tuberculosis can affect the pedicles and posterior elements which is usually not seen with pyogenic infections or *Brucella (50,55)* (Fig. 12).

Tuberculosis often causes severe vertebral body damage with associated spinal deformity/collapse (gibbus) and frequently results in paraspinal and significant epidural involvement with abscess extension, meningeal involvement or bony fragment extension *(55)*. These findings are atypical with *Brucella*. Paraspinal masses have been shown to be larger in tuberculosis than with pyogenic infections *(49,58,59)*.

Tuberculosis tends to spread to adjacent vertebral bodies beneath the longitudinal ligaments and therefore can result in skip lesions *(44,49)*. The presence of skip lesions or posterior element or multiple vertebral body involvement may hinder differentiation of this type of infection from neoplasms *(49)*.

DIFFERENTIAL DIAGNOSIS

An et al. noted that the most consistent differentiating feature between spinal pyogenic infection and neoplasm is the involvement of the disc space with osteomyelitis and the sparing of the disc space with tumors *(60)*. In addition, the loss of vertebral endplate definition, contiguous vertebral involvement, and obscuration of adjacent fat planes are most suggestive of infection, while tumors tend to not affect or only focally obscure the adjacent fat planes *(60)*.

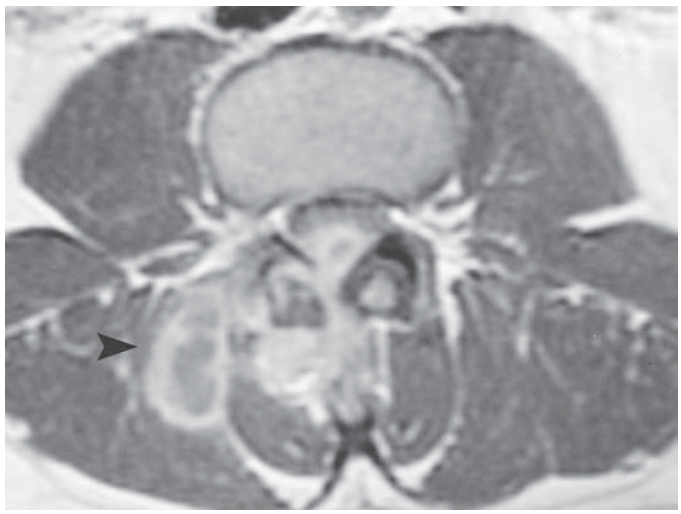


Fig. 12. Tuberculous infection. Axial post-contrast T1-weighted image in a patient with tuberculous spondylitis reveals a paravertebral abscess (*arrowhead*), dorsal epidural abscess, and involvement of the posterior elements.

The differential for the MRI features seen with spinal infections in addition includes seronegative spondyloarthropathies and Modic type I degenerative changes. The spondyloarthropathies including ankylosing spondylitis, psoriatic arthritis, and Reiter's disease can present with similar findings to infection including disc space loss and mixed endplate lysis and sclerosis *(39,46,61–63)*. One must therefore rely on additional clinical information and characteristic radiographic features seen with these processes. Modic type I degenerative changes exhibit decreased T1 signal and increased T2 signal which is often seen in infection. MRI differentiation between these two processes may be difficult and therefore one must try to determine if there is increased T2 disc signal and enhancement of the vertebral metaphysis and disc, which are reliable indicators of infection. Unlike infection, type I Modic discs rarely enhance *(27,39,45,49,64,65)*. An understanding of the MRI findings seen with spinal infections is important as the early diagnosis and treatment may prevent permanent neuralgic deficits *(50)*.

NEOPLASTIC DISEASE OF THE SPINE

MRI is the primary imaging modality used in the evaluation of spinal neoplasms *(66)*. MRI has the advantage of multiplanar imaging capability and contrast sensitivity.

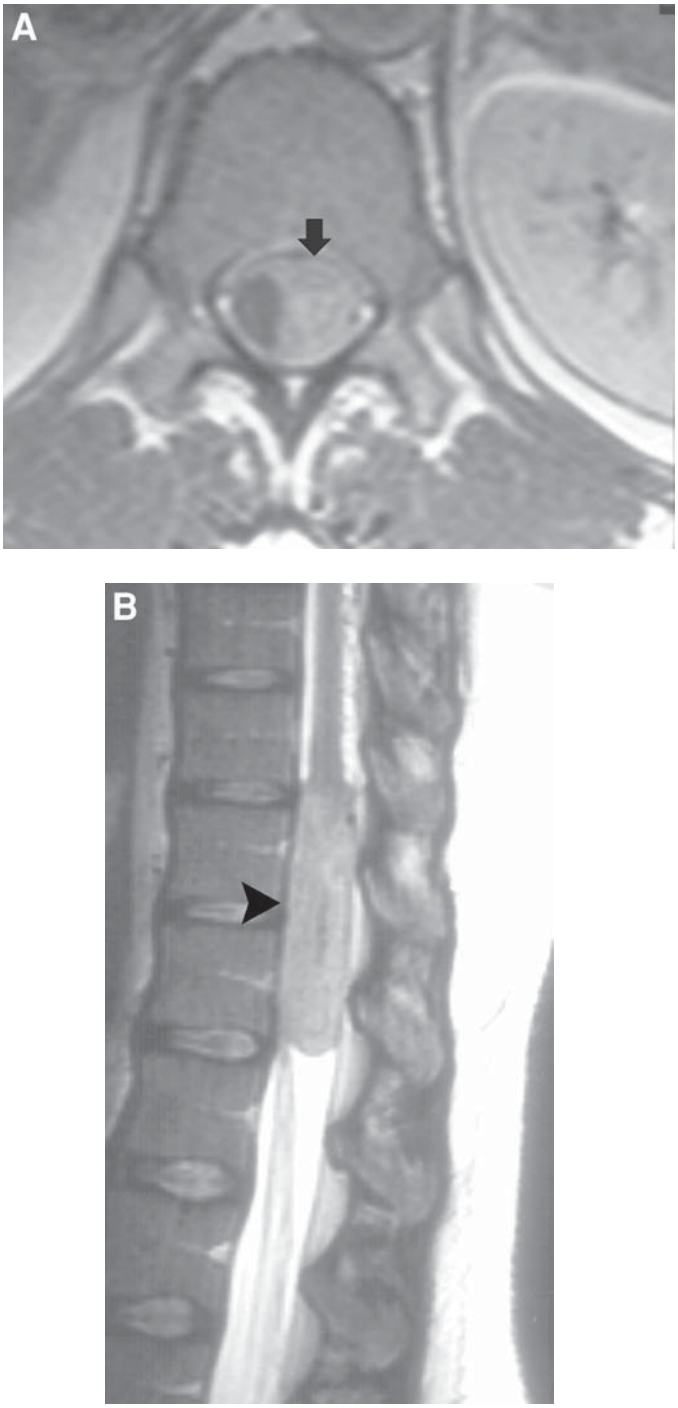


Fig 13. Ependymoma. Axial T1-weighted **(A)** and sagittal T2-weighted **(B)** images demonstrate a large soft tissue mass (*arrow and arrowhead*) in the region of the conus medullaris. The mass shows predominantly intermediate signal with areas of low and slightly increased signal. Myxopapillary ependymoma was found at surgery.

Spinal canal lesions are classified into three categories by the anatomic compartment of origin *(67–70)*:

- Intramedullary: spinal cord masses
- Intradural/extramedullary: lesions in the dura, outside of the spinal cord
- Extradural: mass outside the dura (skeletal, epidural, and paravertebral lesions)

INTRAMEDULLARY NEOPLASMS

Intramedullary lesions of the lumbar spine are mostly malignant tumors, of which gliomas (ependymoma and astrocytoma) are most common *(71)*.

Ependymomas are the most common spinal cord tumors in adults. In the lumbar region, they typically occur in the conus medullaris and filum terminale. Most ependymomas arising in this distribution are of the myxopapillary type (Fig. 13). They are more common in individuals aged 40–60 yr, and there is an increased incidence in patients with neurofibromatosis type II. They are slow-growing tumors that remodel the adjacent bone resulting typically in pedicle and posterior vertebral scalloping and neural foraminal enlargement. Spinal cord expansion and hemorrhage are common and syringohydromyelia may be present. These lesions are usually iso- to hypointense to cord on T1-weighted images (T1WI), enhance avidly, and show increased signal on T2-weighted images (T2WI) with some hypointense areas secondary to prior hemorrhage.

Astrocytomas are the second most common adult spinal cord neoplasms after ependymomas and are the most common intramedullary tumors in children. They occur more commonly in males and typically present in the first three decades of life. Astrocytomas arise more commonly in the cervical cord followed by the thoracic cord, and are unusual in the lumbar region. The vast majority of these lesions are low-grade tumors that may demonstrate multisegmental involvement, cord expansion, and associated syringohydromyelia. They can be seen in patients with neurofibromatosis type I. Back pain and progressive scoliosis are common clinical manifestations. T1W images usually show decreased signal intensity with respect to the cord with some being isointense to the cord. These lesions typically show high T2 signal and heterogeneous enhancement following the administration of gadolinium with areas of cystic changes commonly visualized within the tumor.

Hemangioblastomas are found in patients aged 20–40 yr and in younger individuals with von Hippel–Lindau (VHL) disease. They are rare spinal tumors more commonly found in the thoracic and cervical cord as solitary lesions. Multiple lesions are seen in the presence of VHL. These masses may resemble those found in the cerebellum, with an extensive cystic component and an enhancing mural nodule. A lower percentage of the lesions are solid. Solid and multiple neoplasms are most common with VHL. Cord expansion and edema are visualized with associated syrinxes. MRI clearly depicts these lesions that are of hyperintense signal on T2WI secondary to the cys-

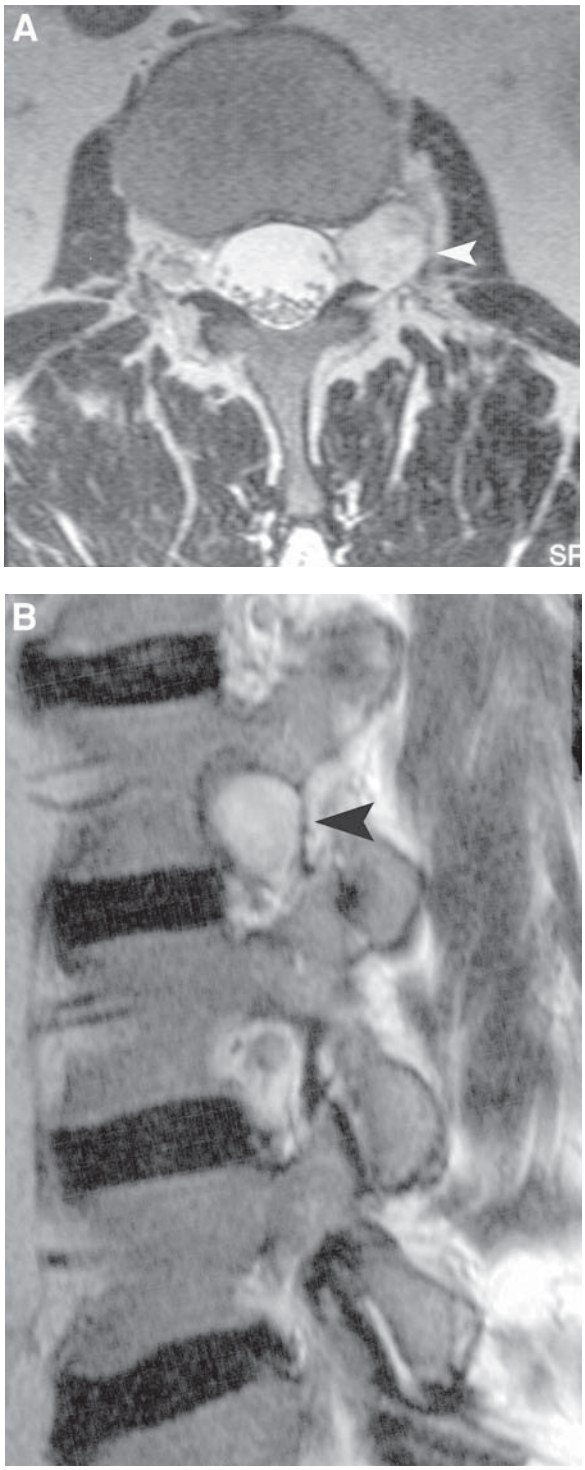


Fig. 14. Schwannoma. An expansile foraminal mass is identified in the left neural foramen on the axial **(A)** and sagittal **(B)** T2-weighted images. The mass is well defined and shows primarily high T2 signal with additional areas of low signal intensity.

tic component or syrinx, and iso- to hypointense to cord on T1WI. The tumor nodule or solid portion of the tumor demonstrates strong enhancement.

Intramedullary metastases are rare and most lesions are solitary. Lung carcinoma followed by breast carcinoma account for the majority of the cord lesions. These are more common in the thoracic spinal cord and are atypical in the lumbar area. They may expand the cord, show contrast enhancement, and not uncommonly show areas of central necrosis. High T2 signal is common, and increased T1 signal may be seen with melanoma due to hemorrhage.

INTRADURAL, EXTRAMEDULLARY LESIONS

Intradural, extramedullary masses are lesions that arise inside the dura but outside the spinal cord. The majority of the intradural tumors are extramedullary, with nerve sheath tumors representing the vast majority.

Schwannomas and neurofibromas are the two main types of nerve sheath tumors found in the spine. Schwannomas are the most common nerve sheath tumors and the most common intraspinal tumor. They are more commonly seen in women aged 40–60 yr. They are typically solitary tumors with a well-defined lobulated appearance that may have hemorrhage or cystic components. They are more commonly found in the lumbar spine usually in an intradural location but they may also present as extradural lesions or both intradural and extradural resulting in a "dumbbell" shaped appearance. They are slow-growing tumors showing bone remodeling with posterior vertebral body and pedicle scalloping and neural foraminal expansion (Fig. 14). Multiple schwannomas are seen in patients with neurofibromatosis type II (Fig. 15) while spinal neurofibromas are more common in patients with neurofibromatosis type I. Neurofibromas are usually multiple, solid tumors with cystic degeneration an uncommon feature. In most cases, nerve sheath tumors are hyperintense to the cord on T2WI, iso- to hypointense to the cord on T1WI, and usually show intense gadolinium enhancement *(72)*.

Meningiomas are the second most common intradural lesion and second most common spinal tumor after schwannomas. They are very rare in the lumbar spine with most meningiomas found in the thoracic spine. There is a female predominance and middle age predilection. Multiple meningiomas are associated with neurofibromatosis type 2. The signal characteristics on MRI are similar to other extraspinal meningiomas with isointense signal relative to spinal cord on T1 and T2W images, and intense uniform enhancement. A dural tail, a common feature of intracranial meningiomas, may be present. Approximately 10% of cases show calcification.

Paragangliomas are rare tumors found in the cauda equina and filum terminale. They are highly vascular lesions that demonstrate strong contrast enhancement. They are usually well circumscribed lesions with isointense signal noted on T1WI relative to cord and hyperintense signal on T2WI.

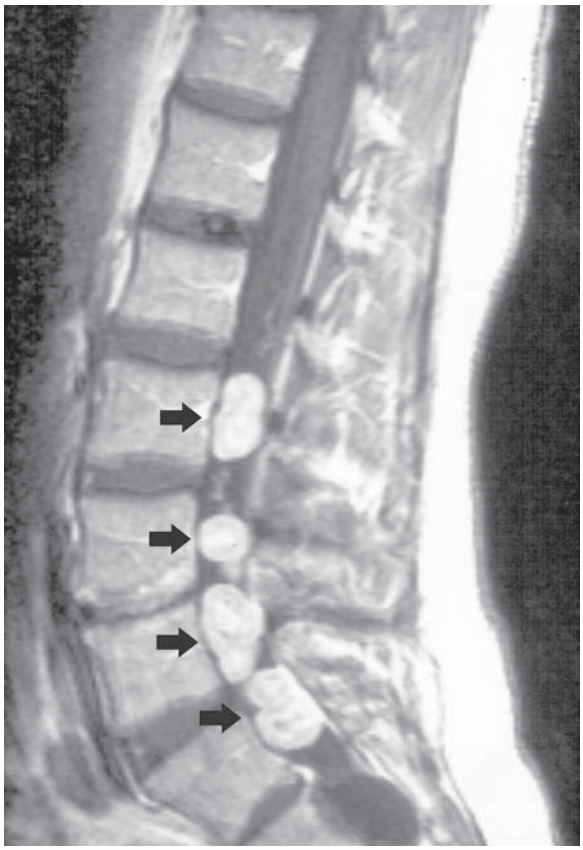


Fig. 15. Multiple schwannomas. This patient with neurofibromatosis II has multiple lobulated canal lesions in the lumbar spine. Contrast-enhanced sagittal T1-weighted image demonstrates significant contrast enhancement with mild heterogeneous signal in these lesions.

Epidermoid cysts may be acquired or congenital masses. Acquired epidermoids are the result of implantation of viable skin elements during spinal puncture or back surgery, and are common in the lumbar spine region. Congenital epidermoids usually occur in the lumbar spine in the distribution of the conus or cauda equina, and often have associated congenital anomalies such as hemivertebrae, spina bifida, and dorsal dermal sinus. Because of their composition, they are usually slightly hyperintense compared to cerebrospinal fluid (CSF) on all sequences but some may be isointense to CSF.

Dermoid cysts may have intramedullary and/or extramedullary intradural components. They may have an associated dorsal dermal sinus, or may be acquired as a result of iatrogenic implantation of dermal cells into intraspinal sites. They are more commonly found in the lumbar spine. This type of tumor has variable signal intensity secondary to the different components and derivatives. The typical hyperintensity seen with dermoids on T1WI has been attributed to the presence of lipid within these cystic masses. The presence of chemical meningitis in the subarachnoid space is a characteristic pattern from rupture of a dermoid.

Arachnoid cysts are rare intradural masses with signal intensity similar to CSF. They are most common in the thoracic region usually posterior to the spinal cord.

Spinal leptomeningeal metastases or "drop metastases" are neoplastic deposits in the subarachnoid space more commonly seen in the lumbar spine where they are frequently visualized in the dependent portion of the thecal sac, hence the term "drop metastases." Leptomeningeal metastatic disease accounts for the majority of malignant extramedullary, intradural masses. These include CNS and non-CNS etiologies. Primary CNS neoplasms include medulloblastomas, ependymomas, glioblastomas, anaplastic astrocytomas, choroid plexus tumors, and pineal gland tumors such as germinomas, pineocytomas, and pineoblastomas. Systemic malignancies such as lung, breast, and gastrointestinal carcinomas, lymphoma, leukemia, and melanoma may also produce meningeal carcinomatosis. MRI offers superior anatomic depiction of these lesions showing thickening and clumping of the enhancing nerve roots, enhancing nodules in the subarachnoid space and pial enhancement on the surface of the spinal cord.

EXTRADURAL SPINAL MASSES

These lesions are found outside the dural sac involving the epidural space, paravertebral soft tissues, and spinal skeleton. The most common extradural masses are metastases from primary breast, lung, prostate, myeloma, and lymphoma. MRI is the preferred imaging modality to detect these lesions. Primary bone tumors rarely involve the lumbar spine. Nerve sheath tumors may present as extradural lesions but this is less common than their presentation in the intradural compartment. Chordomas classically occur in the sacrum and coccyx.

Metastatic disease frequently affects the spine primarily involving the vertebral body, usually followed by neoplastic infiltration of the posterior elements and epidural compartment (Fig. 16). The vast majority of these lesions arise from hematogenous spread to vertebral bodies. The usual MRI appearance is neoplastic replacement of the normal fatty marrow with hypointense T1 signal and hyperintense T2 signal relative to bone marrow. Well defined oval or round lesions are commonly seen but other patterns of neoplastic infiltration include diffuse replacement of the marrow, heterogeneous marrow replacement, and sclerotic bone metastases typically seen with prostate carcinoma. Sclerotic metastases demonstrate low signal on both T1 and T2W images. Metastatic disease usually shows contrast enhancement. In non-fat-suppressed T1W images, the lesions may become isointense with normal marrow after contrast making their identification difficult. There is better delineation of these lesions using fat saturation pulse sequences. Epidural and paravertebral

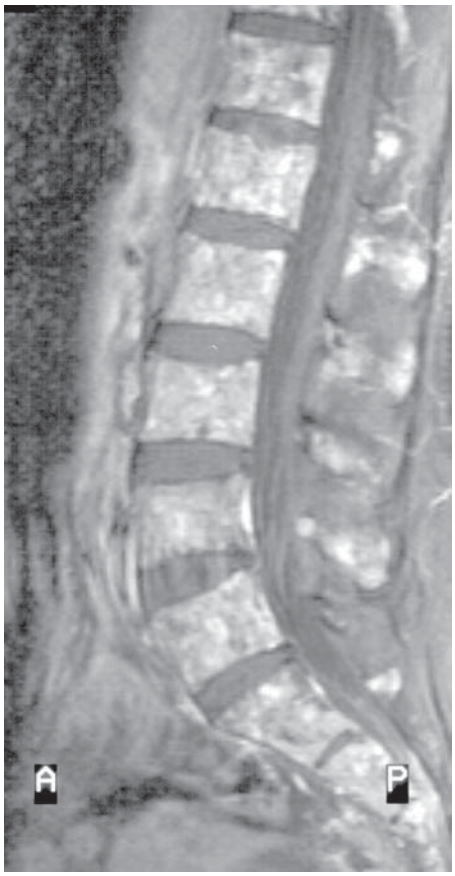
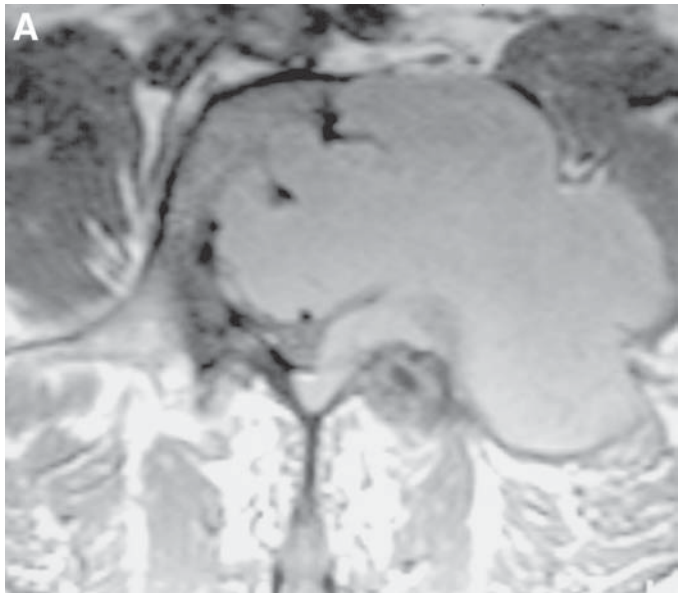


Fig. 16. Metastatic disease. Sagittal post-contrast T1-weighted fat suppressed image shows diffusely heterogeneous marrow signal in the vertebral bodies and posterior elements of the lumbar spine in a patient with neoplastic marrow replacement.

masses show inter- mediate T1 signal with contrast enhancement, which is accentuated if fat suppression techniques are applied.

Multiple myeloma commonly spreads to the spine and generally involves the vertebral body. Extradural compressive masses are frequent in the epidural space. A solitary spinal lesion may be the manifestation of the solitary form of multiple myeloma, plasmacytoma (Fig. 17). This occurs in younger individuals who eventually develop diffuse disease. The MRI findings of the disease also show decreased signal on T1WI and increased signal on T2WI. Enhancement is variable but usually present. Fat suppression is helpful in assessing the extent of neoplastic involvement.

Spinal involvement of lymphoma usually represents a secondary neoplasm. It may occur from direct extension of the disease from affected lymph nodes or secondary to hematogenous dissemination. Non-Hodgkin's lymphoma (NHL) is more common than Hodgkin's disease (HD). It commonly involves the vertebral marrow and the epidural space. Features on MRI that may suggest the diagnosis include an epidural mass that is isointense relative to the cord on T1 and T2WI that demonstrates homogeneous



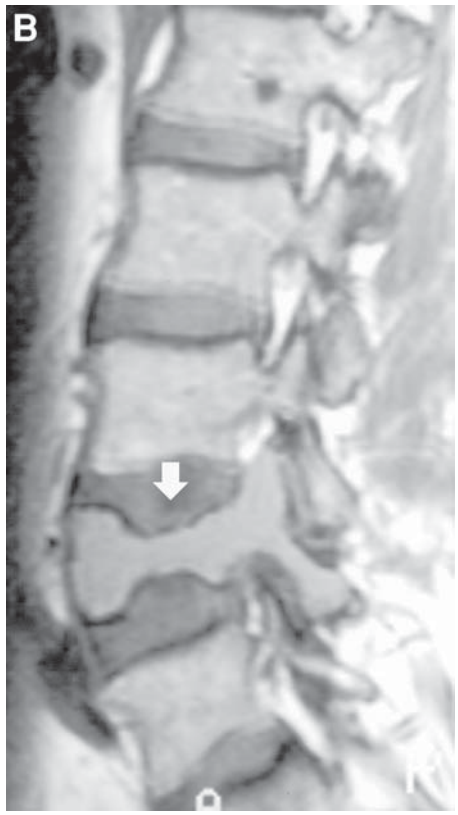


Fig. 17. Plasmacytoma. A large enhancing lobulated soft tissue mass is identified in a lumbar vertebra extending to the paraspinal soft tissues and spinal canal on these axial **(A)** and sagittal **(B)** postcontrast T1-weighted images. The solitary form of multiple myeloma was pathologically proven.

enhancement, and frequently extends to several vertebral levels. It may also show iso- to hyperintense signal relative to cord on T2WI. The tumor has a predilection for the thoracic spine followed by the lumbar spine. Diffuse vertebral marrow signal changes are commonly present.

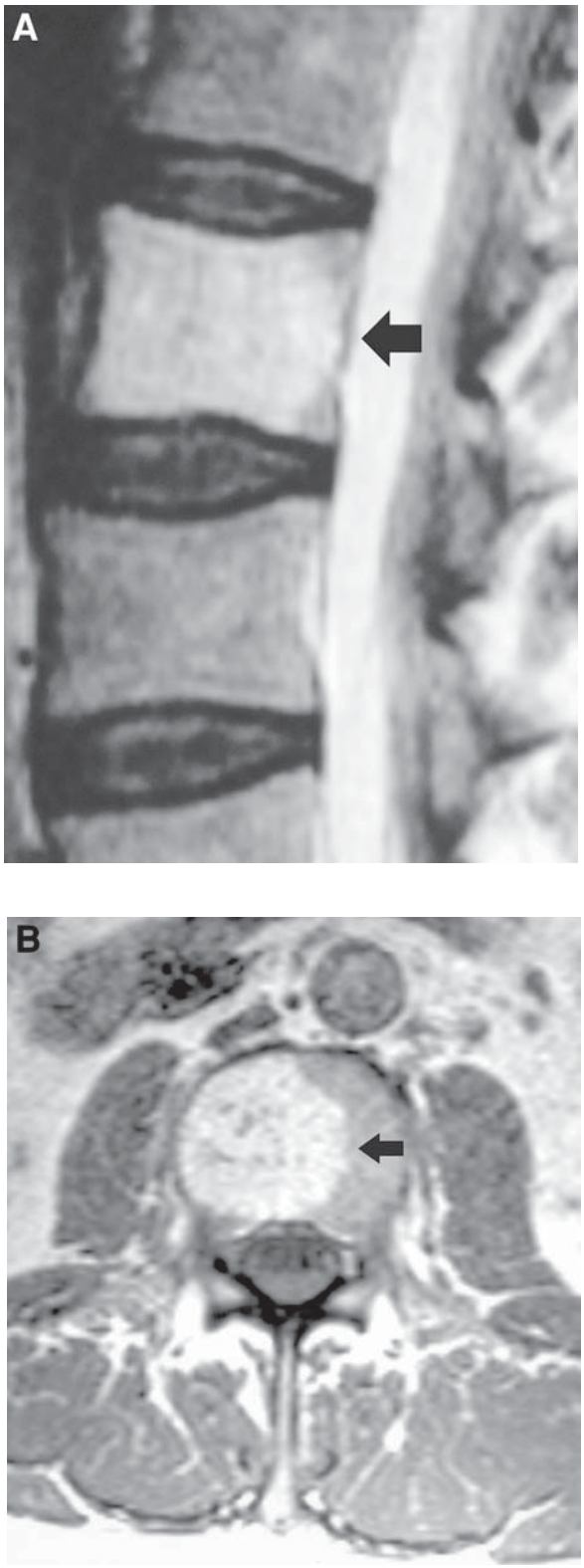


Fig. 18. Vertebral hemangioma. Sagittal T2-weighted **(A)** and axial T1-weighted **(B)** images demonstrate the classic appearance and high signal of a hemangioma.

There is marrow replacement by areas of low signal on T1WI, variable iso- to hyperintense signal on T2WI, and enhancement following gadolinium administration. In the pediatric population, leukemia has a similar appearance.

Hemangiomas are common incidental vertebral lesions. Some lesions may expand and become symptomatic. The most common sites are the thoracic and lumbar spine. The usual MRI appearance is a well-defined mass with hyperintensity on both T1 and T2WI (Fig. 18). The enhancement is variable. Hemangiomas with more vascular stroma demonstrate low signal on T1WI and high T2 signal, and must be distinguished from other primary and secondary vertebral tumors.

Primary bone tumors of the spine are rare and include giant cell tumors, aneurysmal bone cysts, osteoid osteomas, osteochondromas, and osteoblastomas (Fig. 19).

BURST AND COMPRESSION FRACTURES

The burst fracture is a comminuted fracture of the vertebral body caused by axial loading or vertical compression. With vertical compression forces, there is increase in intradiscal pressure with subsequent herniation through the endplate of the adjacent vertebral body, causing the body to explode from within outward and resulting in disbursement of the bony fragments in all directions. Retropulsed fragments are characteristically seen narrowing the spinal canal frequently associated with spinal cord, conus medullaris, or cauda equina injury (Fig. 20).

The simple wedge compression fracture is the result of a hyperflexion mechanism of injury. These are stable injuries because the middle and posterior column remain intact. There is loss of vertebral body height anteriorly, resulting in anterior wedging or depression of the superior end plate, and intact posterior elements.

Osteoporotic compression fractures are seen in patients with a diminished bone mass, commonly found in the elderly (primary osteoporosis). Other common causes of generalized osteoporosis (secondary osteoporosis) include alcoholism, smoking, poor nutrition, drugs, and hormonal and congenital disorders. Pathologic compression fractures are fractures secondary to weakened bone due to neoplastic infiltration with primary or secondary malignancies. Most of these fractures are the manifestation of metastatic disease. MRI has proven helpful in the differentiation between benign and pathologic compression fractures. Chronic benign osteoporotic compression deformities are characterized by isointense marrow signal relative to marrow of normal vertebrae on all pulse sequences. Acute, subacute, and pathologic compression deformities show similar signal characteristics on MRI, with decreased T1 signal and increased T2 signal relative to normal bone marrow. Nonspecific findings have been

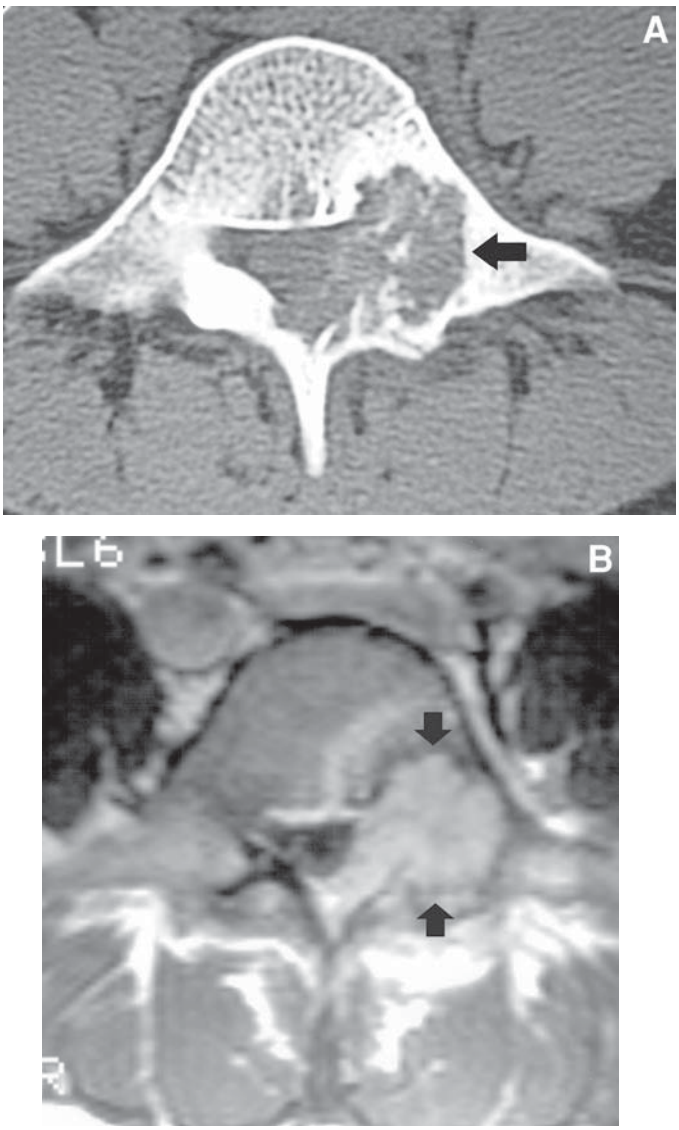


Fig. 19. Osteoblastoma. Axial CT scan image **(A)** shows an expansile lytic lesion involving the posterior elements and posterior aspect of a lumbar vertebral body. Axial T2-weighted image **(B)** demonstrates increased signal in this lesion with some areas of low signal and surrounding reactive edema.

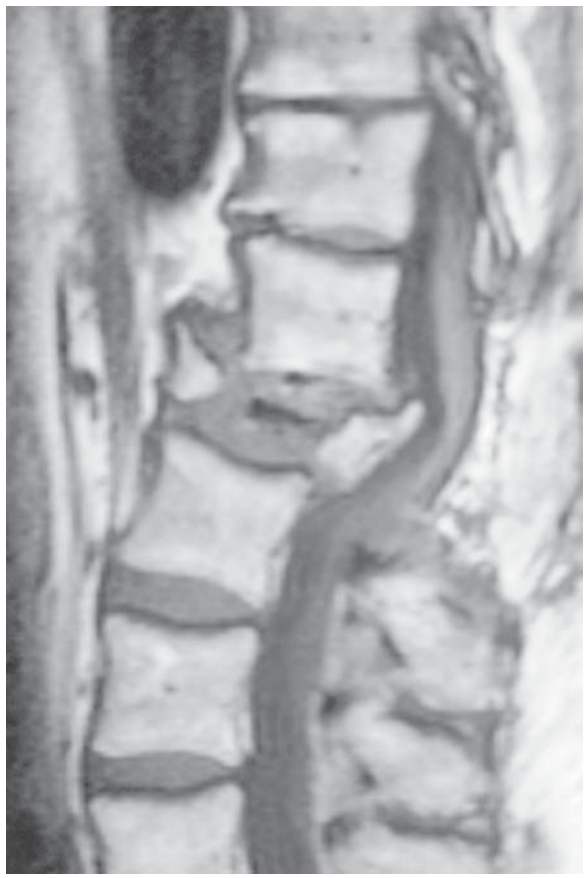


Fig. 20. Burst fracture. Sagittal T1-weighted image demonstrates a markedly compressed comminuted vertebral fracture with retropulsed bone, conus compression, and canal stenosis.

described to help differentiate benign from pathologic compression fractures. Total vertebral body marrow replacement is usually seen with pathologic fractures while benign deformities may show areas of preserved normal marrow. In osteoporotic compressions, the marrow edema eventually resolves. A short-term follow-up study may be useful in this differentiation. Other features that suggest malignant involvement include signal abnormality extending to the pedicle, cortical destruction, abnormal marrow signal in nonfractured vertebrae, and paraspinal soft tissue masses. Increased signal on diffusion-weighted imaging with evidence of restricted diffusion have been described in recent studies of pathologic compression fractures, whereas benign fractures demonstrates low signal intensity utilizing this technique. Diffuse vertebral body enhancement and bone marrow enhancement greater than normal marrow following the administration of gadolinium are other characteristics suggestive of malignant marrow replacement. Increased T1 signal or preservation of normal marrow signal on T1W and T2W images are characteristics of benign compression deformities.

Patients with vertebral body compression fractures may undergo percutaneous vertebroplasty. Vertebroplasty involves a transpedicular injection of polymethylmethacrylate (PMMA) into the vertebral body. The injected PMMA is dark on T1- and T2-weighted images and may show a thin rim of enhancement with contrast (Fig. 21).

POSTOPERATIVE LUMBAR SPINE

Post-contrast MRI is useful in differentiating between recurrent disc herniations and postoperative fibrosis *(39)*. Scarring enhances on contrast images following the injection of gadolinium when imaging is performed within 30

min of injection. After 30 min of injection, recurrent disc herniations may also enhance. Displacement of the thecal sac or nerve roots can be visualized with both epidural fibrosis and disc herniation *(73)*. In some cases, enhancing granulation tissue may not be seen until 3 mo after surgery. After this time period, a nonenhancing structure is most likely a recurrent disc herniation. Of note is that fibrosis can surround a nerve root and sometimes be the cause of the patient's symptomatology. Clumping of the nerve roots is suggestive of arachnoiditis. A potential complication of surgery is the formation of a pseudomeningocele (Fig. 22), which may present as an enlarging palpable mass as the result of a dural tear with leakage of CSF in an extrathecal location *(74)*.

VASCULAR DISORDERS

Delineation of the spinal vasculature has become more accurate with MRI and MR angiographic techniques. MRI is a noninvasive helpful radiological tool that improves detection and characterization of spinal vascular disorders *(75)*.

Vascular malformations of the spine and spinal cord are rare diseases *(76)*. The classification scheme of Anson and Spetzler *(65)* divides arteriovenous malformations into four types. Type I is a dural arteriovenous fistula (Fig. 23). This is the most common type of spinal arteriovenous malformation (AVM). Type I AVMs are subclassified as types I-A = single feeding artery, and type I-B = multiple feeding arteries. The nidus is found in the dura or contiguous to the dura of the proximal nerve root, most commonly on the dorsal aspect of the lower thoracic spinal cord and conus medullaris. It is typically seen in middle-aged to older men. Patients present with slowly progressive neurologic symptoms. Type II or glomus-type AVMs are intramedullary lesions supplied by branches of the anterior and/or posterior spinal arteries. There is drainage into the venous plexus that surrounds the spinal cord. These malformations occur in young patients with acute myelopathy secondary to hemorrhage. Type III or juvenile-type AVMs are large, extensive vascular malformations with a poor prognosis. They are intramedullary lesions that frequently have extramedullary and extradural components. These disorders occur in children and young adults. Type IV is an intradural, extramedullary AVM usually seen in the region of the conus medullaris. Patients typically have progressive myelopathy. MRI generally shows nonspecific findings including low T1 and high T2 signal in the spinal cord. Enhancement and cord expansion can be present. Intravascular flow-related signal abnormality in the subarachnoid space is important in the detection of these lesions. Contrast-enhanced MRA complements the standard MRI, allowing the identifica-

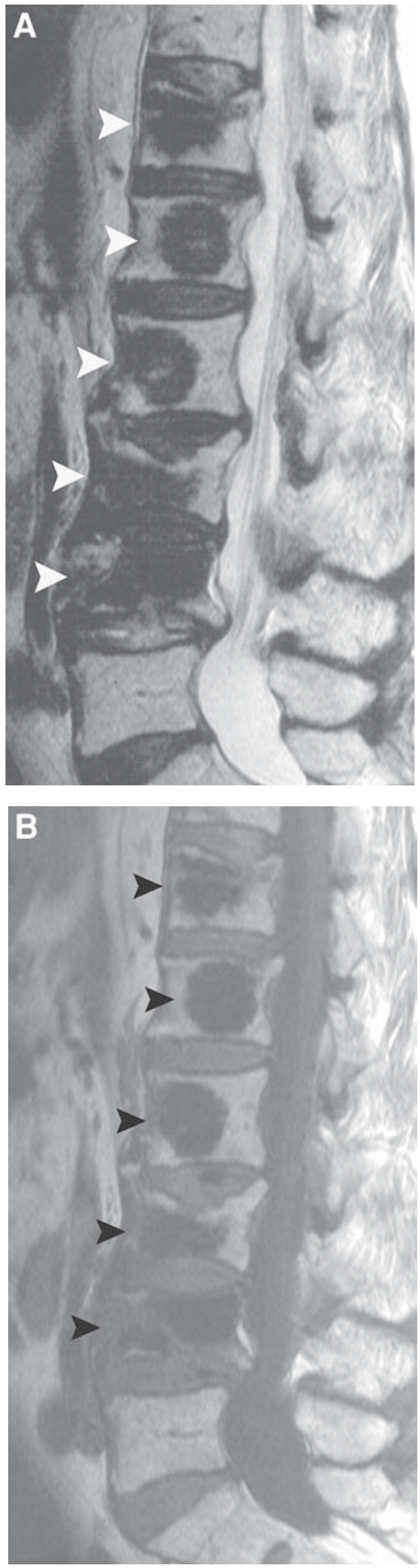


Fig. 21. Vertebroplasty. Sagittal T2-weighted **(A)** and sagittal T1-weighted **(B)** images show the hypointense vertebral body signal seen after multiple vertebroplasty procedures in this patient with osteoporotic compression fractures.

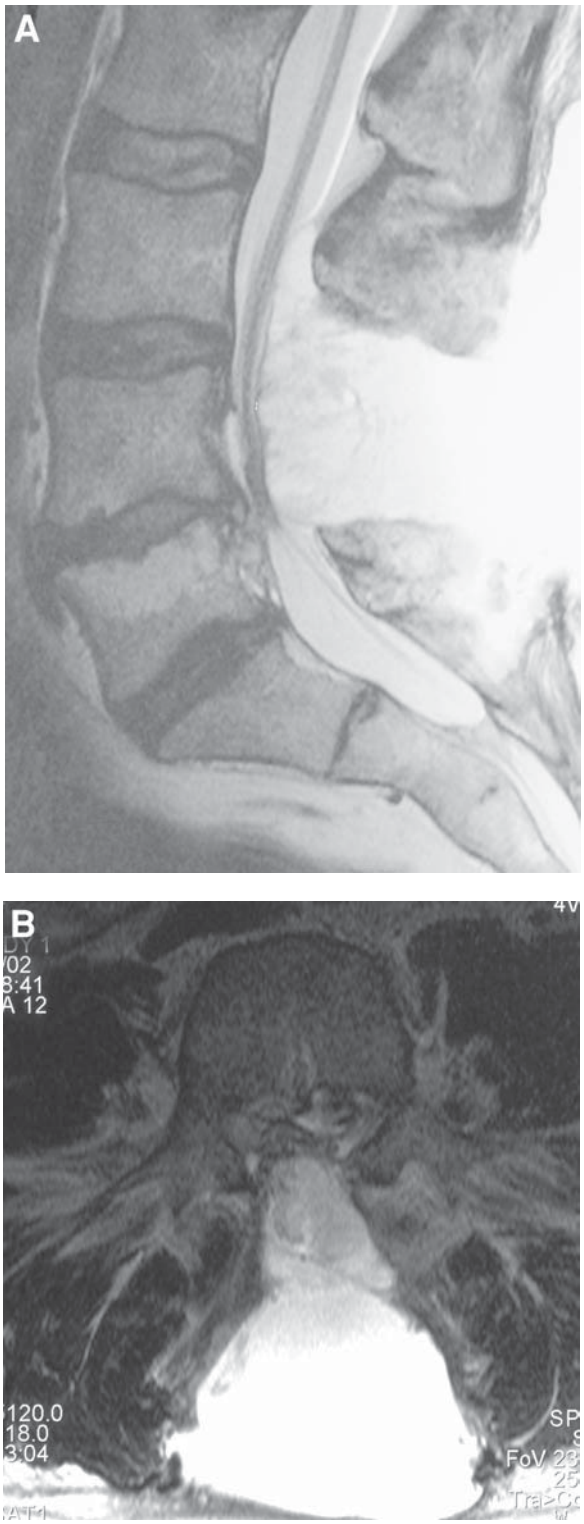


Fig. 22. Pseudomeningocele. Sagittal **(A)** and axial **(B)** T2-weighted images demonstrate a cystic structure extending from the spinal canal into the paravertebral soft tissues consistent with a pseudomeningocele. This was secondary to a dural leak in a postoperative patient.

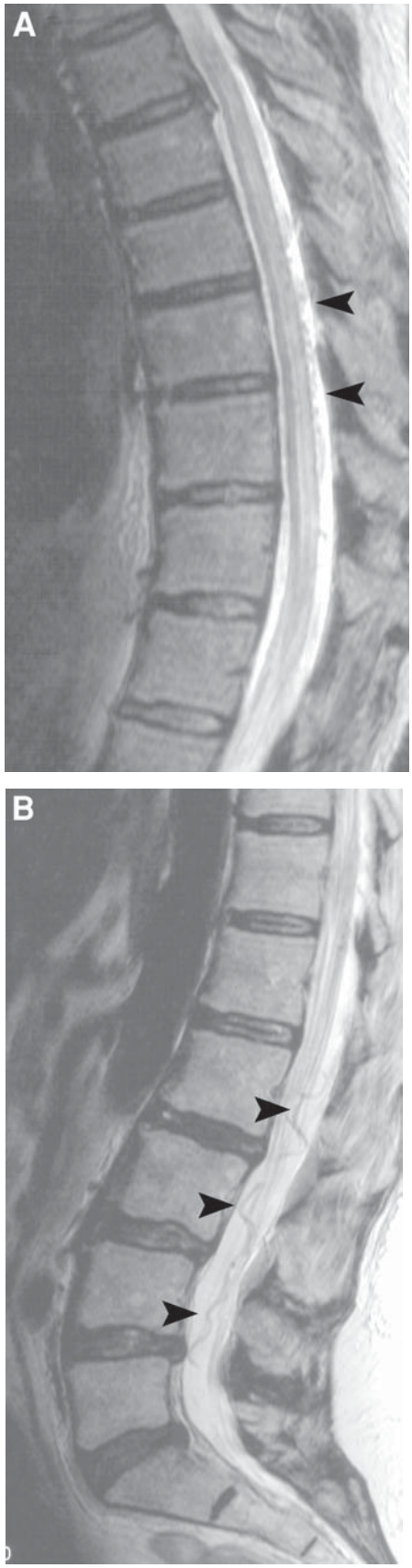


Fig. 23. Dural arteriovenous fistula. A type I AVM is identified on the sagittal T2-weighted images **(A, B)**. Abnormal serpiginous vessels are seen dorsal to the distal spinal cord and in the distal aspect of the spinal canal.

tion and better characterization of these vascular anomalies *(77)*.

Spinal cord cavernous angiomas are rare intramedullary lesions similar in appearance to those in the brain. MRI demonstrates mixed or heterogeneous T1 and T2 signal due to the presence of blood products of different ages. Typical increased T1 and T2 signal areas are identified within these lesions. A peripheral rim of low T2 signal from hemosiderin is characteristic. This hypointensity is more conspicuous on gradient echo technique due to the magnetic susceptibility from hemosiderin. These vascular lesions are most common in the thoracic cord.

Spinal cord ischemia and infarction usually occur in the thoracolumbar junction commonly seen in patients with atherosclerosis and aortic dissections. Most of these are secondary to occlusion of the artery of Adamkiewicz, a primary branch of the anterior spinal artery. The gray matter and anterior two thirds of the cord are generally affected. MRI typically shows cord enlargement in the acute phase and hyperintense T2 signal usually involving the anterior two thirds of the spinal cord. Enhancement may be seen. The characteristic "owl eyes" appearance is the result of enhancement of the gray matter on contrast-enhanced studies. In chronic stages, cord atrophy is visualized. Concomitant vertebral body infarction contiguous to the cord abnormality may be identified. Rarely, venous infarction may occur, which is difficult to distinguish from arterial infarction.

CONCLUSION

MRI of the spine has revolutionized visualization of pathologic conditions that affect the spine and spinal cord. Before any patient undergoes an interventional spinal procedure, he or she should have an MRI to define his or her pathology and extent of disease.

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4 Nuclear Medicine of the Spine

JOHN E. BAUMERT, JR., MD

BONE SCINTIGRAPHY

GENERAL PRINCIPLES

Bone scintigraphy is a frequently requested and widely available method of diagnosing a variety of bony lesions of the spine. Bony lesions have predictable patterns of increased tracer uptake that are characteristic of the underlying disease process. Single photon emission computed tomography (SPECT) of the spine shows greater lesion contrast than planar studies *(1)*. SPECT images are also easier to correlate with other tomographic-based studies, such as magnetic resonance imaging (MRI) or computed tomography (CT).

Comparison of SPECT bone images with planar images is useful in identifying the correct vertebral level. When available, radiographic correlation is useful in identifying normal variants, such as six lumbar vertebrae or sacralization of the lumbar spine *(2)*.

NORMAL VARIANTS

The normal tracer uptake in lumbar vertebrae 4 and 5 is greater than in the other lumbar vertebrae because of a difference in size. The sacral promontory often shows prominent uptake on the coronal views *(2)* (Fig. 1).

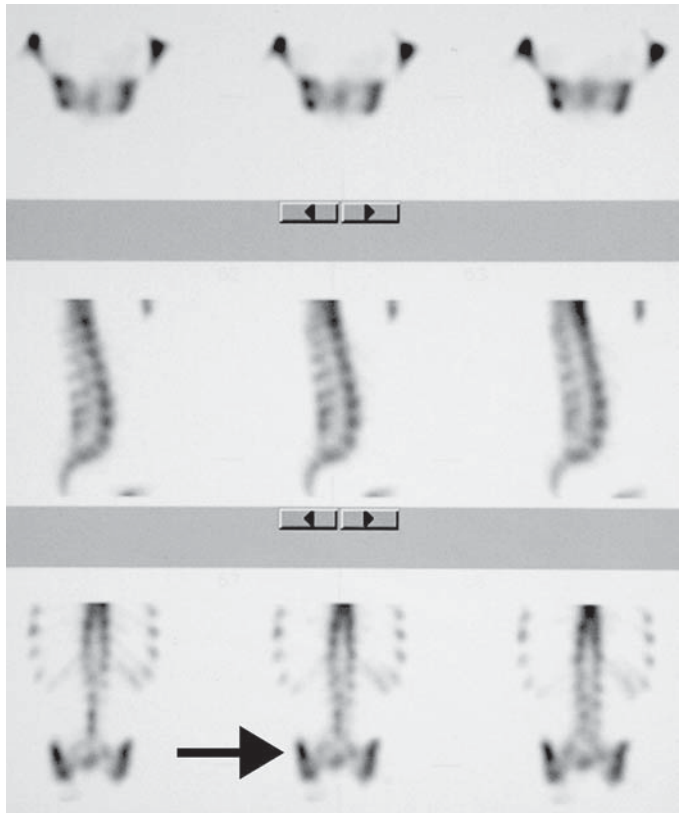

Fig. 1. Normal bone SPECT. The sacral promontory is located between the right (*arrow*) and left sacroiliac joints and is prominently seen on the coronal images but shows normal intensity on the sagittal views (**middle row**).

STRESS FRACTURES, SPONDYLOLYSIS, AND SPONDYLOLISTHESIS

Spondylolysis is a defect in the pars interarticularis that may or may not be associated with spondylolysthesis. There is a familial predisposition for spondylolysis *(3)* and a strong association with repetitive mechanical loading of the spine *(3–6)*. Cadaveric studies show that fatigue fractures of the pars interarticularis occur with levels of repetitive force and deformation significantly below those required to produce failure in a single loading cycle *(4,5,7)*. Furthermore, alternating flexion and extension

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movements cause large stress reversals on the pars that make it particularly vulnerable to spondylolysis *(6)*.

Stress injuries of the pars interarticularis are a common cause of low back pain in athletes. Dancers, gymnasts, weight lifters, and basketball players are involved in vigorous and repetitious activities that concentrate stress over a small area of the pars interarticularis. The initial response to repeated stress injury is a stress injury that may progress to spondylolysis and spondylolytic spondylolisthesis *(3)*.

Bone scintigraphy is valuable in the evaluation of stress injuries of the pars interarticularis. SPECT bone scintigraphy is more sensitive than either planar bone imaging or radiography in detecting pars injuries *(8–10)*. Bellah et al. studied 162 young patients with low back pain referred for bone scintigraphy by orthopedic surgeons *(8)*. SPECT imaging was abnormal in 71 patients. Planar scintigraphy was abnormal in only 32 of these patients. Furthermore, 16 of 56 patients with normal radiographs had abnormal SPECT studies. The authors postulated that this may be due to microfractures of the pars interarticularis that were too subtle to be detected radiographically. Bodner et al. compared SPECT imaging with planar scintigraphy and radiographic evaluation in 15 patients with low back pain *(9)*. All patients were followed until resolution of symptoms. There were five patients in whom SPECT imaging was the only modality to detect a lesion. In all five, the posterior elements showed abnormally increased uptake which was thought to represent stress injuries of the pars interarticularis.

Quantitative techniques have also been used in assessing stress injuries of the pars interarticularis. Anderson et al. studied 34 patients with quantitative SPECT bone scanning before and after treatment with either bracing or activity restrictions *(10)*. The SPECT studies were reported as the ratio of the activity in the affected vertebra over the activity in the superior, contiguous unaffected vertebra. The SPECT ratio before and after treatment was compared to the symptomatic response to treatment and proved to be a reliable indicator of the patient's progress. Patients with high initial SPECT ratios treated promptly with brace immobilization had complete symptom relief and greater improvement in the SPECT ratio than those treated with activity restrictions before bracing who were more likely to have persistent symptoms and more modest improvement on SPECT.

Spondylolysis is seen in 3–10% of adults and may or may not be associated with low back pain *(11)*. Furthermore, adults with either spondylolysis or spondylolisthesis may have low back pain from unrelated causes. Collier et al. *(11)* studied the relationship between SPECT imaging and low back pain in 19 adults with radiographic evidence of either spondylolysis or spondylolisthesis. SPECT imaging was positive in 1 of 6 asymptomatic patients and in 11 of 13 patients with low back pain. The authors hypothesized that the metabolic status of the radiographic abnormality may identify the lesion as the cause of the pain.

ARTICULAR FACET OSTEOARTHRITIS

Articular facet osteoarthritis is a common cause of low back pain in adults. The facets can be a direct source of pain, as the synovial linings and joint capsules are richly innervated *(12)*. Sciatica can be caused by nerve root compression due to facet hypertrophy, focal osteophytes, subluxation, or expansion of the joint capsule due to effusion *(1)*.

SPECT imaging is more sensitive than planar imaging in detecting facet joint lesions *(13–15)* and can be used in selecting appropriate patients for treatment with facet injections *(15,16)*. Ryan et al. compared SPECT imaging with radiography and CT in 34 patients with low back pain referred from a rheumatology clinic *(14)*. SPECT identified 18 lesions of the facet joints. Seventeen of these corresponded to articular facet osteoarthritis on CT or radiography. Planar bone scintigraphy was positive in only two of these lesions. Holder et al. also compared SPECT and planar bone scintigraphy in the diagnosis of facet syndrome *(15)*. All patients had anatomic evidence of facet arthritis as determined by CT, MRI, or radiography. The criteria for final diagnosis included clinical outcome and a sustained positive response to facet injection. Holder et al. found that SPECT was more sensitive (100% vs 76%) but less specific (71% vs 76%) than planar imaging in identifying clinically significant facet osteoarthritis. Scott et al. also found SPECT useful in selecting patients for facet injection *(16)*. Facet joints showing increased tracer uptake had sustained responses to treatment.

DISTINGUISHING PARS INJURIES FROM FACET ARTHRITIS USING SPECT

Abnormal uptake in the pars interarticularis is usually due to a stress injury or spondylolysis. Facet lesions are usually arthritic although fractures and osteoid osteomas may be present. Lesions in the vertebral arch must be accurately localized to differentiate between these disorders. SPECT is particularly useful in lesion location because multiple projections can be reconstructed *(1)*. It is difficult to distinguish a pars injury from facet arthritis in the coronal and transverse reconstructions. However, these lesions can be distinguished in sagittal projection constructed slightly off midline toward the affected side (Fig. 2). Sagittal imaging shows the relationship between the lesion to the disc space and the posterior column of the vertebral body *(1)*. The apophyseal joints are on the same horizontal plane as the disc space whereas the pars

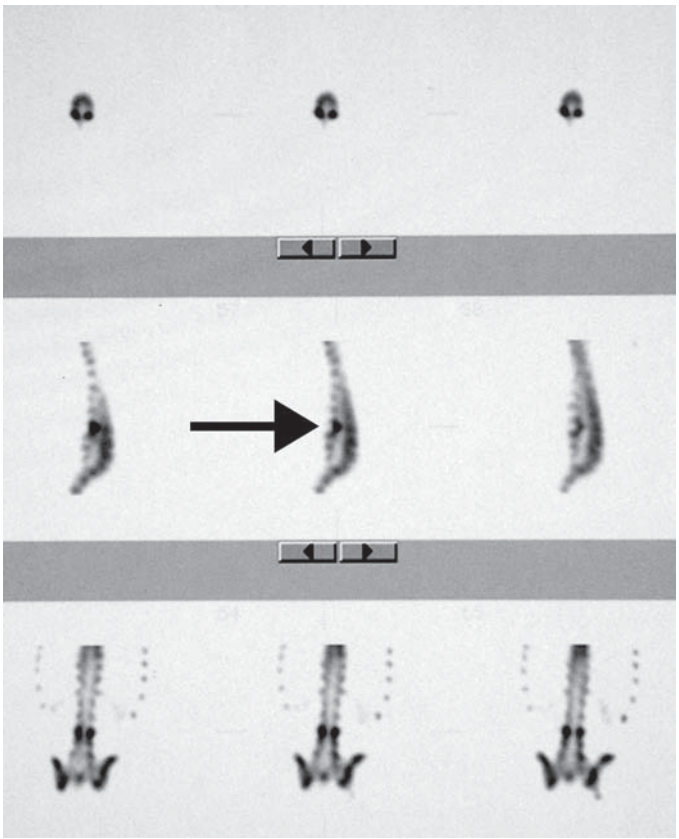

Fig. 2. Pars interarticularis stress fracture. The off-midline sagittal images (**middle row**) show the lesion to be below the disc space and behind the posterior margin of the vertebral body (*arrow*).

interarticularis lies below this level and posterior to the vertebral body.

DEGENERATIVE DISC DISEASE

Degeneration of the intervetebral lumbar disc is often associated with back pain *(17)*. MRI studies often show marrow changes adjacent to the endplates in patients with degenerative lumbar disc disease *(18,19)*. Modic et al. *(19)* showed that hyperemic bone marrow changes (type 1 pattern) may progress to conversion of red to yellow marrow changes (type 2 pattern). Lusins et al. compared SPECT bone scintigraphy and lumbar MRI in detecting endplate changes in 48 patients with back pain and MRI disc degenerative changes *(20)*. Thirty-seven patients had increased activity of the endplates seen in SPECT scintigraphy and type I and type II MRI marrow endplate changes. However, 10 patients had abnormal SPECT scintigraphy despite normal MRI marrow endplates. The authors postulated that the increased activity seen with SPECT imaging is attributable to marrow changes and that the marrow changes can be identified by SPECT imaging prior to being seen on MRI.

MALIGNANCY

Whole body bone scintigraphy is used in the initial staging and follow-up of cancer patients. Distinguishing benign from malignant lesions may pose a diagnostic dilemma in patients with known malignancies but no known metastases *(21,22)*. Jacobson et al. studied the bone scintigrams of cancer patients and found metastatic disease in 11% of patients with one new skeletal lesion and in 24% of patients with two new lesions *(21)*. Follow-up bone scintigraphy showed an interval increase in activity in most patients with metastatic disease, whereas benign lesions usually remained either unchanged or showed less activity. Benign degenerative changes in the spine showed increased activity either permanently or for extended periods of time. Correlative radiography is routinely used to evaluate new lesions seen on bone scintigrams of cancer patients. Malignancy is effectively excluded when radiographs show a corresponding benign lesion. However, normal radiographs do not exclude a malignancy *(22)*.

Coakley et al. studied solitary spinal lesions on planar bone scintigraphy and found that the location of the lesion is helpful in distinguishing benign from malignant disease *(23)*. Lesions projecting beyond the vertebral body surface were all benign. Increased uptake extending diffusely through a vertebra, but not extending outside the lateral spinal margin, was a nonspecific finding and seen in patients with osteoporotic compression fracture, malignant collapse, spondylolysis, and crush fractures. Increased uptake confined between the midline and lateral spinal margin was also a nonspecific finding and seen with both malignant involvement of the vertebrae and in apophyseal joint arthritis. In the Coakley study, the spinal level of the lesion also had prognostic significance. Eight of 10 lesions in the thoracic spine were malignant, whereas only 10 of 32 lumbar lesions were malignant. Even-Sapir et al. studied the location of lesions of the lower thoracic and lumbar vertebrae with SPECT imaging and identified additional useful information distinguishing benign from malignant disease *(24)*. Lesions confined to the apophyseal joints and lesions projecting beyond the vertebrae body surface were all benign. Uptake in the vertebral body with contiguous uptake in the pedicle was caused by metastases in 83% of the patients (Fig. 3), whereas focal or diffuse uptake confined to the body was benign 89% of the time. Conversely, Rineartz et al. found that SPECT lesions confined to the vertebral body were benign only 64% of the time *(25)*. In the Reinartz study, lesions affecting the pedicle had a high likelihood of malignancy (> 87%) while lesions involving the facet joints had a relatively low likelihood of malignancy (< 22%). Lesions confined to the spinous process were indeterminate for malignancy. Algra et al. studied metastatic patterns within

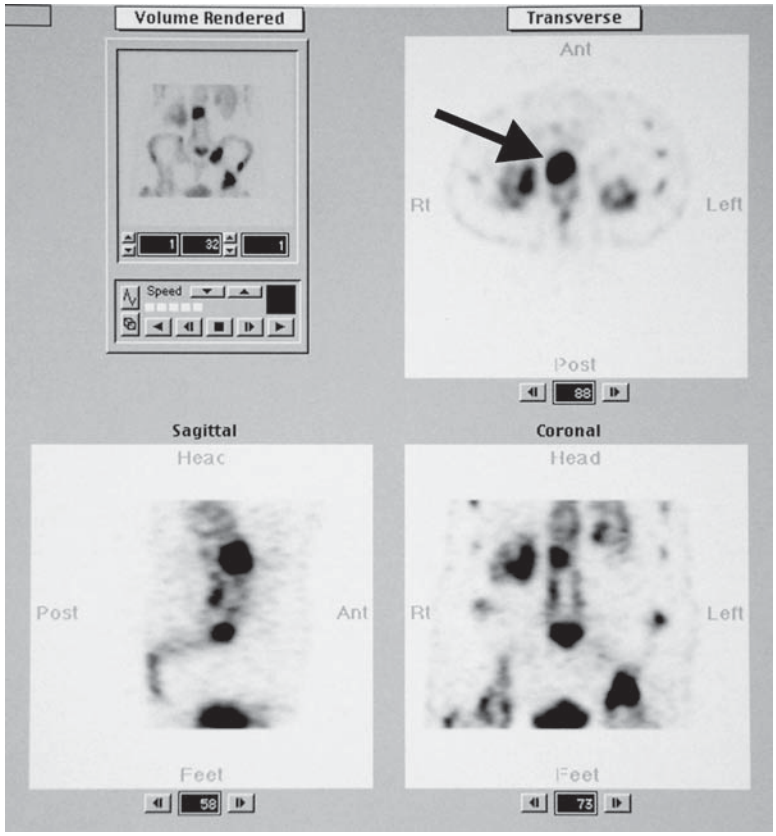

Fig. 3. Metatastic lung cancer. The volume rendered SPECT image (**upper left**) shows metastases to the spine and pelvis. The transverse image (**upper right**) shows involvement of the vertebral body and right pedicle (*arrow*).

vertebrae using CT and found that vertebrae arch sites always had associated metastatic tumor in the posterior column of the vertebral body *(26)*. He found a predilection of metastatic disease in the posterior column of the vertebral body which he postulated to be due to posteriorly located basevertebral veins providing a route for hematogenous spread of tumor into the vertebrae with subsequent arch lesions occurring from direct invasion.

OSTEOID OSTEOMA

Osteoid osteoma is a benign bone tumor often associated with severe skeletal pain. The tumor is usually < 2 cm in size and consists of a nidus of osteoid and bone in highly vascular tissue. The lesion causes an intense reaction in the surrounding periosteum. Seventy percent of osteoid osteoma patients are younger than 20 yr of age. Osteoid osteoma occurs 2.3 times more frequently in males *(27)*.

Kaweblum et al. collected 52 cases of osteoid osteoma in children from the English literature and seven cases from the Hospital for Joint Diseases *(28)*. Six patients had lesions in the spine. Both planar bone scans and CT were sensitive in detecting osteoid osteoma in patients in whom radiographs were normal. Mandel et al. studied scintigraphy of spinal disorders in adolescents and found 10% of osteoid osteomas to be located in the spine *(29)*. They were located in the laminae, facets, pedicles, and spinous processes in order of decreasing frequency.

VERTEBRAL FRACTURES AND VERTEBROPLASTY

Vertebral body fractures show an intense increase in acti-vity that occurs within 72 h in most patients *(30)*. Osteopenic compression fractures do not extend posteriorly into the vertebral arch and do not obscure the disc space. Matin et al. showed that 59% of fractures are normal by the end of the first year, 91% by the second year, and 95% by the third year *(30)*.

Planar bone scintigraphy is useful in predicting pain relief from percutaneous vertebroplasty in patients with osteoporotic vertebral fractures *(31)*. Current vertebroplasty practice includes the evaluation of patients with chronic pain who have multiple fractures of uncertain age. In many patients the physical examination does not reliably identify the fracture that is responsible for the pain. Maynard et al. *(31)* used planar bone scintigraphy to guide patient selection for vertebroplasty. Significant pain relief was noted in 26 of 28 treatment sessions.

SACROILIITIS

There is conflicting information regarding the role of planar bone scintigraphy in the evaluation of sacroiliitis. Some studies show planar bone scintigraphy to be efficatious in the diagnosis of sacroiliitis *(32,33)* while other studies show poor diagnostic accuracy *(34,35)*. Hanley et al. showed SPECT bone scintigraphy to be superior to quantitative planar bone scintigraphy in diagnosing sacroiliitis (36). Hanley et al. also compared MRI and SPECT bone scintigraphy in early sacroiliitis and found MRI to be more sensitive (54% vs 38%) but less specific (67% vs 100%) than SPECT imaging in diagnosing sacroiliitis *(37)*.

PAIN FOLLOWING SPINAL SURGERY

Patients undergoing laminectomy and laminectomy with fusion have a 10–30% rate of continued or renewed low back pain *(38)*. Causes of low back pain following surgery include degenerative facet or disc disease, recurrence of disc extrusion, infection, spinal stenosis, sacroiliitis, and pseudarthrosis (failure of fusion).

Pseudarthrosis is a common complication of spinal fusion procedures. Unfortunately, flexion–extension radiographs and CT are often inaccurate in the diagnosis of pseudarthrosis *(39)*. SPECT bone scintigraphy appears to be promising in the diagnosis of pseudarthrosis in the early years following spinal surgery *(40,41)*. Slizofski et al. studied painful pseudarthrosis following lumbar fusion using SPECT and planar bone scintigraphy *(40)*. SPECT was superior to planar bone scintigraphy. SPECT bone scintigraphy had a sensitivity of 78% and a specificity of 83% in diagnosing pseudarthrosis in symptomatic patients. However, it also showed increased activity in the fusion mass of 6 of 11 asymptomatic patients. Exploratory surgery was not performed on the asymptomatic patients; therefore, the cause of the increased uptake is uncertain. The authors postulated that it may be due to painless pseudarthrosis.

SPECT bone scintigraphy is also useful in diagnosing early degenerative facet and disc disease related to changes in biomechanical stress on the spine following fusion surgery. Lusins et al. studied 25 patients with persistent low back pain following lumbar spine surgery and found that more extensive surgery was associated with a greater number of lesions identified in SPECT imaging *(42)*. Patients with single level laminectomy had less extensive facet stress than those with multilevel laminectomy. Patients subjected to laminectomy and fusion had chronic facet stress above and below the fusion mass. This was attributed to transfer of biomechanical stresses to the segments above and below the fusion mass causing increased load on the facets at these levels. Even-Sapir et al. studied 33 patients with back pain after lumbar fusion surgery to determine the value of SPECT bone scintigraphy in the assessment of pain occurring more than 4 yr after surgery *(41)*. The most common findings were lesions in the facet joints and vertebral bodies in the free motion segments adjacent to the fused segments.

In the Even–Sapir study pseudarthrosis in the early years after surgery was associated with increased uptake in the fusion mass while pseudarthrosis in the late years after surgery showed no corresponding abnormalities in four of five patients. The authors hypothesized that the increased metabolic activity associated with pseudarthrosis in the early years after surgery decreases with time.

INDIUM-111-LEUKOCYTE AND GALLIUM SCINTIGRAPHY

VERTEBRAL OSTEOMYELITIS AND DISC SPACE INFECTION

In adults, vertebral osteomyelitis is the result of hematogenous seeding of the subchondral bone of the vertebral body *(43)*. Patients with urinary tract infections, intravenous drug use, spinal surgery, dental infections, and abdominal and pelvic surgery are at increased risk of bacteremia. Presumably this results in septic emboli lodging in the end-arteriole in the vertebral body metaphysics *(44)*. The areas of the vertebral metaphysis supplied by the end-arterioles undergo septic infarction with subsequent osteomyelitis. There is no direct route of communication with the intervertebral disc which becomes involved following the destruction of bone *(43)*.

Disc space infections are associated with direct inoculation of bacteria into the disc space. Disc space infections are seen most often following surgical removal of the nucleous pulposus but can also be associated with spinal tap, myelography, and discography. Although disc space infection and vertebral osteomyelitis differ in route of infection, their clinical course and findings are similar *(43)*.

Indium-111-leukocyte scanning is neither sensitive nor specific in the diagnosis of osteomyelitis *(45,46)*. Palestro et al. performed 76 indium-111-leukocyte scans in 71 patients with suspected vertebral osteomyelitis *(46)*. When increased activity of the vertebral body was seen it was highly specific for osteomyelitis (98%). Unfortunately, increased activity was seen infrequently (sensitivity of 39%). More than half (54%) of the patients with vertebral osteomyelitis had a photopenic defect on the indium-111-leukocyte scan. Photopenic defects were neither sensitive (54%) nor specific (52%) for infection. The cause of the failure of indium-111-leukocyte migration is uncertain, but has been postulated to be due to infection-induced occlusion of the microcirculation *(47)*

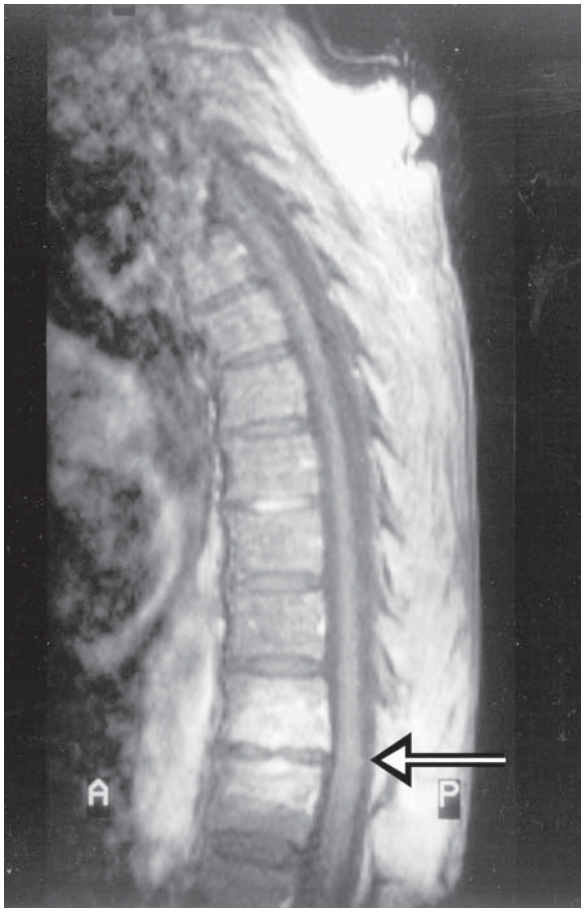

Fig. 4. Vertebral body osteomyelitis with discitis. The contrast MRI does not show disc space enhancement or endplate erosion (*arrow*).

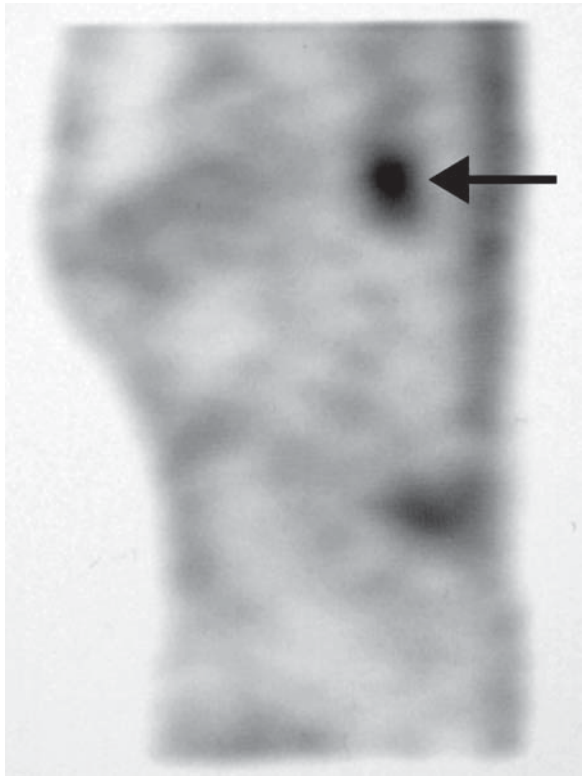

Fig. 5. Vertebral body osteomyelitis with discitis. The SPECT gallium scan shows involvement of both vertebral body endplates and the disc (*arrow*) despite the negative MRI (Fig. 4).

and death of the reticuloendothelial cells that normally accumulate leukocytes *(40)*.

Gallium scintigraphy is the preferred radionuclide study in the evaluation of patients for either vertebral osteomyelitis or disc space infections. Bruschwein et al. evaluated planar gallium scanning in 100 consecutive patients with suspected disc-space infection. Planar gallium scintigraphy was sensitive (89%), specific (85%), and accurate (86%) in detecting disc-space infection *(48)*. Modic et al. compared MRI with combined gallium and bone scanning and found that the sensitivity (96% vs 90%), specificity (92% vs 100%), and accuracy (94% vs 94%) were similar *(49)*. MRI, however, provided additional information regarding the neural structure, the discs, and the paravertebral regions *(49)*. Love et al. compared bone and gallium scintigraphy and MRI in the diagnosis of vertebral osteomyelitis in 22 patients *(50)*. Gallium SPECT imaging was more accurate than planar gallium scintigraphy, planar bone scintigraphy, and SPECT bone scintigraphy. SPECT gallium scintigraphy was as sensitive for vertebral osteomyelitis as MRI (91% vs 91%). It was slightly, but not significantly, more specific (92% vs 77%). The authors concluded that, although MRI is the procedure of choice, SPECT gallium is an excellent alternative exam to use in patients with pacemakers or orthopedic hardware. It is also a useful complementary test for patients in whom the diagnosis is uncertain (Figs. 4 and 5).

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5 Clinical Evaluation of the Spine Patient

L. MARK DEAN, MD

INTRODUCTION

Evaluation of a patient with back symptoms such as pain or neuropathy can be challenging. In this chapter we outline features of the patient's history, physical examination, and diagnostic imaging studies used to evaluate the symptoms. Several common spinal disorders are outlined, and a review of diagnostic and radiologic tests follows.

The initial assessment focuses on identifying the cause of the pain or neurological deficit, including whether it is neurological or musculoskeletal in origin, and differentiating whether the source is within the spine or referred to the back (as from the viscera in erosive gastroesophageal reflux) *(1)*.

HISTORY OF THE PRESENTING SYMPTOMS

After greeting the patient, begin to establish a rapport and initiate your general assessment. Allow the patient to describe the symptoms voluntarily. The general assessment should include the following details concerning the character and intensity of the neuropathy or pain:

1. Onset and pattern: When did it start? How often does it occur?
2. Location: Where was the pain or neuropathy located?
3. Origin: What was the setting in which the pain developed? Was there trauma? Was it insidious?
4. Character: How does the patient describe the pain or neuropathy? What did it feel like? Was there numbness or a prickly sensation?
5. Intensity: How does the patient rate the pain? Use a visual analog scale from 0 to 10, with 0 being no pain and 10 being the most severe pain the patient has ever experienced *(2)*.
6. Aggravating and relieving factors: What aggravates the pain? What relieves the pain? How does the pain respond following rest?
7. Previous treatment: What types of therapy have been tried? How did the pain or neuropathy respond to the therapy *(3)*?

Additional questions will form the basis for a detailed analysis of the course and development of the patient's symptoms. Determine whether the pain involves a focal area, or if there are multiple joints involved, for example, as found with rheu-matoid arthritis. Determine if there is a pattern to the pain or neuropathy. Find out whether the pain has disappeared from one or more joints, or if it has migrated, which may be associated with rheumatoid arthritis or sexually transmitted disease. Determine whether the pain varies over the course of the day, that is, if it is different in the morning than during the day or evening *(4)*. Ask the patient whether the pain is associated with periods of inactivity, or if the patient perceives it as stiffness or resistance.

When evaluating pain in the back learn whether there are associated cord symptoms, such as loss of bladder or bowel control. Be alert for weakness, any inability to move a limb, or altered sensation. Changed sensations may be present, including tingling, prickling, warmth, or cold. The patient may also report an extremity "falling asleep," which occurs after compression of a nerve and may represent a paresthesia.

When evaluating patients, be mindful of cultural differences and traditions. There may be unique needs and circumstances of patients from various ethnic and cultural backgrounds as well as different age groups. Help from a translator can facilitate effective communication.

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PAST MEDICAL HISTORY

The past medical history concerning the spine can be informative. Evaluate details of any relevant medical history that can create back discomfort, including respiratory tract infection (with or without a cough), cardiovascular disease, angina, or gastrointestinal disease (such as regurgitation, reflux, or cholecystitis radiating to the thoracic spine). Pain referred to the back may also originate from urological lesions such as hydronephrosis and renal stones. Review the history of any previous episodes of back pain or neuropathy—how many episodes, when they occurred, what was the apparent cause, what was the duration of the discomfort, and did the patient fully recover? The history should also review the hip, knee, ankle, and shoulder as well as any trauma or any series of minor trauma. Determine if the patient has sought treatment previously for the pain complained of and the extent of any therapy and the results. Inquire as to whether there is a personal history of cancer. Obtain any medical records for further information.

MEDICATION

Obtain the list of any medications being taken. The patient being screened for back pain or neuropathy is commonly taking analgesic medication. Determine what medications the patient has tried and found to be effective and ineffective in treating the pain. The assessment should include information relating to the dose and schedule of any medication. Commonly asked questions include: does the medication reduce or eliminate the pain? How often and when is the medication taken? Are any medications used for problems with sleeping? Inquire about the use of herbal therapy. Although it is a sensitive topic, you must ask the patient about recreational drug use.

REVIEW OF SYSTEMS

The systems review should address:

1. General health: What is the level of the patient's conditioning? Is there daily or weekly exercise?
2. Weight: Has the patient experienced weight gain or loss, for example, 10–15 pounds over the past 6 mo? If the patient is obese determine its duration and whether fluctuations in the weight affect the symptoms.
3. Rheumatoid arthritis: Determine if there is a personal or family history and if the patient is undergoing therapy at present.

DEPRESSION

Be alert and try to identify depression. Mysterious aches and pains are a common manifestation. Depression can masquerade as tearfulness, fatigue, grief, listlessness, and insomnia or weight loss. Pay attention to the patient's mood. A sense of weariness, loss of energy, and inability to respond to the stress of normal activities are also signs of depression *(5)*.

SUBSTANCE ABUSE

Patients who are substance abusers vary in age, gender, and ethnicity as well as cultural, occupational, and social backgrounds. Patients' attitudes or feelings toward their prescriptions may dominate their thoughts and beliefs with regard to their pain, which can create an unrealistic response to their health problems. Patients requesting specific medications, dosages, and volumes should raise apprehension in the physician and may warrant a more critical evaluation. Patients who abuse the privilege of receiving medication are frequently deceptive. The abusive patient may appear apprehensive, embarrassed, resentful, or angry. Respond to these patients by communicating appropriately that you are concerned about their medical conditions, but that you are unable to comply with the request.

All new patients should be encouraged to enter into an agreement to refrain from medication abuse. This approach may place the practitioner in a better position to manage these patients should one need to terminate the relationship.

As a healthcare provider, resist the temptation to believe that when the patient states that three or four other physicians could not adequately diagnose or prescribe medication for the patient, you would indeed be the one to resolve the symptoms. This may create an unrealistic relationship of dependency that can result in a poor relationship if the patient's expectations are not met. A psychological evaluation in this setting can help separate the biomechanical and psychological conditions present.

DIAGNOSTIC IMAGING

Depending on the clinical condition, diagnostic imaging may provide the best clues to the diagnosis. Plain film evaluation of the region of concern provides a good diagnostic tool. Plain film radiography is readily available and cost effective when diagnosing acute low back pain *(6)*.

Images of the cervical, thoracic, and lumbar spine can be obtained without concern for an implant device, sedation, or claustrophobia. Spinal instruments such as screws and plates may limit plain film evaluation, but do not produce the multiple artifacts as would be seen by computed tomographic (CT) scans and magnetic resonance imaging (MRI). Images are obtained in at least two planes, frontal and lateral. Special projections, such as oblique views in the lumbar and thoracic region and pillars or odontoid views in the cervical spine, are helpful in evaluating

pathology and postoperative change, including fusions *(7)*. In addition, congenital anomalies, fractures, osteoarthritic impingement, or bone erosion may be differentiated from tumor involvement with plain film radiography.

The CT scan is a noninvasive tool that uses X-rays to visualize rapidly the brain, spinal cord, and enclosing spine. CT represents the imaging tool that best visualizes the bones of the spine. New three-dimensional, reconstructed imaging allows visualization with good resolution beyond the axial plane *(8)*. CT is most helpful in viewing abnormal density and the presence of calcification, which can signal an abnormal pattern. A decrease in density around the spine may be associated with edema, infarction, cyst, or abscess. Increased density has been associated with calcification or acute hemorrhage. Infusion of iodinated contrast using CT helps visualize the blood vessels, and vascular malformations and vascular tumors of the spine.

Myelograms are performed with the assistance of CT imaging. This procedure allows access to the cerebrospinal fluid (CSF) for diagnostic purposes. Intrathecal administration of iodinated contrast allows detection of abnormalities encroaching on the spinal cord or nerve roots, including herniated disc, meningeal carcinomatosis, or spinal vascular malformation. In patients with scoliosis, CT is the preferred imaging tool over MRI, which may have limitations with visualization of the sagittal plane.

MRI uses protons and high field strength magnets for imaging. MRI is noninvasive and does not use X-rays. MRI has revolutionized the imaging of the brain, spine, and surrounding soft tissues. Lesions of the spinal cord, such as a syrinx, tumor encroachment, hemorrhage, or edema, can be effectively seen and monitored by MRI.

Positron emission tomography (PET) is a clinical tool that uses blood flow and glucose and oxygen metabolism with radioisotope tracers to locate abnormally functioning tissues. PET can be helpful in evaluation of the spine if the offending lesion is a metastasizing neoplasm.

Radionuclide imaging is performed using internal radioisotopes to scan the body. Injected radioisotopes slowly migrate throughout the body, and the accumulation or absence conveys information about the anatomy. Patients with defibrillators, magnet-sensitive implants, contrast allergies, and posture restriction can be imaged with radionuclide scans. Radionuclide imaging is particularly helpful in identifying abnormal metabolic activity from infection, fracture, and tumor invasion in the spine or pelvis. The bone scan may give a false-negative result in the setting of myeloma, lymphoma, or previous radiation.

Bone mineral densitometry can be used to detect changes in the matrix of bone. The bone mineral density is a noninvasive measurement of the bone mineral content in grams per square centimeter. Bone mineral densitometry is helpful in diagnosing osteoporosis.

OTHER TESTS

Neurophysiologic testing can be used in the setting of muscle dysfunction or nerve deficit. Electomyography (EMG) and nerve conduction velocities are particularly helpful in identifying and recording the electrical properties of the muscles and nerves that are affected clinically. If weakness is clinically attri-buted to a nerve or muscle, electrical studies can be performed to determine the nerves and muscles involved. The physiologic pathway can be tested by insertion of the needle into the muscle at rest or during contraction and evaluation of the visual and audible electrical signals. The patterns of activity and recruitment of motor units demonstrated on EMG will help differentiate normal resting muscle, denervated muscle, and primary muscle disease.

Lumbar puncture and CSF examination provide information on intracranial pressure and allow diagnostic analysis of the CSF. Placement of a fine 22-gauge needle will measure the opening pressure. CSF appearance, cell count, glucose level, and protein level should be evaluated and provide definitive diagnosis for meningitis or subarachnoid hemorrhage. Other special tests such as cytology and gamma-globulin levels can be helpful in diagnosing demyelinating disease.

PHYSICAL EXAMINATION

GENERAL ASSESSMENT

The physical assessment helps the physician reliably document the back pain or neuropathy, which is challenging as several signs and symptoms may overlap. Repeat physical examinations are often necessary to construct the pathway to the offending lesion.

Examine the primary site of the discomfort and extend the evaluation to the shoulder, ribs, and pelvis to determine if there is a referred source. Shoulder pain may be referred from a subdiaphragmatic source; knee and hip pain may be referred from a lumbar spine lesion. The source of pain can be created by muscle or tendon insertions from the shoulders, ribs, or pelvis to the back and cause limitation in motion.

The neck evaluation will embody the head, including cranial nerves, and a fundoscopic evaluation, which will help assess for suspected intracranial pathology and lesions at the skull base that extend to the neck.

The spine is evaluated from the front, sides, and back. The curves of the spine are also assessed. Look for flattening of the lumbar curve. Assess for muscle spasms and decreased spinal mobility, which may be associated with ankylosing spondylitis. An accentuated lumbar lordosis

can be associated with a protuberant abdomen. The accentuated thoracic kyphosis can be associated with compression fractures of the spine. Collapsed vertebrae can cause a protuberant spinous process such as that found in a gibbus deformity. Collapsed vertebrae have also been associated with osteoporosis and infections (such as tuberculosis, metastatic diseases, and multiple myeloma).

Look for differences in height of the shoulders and for tilt of the neck. If scoliosis is suspected create an imaginary line down the center of the spine and observe for curvature. Examine the iliac crest height to exclude pelvic tilt associated with leg length discrepancy.

Palpate the spine from behind. The patient may be in a sitting or standing position. Identify any prominent spinous processes. Palpate for tenderness on the spinous process. Inspect and palpate the paravertebral muscles for tenderness and spasm. Spasm of the paravertebral muscles causes the muscles to appear prominent, feel tight, and be tender on palpation. Palpate the sacroiliac joint. Feel and observe for fine muscle fasciculations and any areas of warmth.

The upper and lower back examinations include both sensory and motor pathway evaluations, which are beneficial for patients with a distorted posture or restricted limb movement.

Observe the patient rising from a sitting position without the use of arm support, if possible, without the use of arm support. Ask the patient to step up onto a platform or step. Alternatively, the patient may stand on his toes or roll back on his heels while lifting his toes. If there is proximal muscle weakness involving the pelvic girdle and legs the patient will have difficulty performing these activities.

Back pain and neuropathy can affect movement and attitude of the gait. Observe the gait pattern and inquire into the use of an ambulatory aid, for example, a cane, corset, wheelchair, or walker. Observe the gait from several projections. With aging, the normal step becomes short (even shuffling), with diminished speed and balance. The legs may be flexed at the hip and knees.

A gait disturbance can be characterized by several patterns, including antalgic, drop foot, and foot drag. Antalgic gait displays a shortened stance or bend in the affected limb, which may be due to pain at the hip, knee, or foot. Drop foot is due to weakness of the dorsiflexor muscles affecting the ankle and foot. The weakness causes the patient during the stepping to lift the knee higher than the unaffected leg and the foot appears to be slapping onto the floor. Drop foot can affect one or both sides of the body and is usually related to a lower motor neuron process. Foot drag can indicate a nerve injury and may not be muscular in origin. Upper or lower motor neuron lesions can be suspected.

A rectal examination and assessment of urinary function are useful for suspected plexopathy and spinal cord lesions.

Patients should be evaluated for tremors or involuntary movement in the digits of the hands and feet. Also determine if there is a sense of loss of balance by having the patient stand with closed eyes and feet together. A positive Rhomberg's sign is discovered by loss of balance and has been associated with posterior fossa or cerebellar symptoms.

LEG LENGTH

Examination of leg length for symmetry assists in evaluating balance. Measure a supine patient from the anterior superior iliac spine to the medial or lateral malleolus. Gross symmetry can also be evaluated using string or a tape centered at the umbilicus and drawn to the medial malleolus of each leg. Differences <1 cm are considered to be within the normal range. Assessment of the length of the leg and individual bones can be performed by conventional radiography *(9)*.

MUSCLE STRENGTH

Evaluate the patient's muscle strength by isometric testing, which can be enhanced by establishing a graded scale for focusing the patient's responses. Six possible responses to isometric muscle testing for grading are:

- Strong and painless—normal.
- Strong and painful—suggests a minor lesion of muscles or tendon.
- Weak and painless—complete rupture of muscle or tendon or disorder of the nerves.
- Weak and painful—suggests gross lesion.
- Painful on repetition—suggests intermittent claudication *(10)*.

If all movements are painful this may suggest emotional hypersensitivity.

Weakness denotes a demonstrable loss of muscular power and should be differentiated from fatigue. Try to localize any weakness in a neuroanatomic pattern, to determine whether there is a disorder of the nerves innervating the muscle group.

RANGE OF MOTION

Limitation of the range of motion can suggest the muscle systems involved *(11)*. Determine if decreased range of motion affects any activities, including walking, standing, bending over, sitting, climbing stairs, or raising arms over the head.

Range of motion can be evaluated with the following graded scale:

None	Normal
Mild	Slight motion loss, <15%, with minimal clinical significance
Moderate	Loss of up to 50%, and is clinically significant
Marked	Loss of 50% or greater in a major joint
Rigid	No motion in a major joint

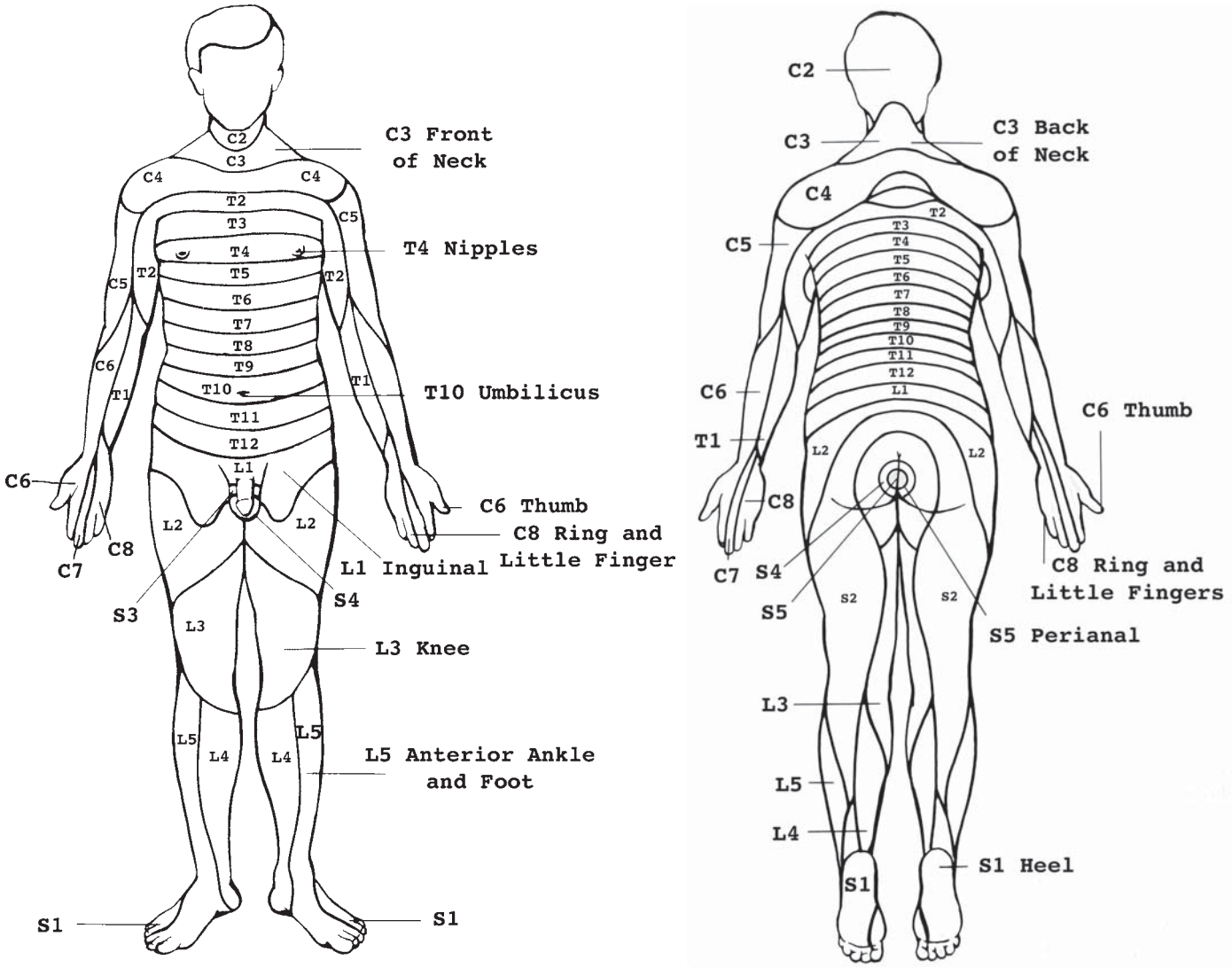

Fig. 1. **(A, B)** Anterior and posterior neuromuscular dermatome pattern.

Limitation of range of motion should be differentiated from stiffness. Stiffness may indicate a resistance to movement and often accompanies pain and discomfort. It is typically brief and may be relieved as activity progresses. Prolonged inactivity, such as sitting or sleeping, and strenuous activity, such as exercise, can be followed by stiffness.

PERCEPTION OF DISCOMFORT

Evaluate the pain for a dysesthesia, a distorted response to sensation. In a dysesthesia a light touch can be perceived as burning, pinprick, or tingling or as a pain sensation lasts much longer than the stimuli creating it.

DERMATOME AND MYOTOME ANALYSIS

A general knowledge of the skin innervation or dermatome is helpful in understanding neuromuscular pathway patterns (Fig. 1A, B). The myotome test localizes the primary neuro-anatomical pathway of a muscle group, although the pathway may be slightly variable in patients *(12)*. Resistance is applied to test the strength of the muscles supplied by specific nerves (Fig. 2A–I [from the cervical and upper thoracic spine] and Fig. 3A–H [from the lumbar and sacral spine]).

DEEP TENDON REFLEXES

The deep tendon reflex is an involuntary muscle contraction created from a brisk tap on a tendon. The tap generates a sensory impulse that travels to a neuromuscular junction and returns as a muscle contraction. This reflex arc depends on an intact sensory nerve fiber, functional synapse in the spinal cord, intact motor nerve fibers, and functional muscle fibers (Fig. 4).

The reflexes are tested in an ascending segmental order:

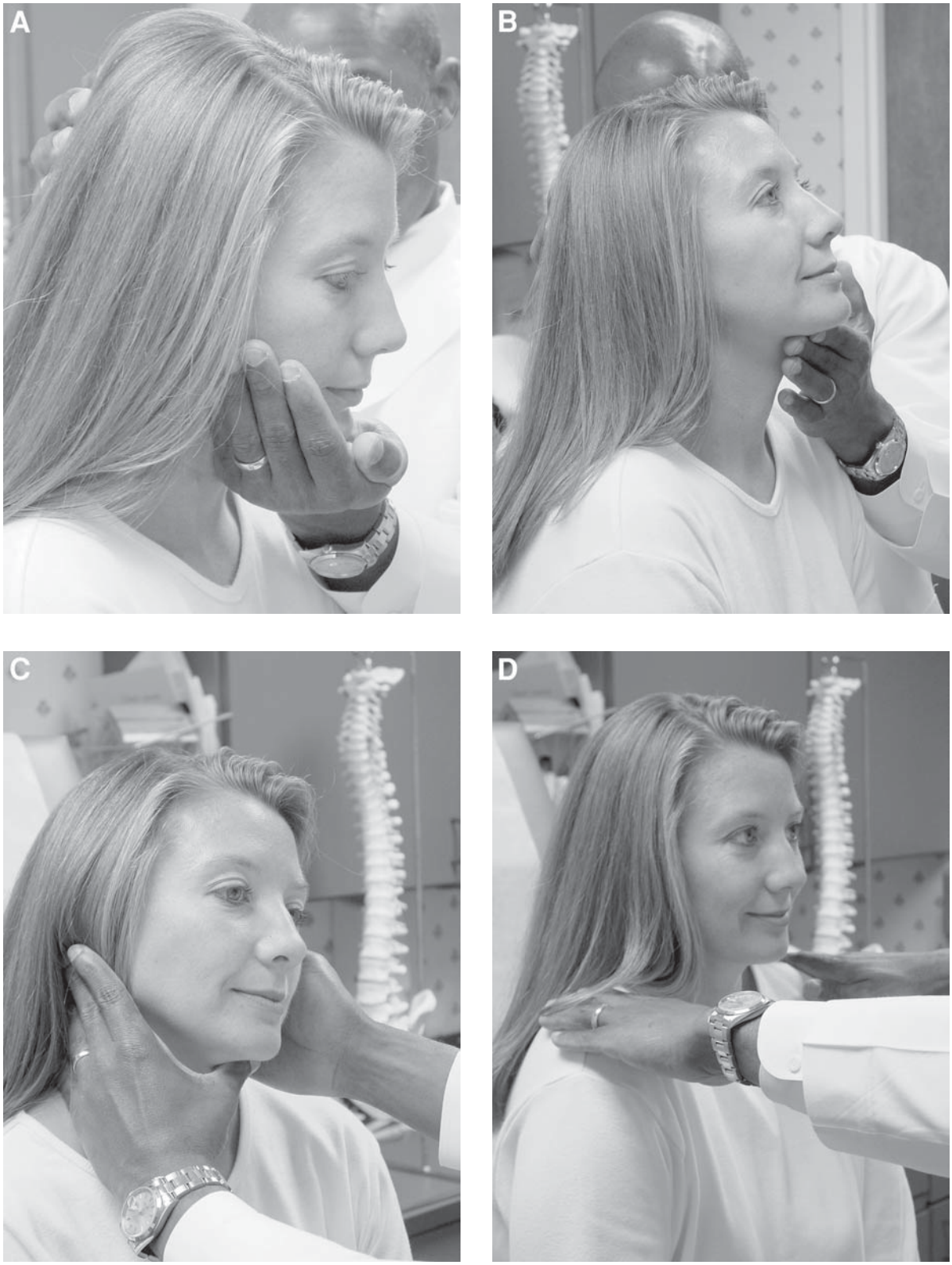

Fig. 2. **(A)** Test of cervical flexion: C1. **(B)** Test of cervical extension: C2. **(C)** Test of lateral flexion: C3. **(D)** Test of shoulder elevation: C4.

Fig. 2. **(E)** Test of shoulder abduction: C5. **(F)** Test of elbow flexion: C6. **(G)** Test of elbow extension: C7. **(H)** Test of thumb extension: C8.

Fig. 2. **(I)** Test of finger abduction: T1.

Reflex	Nerve
Ankle reflex	Sacral 1 primarily
Knee reflex	Lumbar 2, 3, 4
Brachioradialis reflex	Cervical 5, 6
Biceps reflex	Cervical 5, 6
Triceps reflex	Cervical 6, 7

The reflex response may be graded 0–4 as follows *(13)*:

0+: absent
1+: diminished
2+: average
3+: exaggerated
4+: clonus

NEUROLOGICAL ASSESSMENT

Nerve fibers conduct sensory information along a specific pathway. To locate the lesion causing back pain or neuropathy, the pattern of its sensory deficit and its associated motor findings can help. Determine whether the patient is impaired to pain, touch, or position. The patient's ability to distinguish the shape, size, or texture of an object such as a key or paperclip is tested. Test to determine whether there is a loss of the sense of position by moving a digit up or down and asking the patient to indicate the concordant position. The pinprick test is used to elucidate an area of disturbed sensation. The pattern of pain sensation is evaluated by gently applying a sharp pin and asking the patient if the two stimulated areas feel the same. Begin the evaluation in an area where the patient's sensation is considered normal and then proceed to the affected area. Analgesia or hyperalgesia represents abnormal sensation and can indicate an organic lesion. Other tests used to evaluate discriminatory sensation are the two-point perception tests, light touch test, and temperature sensation.

Loss of vibration points to a lesion of the posterior columns of the spine. Apply a vibrating tuning fork to the extremity and spinous process to evaluate for a suspected posterior column lesion. Loss of perception to cold or pain may be localized at the cortical level, such as the thalamus. A lesion at the level of the cerebellum can impair coordination, gait, equilibrium, and decrease muscle tone. Rhomberg's sign evaluates balance and dysequilibrium. Stand the patient with feet close together and close the eyes, and observe for loss of balance.

MENINGEAL SIGNS

In the absence of traumatic causes of cervical or back discomfort, testing should be performed for signs of suspected meningeal inflammation from infection or subarachnoid hemorrhage. Be alert to the patient with pain or resistance to flexion of the neck. The evaluation for meningeal signs is performed by cradling the occiput and gently flexing the neck forward until the chin touches the chest. In the normal setting, the neck is supple, and the patient easily flexes the neck forward.

Evaluate the patient for Brudzinski's sign. While the patient is sitting, and as the neck is flexed forward, observe the hips and knees for flexion. Normally they remain relaxed. Flexion of the hips and knees is a positive indicator of meningeal inflammation called a Brudzinski's sign (Fig. 5).

Evaluation for meningeal inflammation can also be performed from the supine position. The leg is flexed at the knee and hip. If raising the foot upward produces pain and resistance this may represent a positive Kernig's sign.

SPECIFIC SPINE DISORDERS AND ASSOCIATED FINDINGS

RADICULAR PAIN

Radicular pain can be created by compression or irritation of the nerve root in the lateral recess or from zygapophysial joint hypertrophy. Extruded disc material within the neural foramen compresses the ipsilateral exiting nerve root and is most often seen at the C4–5 and C5–6 levels in the cervical region and at the L3–4 and L4–5 levels in the lumbar region. The disc can bulge initially, and later the disc can herniate through the fibers of the annulus centrally or laterally. Radicular lesions commonly present as focal pain, and the natural course is to progress. In the cervical spine, spondylosis can present as focal acute pain and can become chronic.

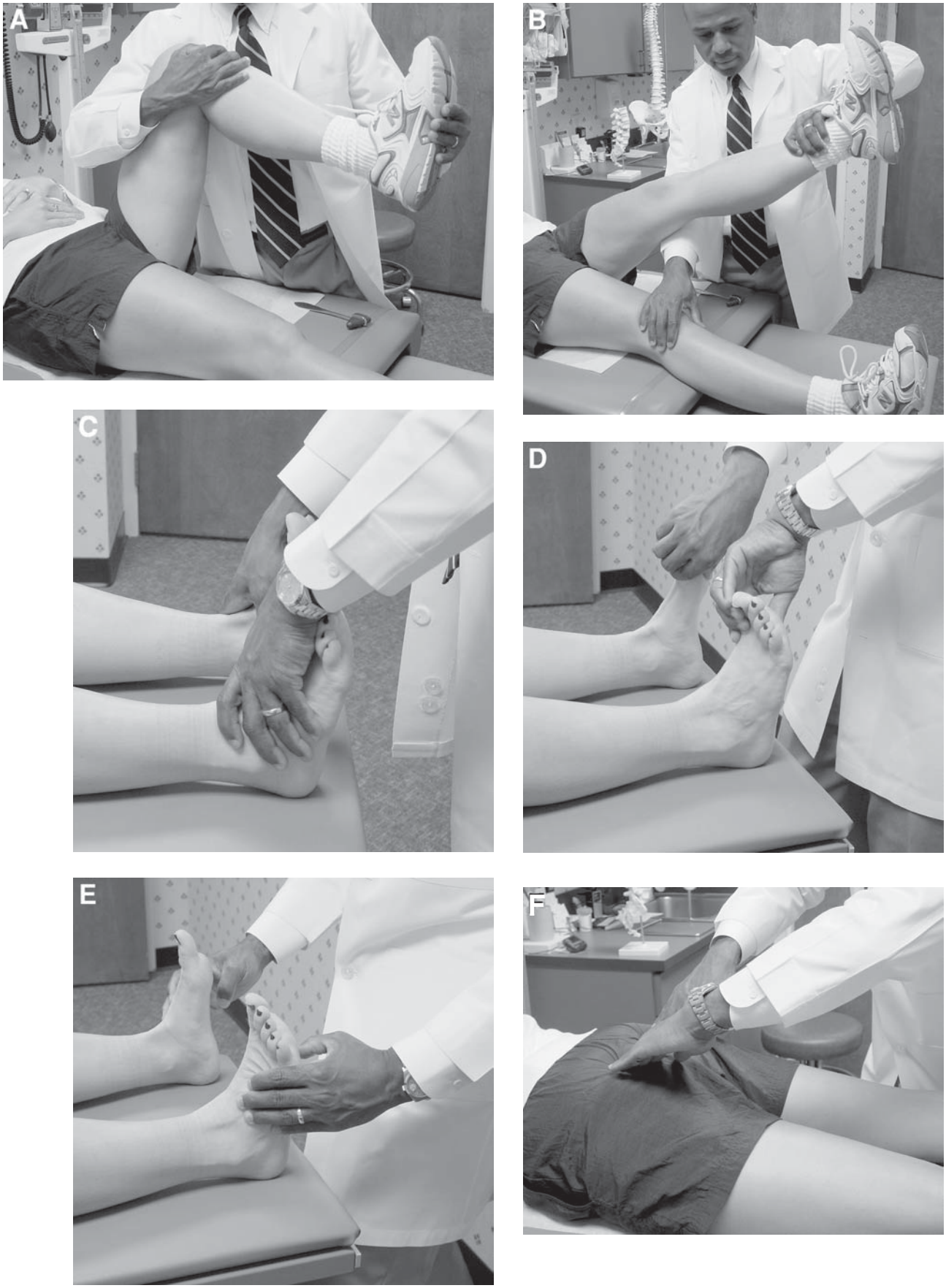

Fig. 3. **(A)** Test of hip flexion: L2. **(B)** Test of knee extension: L3. **(C)** Test of foot dorsiflexion: L4. **(D)** Test of great toe extension: L5. **(E)** Test of foot eversion: S1. **(F)** Test of buttock contraction: S2.

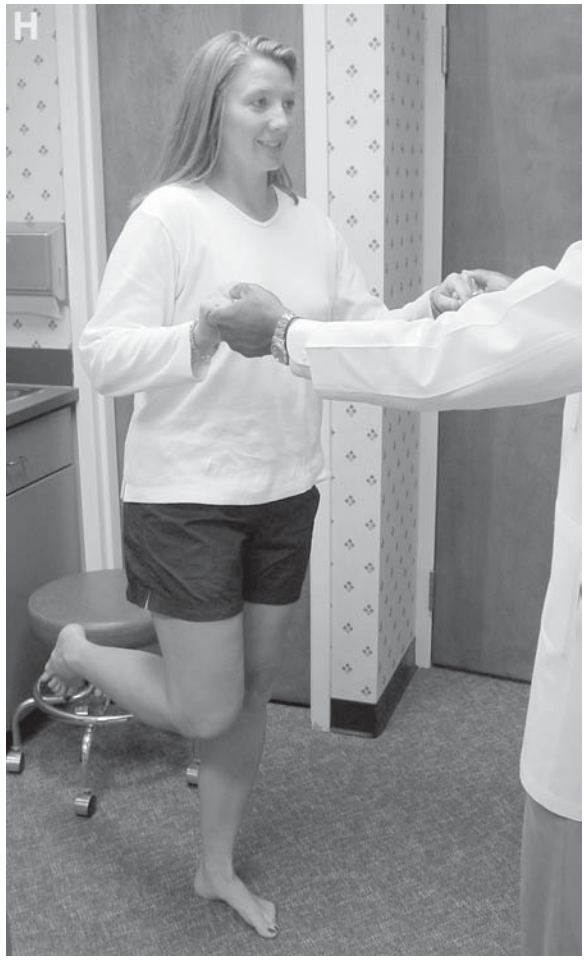

Fig. 3. **(G)** Test of knee flexion: S1 and S2. **(H)** Test of toe standing: S2.

In the neck, pain can radiate to the occiput or upper extremities. Patients may experience numbness in the upper extremities and episodic spastic paresthesias. Over time there may be loss of position and vibration sense.

In the lumbar spine, patients complain of persistent low back pain. There can be weakness, paresthesias, and bilateral or unilateral lower extremity pain that are exacerbated by prolonged standing and walking. The patient may find that squatting or sitting often relieves the pain. Radicular pain suggests tension on, or compression of, the nerve root, which can be caused by a herniated disc. Radicular pain from a herniated lumbar disc may be replicated by dorsiflexion of the foot.

Physical Examination A straight leg raise test can confirm radicular pain. Lay the patient supine, raise the leg slightly bent, and then straighten the leg or dorsiflex the foot to re-create the pain. Radicular pain may also be re-created in the affected side by raising the opposite leg. Test the legs and feet for loss of sensation or for vibration and for weakness with resistance. The range of motion and reflexes may be normal.

Diagnostic Imaging Several common disease entities may present with radicular pain, including lesions causing compromise of the spinal canal and neural foramen (such as diffuse idiopathic skeletal hyperostosis [DISH], hypertrophy of the posterior longitudinal ligament, spondylolisthesis, facet arthropathy, and disc herniation). The plain film and CT image findings can optimize a diagnosis. Although plain film radiographs can be diagnostic for evaluation of the spinal column, axial or three-dimensional imaging with CT produces a more detailed analysis of the central canal.

With spondylolisthesis and spondylolysis, plain films are observed for a step off or break in the pars interarticularis, and these fractures are best viewed on an oblique projection. In cases of facet arthropathy, observe for overgrowth of the facet and cartilage erosion leading to joint space narrowing. Ankylosis, erosions in ankylosing spondylitis, cranial settling, and atlantoaxial subluxation in rheumatoid arthritis are signs that are readily observed on plain film radiography. Skeletal hyperostosis in DISH, ossification of the posterior longitudinal ligament, and ossification of the ligamentum flavum are better observed with CT imaging.

SPINAL STENOSIS

The spinal cord is surrounded by ligaments and bones that provide support and protection. The central canal containing the cord is constructed from bones of the spine, ligaments, and fat. Depending on the patient's body habi-

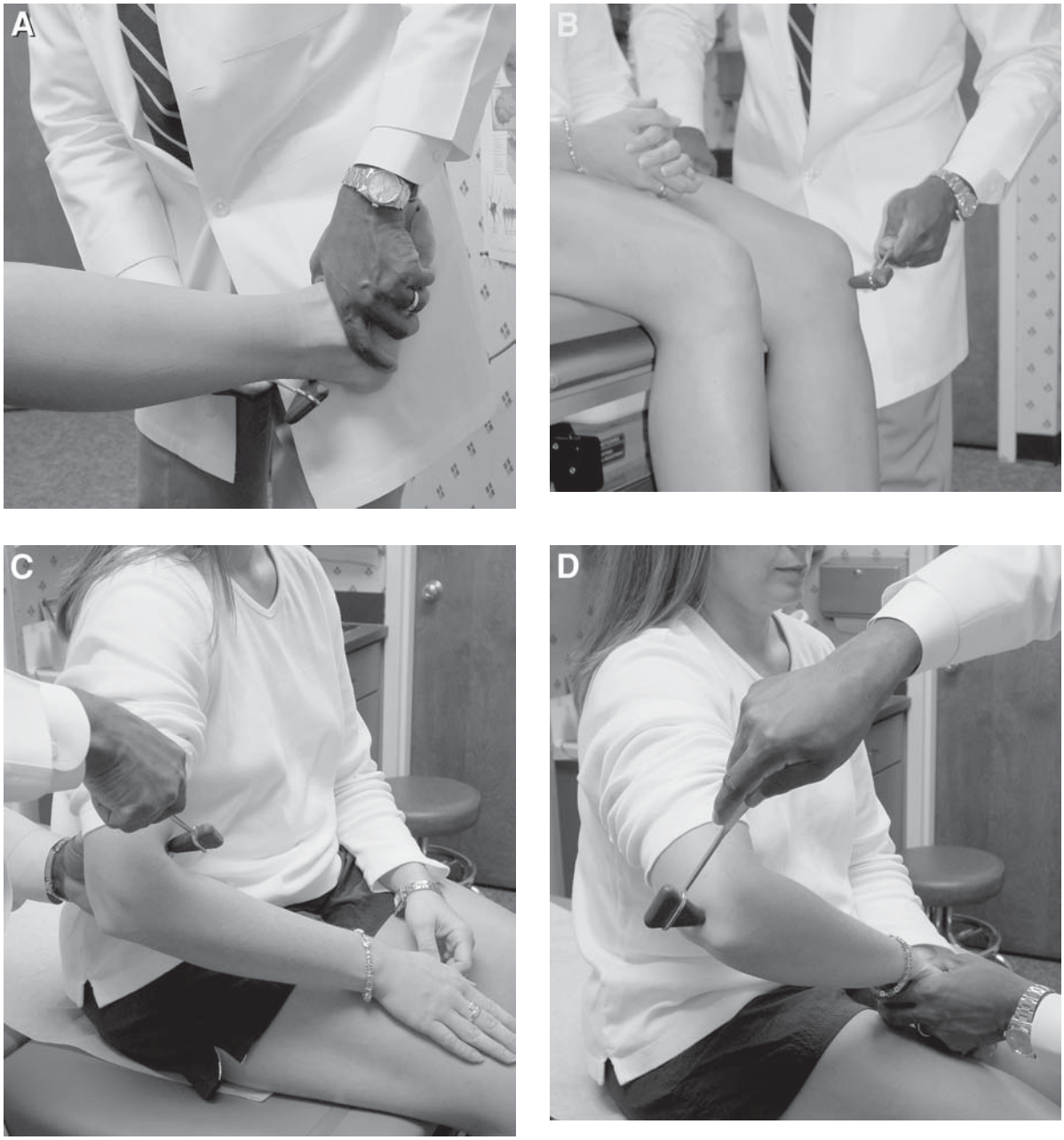

Fig. 4. **(A)** Ankle reflex: S1. **(B)** Knee reflex: L2, 3, 4. **(C)** Biceps reflex: C5, 6. **(D)** Triceps reflex: C6, 7.

tus, a central canal anteroposterior (AP) diameter of <14 mm in the cervical region and <15 mm in the lumbar region could be diagnostic *(14)*. Neural compression may be congenital, but may not present clinically until later in life. This process can plague patients with achondroplasia, Down's syndrome, and Morquio's syndrome and those who have a congenitally developed short pedicle.

Trauma is a common cause of spinal stenosis and is not uncommon in athletes. A posttraumatic cord syndrome develops from extreme whiplash and causes edema and swelling of the cord. Whiplash is associated with disc protrusion, herniation, fractures, and subluxation.

Spinal stenosis can also be a slowly progressive process. The central canal and neural foramen are narrowed in degenerative disc disease by endplate osteophytes in the lumbar region and by uncovertebral facet joint in the cervical region. This process is more common in men and generally occurs after the fifth decade. Long-term steroid use or other causes of adipocyte hypertrophy can result in cord or nerve root compromise. Other lesions narrowing the spinal canal may include Paget's disease, osteoarthritis, and epidural hemorrhage.

Facet joint disease of the spine can be age related and is less often found in the young. Age-related degenerative

Fig. 5. Test cervical flexion for meningeal signs.

changes affect the ligamentum flavum. Prior to development of the disease process the ligamentum flavum is tightly stretched. The ligament becomes redundant and hypertrophies as a result of loss of height from disc space narrowing, from thinning of the cartilage that separated the facet joints, as well as from slippage between the facets due to wear. The hypertrophied ligamentum flavum can compress the spinal cord in the narrowed canal; this process can be progressive and lead to spinal stenosis.

History Defining the location and characterizing the pain are important to the diagnosis. The patient's age and mechanical factors, such as conditioning and obesity, may differentiate an acquired from a congenital process. Patients often describe their legs as cramped, tired, or weak. Whereas the discomfort can start when the patient stands, and in some patients standing for prolonged periods worsens the pain, in other patients the pain may start only when they begin to walk. The pain worsens as they continue walking and is often relieved when they stop. Relief of the discomfort has also been reported from crouching down or sitting with a bent posture.

The natural course of this process is a progressive neurological deficit. Therefore, with an acute exacerbation of symptoms, determine if there are signs of bladder or bowel dysfunction. Spinal stenosis in the lumbar region is often associated with back pain, leg pain, and weakness and numbness in the leg. The leg pain may start in the buttocks and progress to the foot. Patients commonly complain of paresthesias, such as burning or a prickly feeling in the buttocks that may spread to the leg or foot.

Physical Examination The clinical evaluation may not always disclose the level of the lesion. Findings on the examination tend to be vague or inconsistent with a known neuroanatomic pathway. The anxiety and stress of the patient, stiffness, muscle strain, and fatigue associated with the spinal stenosis can masque the true clinical findings. Compression of the peripheral nerve roots from an intervertebral disc, hypertrophied ligament, or tumor can be challenging to locate. Examine the extremities and digits for the presence of focal weakness or muscle atrophy. Although loss of muscle mass may not be readily apparent to patients, the patient may report signs of weakness in the arms or legs, which may be an indication of the nerve level or roots that are affected.

The straight leg raise is often positive in spinal stenosis but may not lateralize. Palpate the paravertebral tissues for point tenderness to differentiate spinal pain from referred pain, such as pyelonephritis or aorta aneurysm. Differentiation of cervical, thoracic, or lumbar lesions can be challenging when back range of motion is limited owing to pain or stiffness.

Evaluate the arms and shoulders for weakness and determine if there is early onset tiredness or claudication in the shoulders with repetitive motion. Evaluate for numbness or tingling in the digits; numbness in the first three fingers has been associated with spinal stenosis near the sixth or seventh nerves. Examine for loss of reflexes and sensory deficit changes. Test the patient for loss of position or vibration sense.

Diagnostic Imaging Plain film imaging of the spine for spinal stenos is often unremarkable, except in congenital causes. In the setting of a congenital spinal stenosis, measurement of the interpediculate distance and an estimation of the level and extent of the spinal stenosis can be performed. Plain film radiographs may reveal spondylitic changes or ossification of the posterior longitudinal ligament. The films assist in excluding other lesions in the adult patient. CT imaging is ideal for diagnosing calcified lesions, such as osteoarthritis in the uncovertebral joints of the cervical spine and the facet joints of the lumbar spine. Short pedicles can be readily identified and measured by CT.

MRI best characterizes compromise of the cord at all levels; anteroposterior compression of the cord; and signal changes associated with edema, hemorrhage, or myelopathy. In the sagittal projection on MRI the canal may have an hourglass appearance when the perineural fat is obliterated from around the cord and neural foramen. Observe for atrophy of the cord below an area of cord compression and for crowding of the nerve roots in the lumbar region.

Other Tests An EMG may assist in localizing involved nerve and muscle groups and in excluding a myelopathy.

CSF examination may not be as helpful because the fluid protein level may be elevated with a ruptured disc, ligamentous stenosis, and a tumor.

FACET JOINT DISEASE

Low back pain may affect 60–85% of the population at least once, and 10–20% of these patients develop chronic discomfort *(15,16)*. Degenerative disc and facet disease often accompany one another. These processes mechanically alter the spine and often reduce mobility.

The underlying pathology is often osteoarthritis at the facet joints. The cartilage lining the facets can form fissures, sites of fraying, and erosions. These changes can lead to bone hypertrophy, sclerosis, and osteophyte formation. The association of disc degeneration, loss of disc height, and slippage along the facet articulation from the degenerative process can create a dynamic instability of the ligament support, which can result in forward motion of one vertebra on the other with or without a pars defect. The forces that destabilize the spine work not only in a transverse fashion but also in an axial fashion. The facet joint carries up to one third of the static compression load of the lumbar motion dynamically and as much as one third of the axial load depending on the position of the spine, as reported by Yang and King *(17)*. Facet joint changes are more often noted at the L4–5 level and are commonly found in younger patients with congenital anomalies of fusion in the lumbosacral region.

History The pain of the back created by facet disease can be challenging to characterize. The pain can be unilateral or bilateral, cervical or lumbar. The discomfort may be a deep dull ache that is difficult to localize. The pain is associated with twisting and bending and may be aggravated by sitting and relieved with walking. The discomfort may be worse in the mornings or after prolonged rest and inactivity.

Other patients may present with a slowly developing back pain that appears to worsen with activity and to be relieved with rest. The back pain is often accompanied by leg pain, which may be radicular. Patients with facet disease may develop neurogenic claudication in the later stages of the disease process. The spinal canal is narrowed and the thecal sac constricted from the combination of facet hypertrophy with osteophyte formation, bulging of the ligamentum flavum, disc degeneration, and herniation. Patients with neurogenic claudication complain of bilateral thigh and leg tiredness, aches, and fatigue. They also report that forward flexion of the spine, as with leaning on a counter, relieves the symptoms. In the setting of long-standing disease, patients may discover a slow onset and chronic loss of bladder control. Associated conditions, such as prostatism in men and bladder suspension in women, should be ruled out.

Physical Examination Impairment caused by low back pain can be evaluated by a physical assessment. Evaluation of the patient's response to lumbar flexion, trunk flexion, extension, lateral flexion, straight leg raise, tenderness to palpation, and a sit-up procedure can help characterize and measure the degree of impairment. The patient's gait may demonstrate a forward stoop. The forward flexion in the stoop relieves discomfort by increasing the AP diameter of the central canal.

The range of motion test is commonly normal. Typically, motor strength is intact and rarely is there weakness. Patients may have vague paralumbar tenderness when palpated over the facet joints. In the acute setting, warmth and muscle spasm are present. At times there are no neurological findings. Although the patients have pain in the buttocks, hips, and thighs, the discomfort does not extend below the knees. The discomfort is aggravated with extension of the back and hyperextension of the spine. From the prone position the patient is asked to arch the back and extend the spine, which may re-create the pain in the lumbar, thoracic, and cervical regions. Passive range of motion twisting, lateral bending, and rotational movements from the sitting position can exacerbate the symptoms. The recumbent position can sometimes provide pain relief. The sensation and response to vibration are intact. The deep tendon reflexes will generally be normal to diminished.

Diagnostic Imaging Routine radiographs to evaluate a patient with lumbar pain include AP and lateral radiographs with the patient standing. Radiographs of the lumbar spine in the oblique projection and in flexion and extension as well as an AP radiograph of the pelvis would form a complete protocol. If a spondylolisthesis is discovered it should be graded 1–4 based on the percent of slippage, that is, 25%, 50%, 75%, or 100% *(18)*.

In cases of mechanical back pain related to bony disease, the hypertrophic bony changes originating in the facet joints of the posterior elements are better evaluated with CT. The bone overgrowth and proliferation commonly narrow the neural foramen. When the facet joints narrow, occasionally a vacuum phenomenon or intraarticular gas can be seen in the narrowed facets.

MRI can show signal in the synovial joint, and the earliest degenerative changes may be detected. Synovial cysts and signs of inflammatory disease can also be detected. The hypertrophic bone changes of the facets are not as readily seen by MRI because bones generate little signal. Associated disc degeneration and herniation are readily seen by MRI. Sagittal and axial T1 and T2 images demonstrate loss of the epidural fat as degenerative facets compromise the thecal sac and neural foramen.

The radionuclide bone scan with single photon emission computed tomographic (SPECT) imaging displays abnormal accumulation of activity in the facet joints of the spine. SPECT imaging has a high sensitivity for osteoarthritis in the facet joints as the tomographic technique

removes the activity from overlying tissue and bone and the facets become pronounced. The presence and sensitivity of facet disease are further enhanced by diphosphonate radiotracer compounds, which have a high affinity for reactive bone.

SACROILITIS

Sacroiliac arthritis can cause buttock or low back pain. Inflammation of the synovial compartment resulting from erosion and laxity of the ligaments can decrease the fluidity of the pelvic girdle and cause a faulty posture or gait.

Degeneration of the sacroiliac joints has primary or secondary causes. The primary causes commonly affect many joints and include rheumatoid arthritis, ankylosing spondylitis, Reiter's disease, and osteoarthritis. Secondary causes of sacroiliac dysfunction include trauma, obesity, contact sports, and septic arthritis. The pattern of involvement of sacroiliac disease can be characterized by its presentation, such as bilateral, unilateral, symmetrical, or asymmetrical. Ankylosing spondylitis and rheumatoid arthritis are commonly bilateral and symmetrical. Psoriatic arthritis, Reiter's disease, and osteo-arthritis may be bilateral but are asymmetrical in presentation. The unilateral presentation can be associated with septic arthritis or osteoarthritis.

History The pain from sacroilitis is caused by periosteal irritation at the myofascial insertions. The joint line is innervated from several levels including L3–S1. A deep dull ache or hypersensitivity to the ipsilateral joint line is often found. In males the discomfort may radiate to the groin or testicles. Pain emanating from the sacroiliac joint can cause buttock discomfort that can be referred to the hip or anterior thigh. The pain of the sacroiliac joint may become worse with sitting and relieved with walking. Patients have reported to be worse in the morning and relieved as mobility progresses throughout the day.

Another etiology of low back pain is the anomalous lumboiliac transitional articulation. The articulation between the L5 transverse process and the sacrum or ilium is present in 5–7% of the general population–*(19)*. A diverse array of pain symptoms will arise during evaluation of this subset of patients, but a majority of patients report discomfort in the buttocks and pain radiating to the lower limb. In addition, most patients are found to be symptomatic on the side of the anomalous articulation.

Insufficiency fractures of the sacrum and of the sacroiliac joint can often occur in patients with primary or secondary osteoporosis such as transplant patients *(20)*. Transplant recipients with osteoporosis who develop low back pain with or without trauma should be screened for insufficiency fractures.

Physical Examination Examination of the hips should be part of the complete back examination. The patient may present with an obvious antalgic gait. In the sitting position there may be a pelvic tilt. Point tenderness is instructive where the patient is asked to point to the area of pain with one finger. Positive identification of the sacroiliac joint as the area of pain is significant.

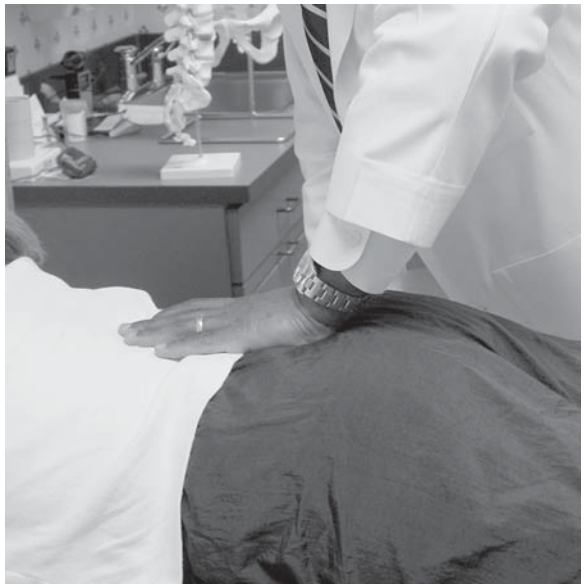

Fig. 6. Pelvic pressure test for sacroiliac disease.

The pelvic pressure test is also informative. On the prone patient, a vertical posterior to anterior compression of the central aspect of the sacrum or adjacent to a sacroiliac joint can elicit pain or pressure symptoms that are concordant with the patient's usual symptoms (Fig. 6).

The pelvis can be manipulated to re-create the zone of discomfort. The Gaenslen test is also a good provocative test. The patient is placed supine, and the hip and knee are maximally flexed toward the trunk. The opposite knee is raised. A positive result is pain across the sacroiliac joint.

Diagnostic Imaging Plain film imaging of the sacroiliac joint is commonly negative in the initial phase of sacroilitis. Later in the disease process, erosion and subchondral cyst formation create pseudowidening. However, this widening represents an early radiographic change. As the process becomes advanced, narrowing of the joint space occurs. The joint cartilage is roughened and wears away. Spur formation and lipping occur at the edge of the joint surface. Sharpened articular margins, osteophyte formation, and lipping of the marginal bone formation take place and create thickened, dense subchondral bone, ankylosis, and osteophytes. In ankylosing spondylitis, ankylosis or erosions may be seen depending on the stage of the process.

CT scan findings of sacroiliac spondylitis may show normal bone density with fusion and syndesmophytes across the joint. The higher resolution of bone detail pro-

vided by CT imaging can show the degenerative and erosive changes of the joint earlier than plain films.

The radionuclide bone scan is commonly helpful in characterizing the pattern of inflammatory reaction. Increased activity in the sacroiliac joints may be unilateral or bilateral. Bilateral and symmetrical appearance of activity may lead to characterization of an inflammatory process, rheumatoid arthritis, or other detectable cause (such as fracture). Involvement of other joints may demonstrate the pattern and distribution of disease. Sacral insufficiency fractures may go undiagnosed on plain film radiographs. A characteristic "butterfly" or "half butterfly" appearance of the fractures on radionuclide bone scans can establish the diagnosis. Other diagnostic clues include blood tests for rheumatoid factor, sedimentation rate, and the HLA–B27 haplotype.

DISCOGENIC BACK PAIN

Back pain arising from the disc may be acute or slow in onset but become chronic, persistent, intractable, and disabling. The pain may be caused by inflammatory substances from the nucleus pulposis leaking into the surrounding tissues and inflaming the meninges. Disruption of the concentric collagenous fibers of the annulus fibrosus can also create pain. Innervation of the annulus from the recurrent meningeal nerve and ventral ramus of the somatic spinal nerves are sources of the pain. Disc desiccation or disruption of the collagenous fibers can promote annular fissures.

History The discomfort of discogenic pain can be sudden in onset. The original cause, such as a fall, twisting, or sport activity, may be known. Annular tear or disc bulge may be asymptomatic and may go unnoticed initially but with further activity or trauma can be re-injured and become symptomatic.

In the thoracic spine, pain can be focal, stabbing, and radiate to the trunk. In the cervical spine, patients suffer from persistent pain and cervical radiculopathy. Cervical disc fissures or herniations can produce a myelopathy. Compression of the cord from a herniated disc can result in upper or lower extremity numbness or pain. Bowel or bladder dysfunction (even quadriparesis or rarely quadriplegia) can be the end result.

Repetitive stress and microtears may lead to trabecular biomechanical disruption, and these changes may include collagen revision as seen with Scheuermann's syndrome and discitis. Herniation can pinch one or two nerves and cause pain. In the lumbar region, the discomfort begins in the back and shoots down the leg. The discomfort from the herniation may be experienced in activity or inactivity, which distinguishes discogenic back pain from neurogenic claudication, in which the discomfort can be relieved by lying down in a flexed or fetal position.

Fig. 7. Straight leg raise test.

Physical Examination The low back discogenic pain can be referred to the lower extremity. On first observation the patient may present with an antalgic gait. The best maneuver for evaluating the discomfort is the straight leg raise test, which can be performed from either the supine or sitting position. Raising the leg as little as 60° reproduces the pain. The contralateral leg raise test, which may be performed from the supine position, may also be positive and reproduce the discomfort with as little as 30–40° of elevation (Fig. 7).

Diagnostic Imaging Plain films of the cervical, thoracic, and lumbar spine may reveal loss of disc height, endplate sclerosis, or bone hypertrophy. Plain films assist in ruling out other benign and malignant conditions. Often, plain films are negative.

CT scans are capable of determining the level of disc bulge or herniation in the spine. Gas within the disc, intradiscal herniation, and disc height loss on sagittal reformation can be seen on CT.

MRI shows disc height loss, annular tears, and intradisc hypointensity on T1 and T2 images. In the presence of annular tears, sagittal T2 images with fat saturation show focal high signal, and subchondral marrow shows T2 hyperintensity in the vertebral bodies abutting the disc. Central canal, lateral recesses, and neural foraminal narrowing can be seen on MRI. Associated changes such as facet hypertrophy, degenerative spondylolisthesis, and hypertrophy of the ligamentum flavum can also be seen by MRI.

Radionuclide bone scans show linear accumulation of increased activity from bone turnover and remodeling at the site of the injured disc.

The best diagnostic tool to identify discogenic back pain accurately is a discogram, which will record the injec-

tion pressure, characterize contrast spread throughout the disc, and identify spill into the epidural space. Concordant pain is reproduced with injection of the offending disc. Correlation with a CT scan demonstrates the spread of contrast through the nucleus pulposus and into the fissures of partially or completely torn annular fibers.

PRIMARY AND METASTATIC SPINAL TUMORS

Approximately 10% of spinal tumors are intramedullary. Ependymoma is the most common type of intramedullary tumor in adults *(21)*. The remainder are other types of gliomas. Intramedullary lesions disrupt cord function by invasion and infiltration.

Extramedullary tumors may be extradural or intradural in location. Among the primary extramedullary tumors, neurofibromas and meningiomas are relatively common, often benign, and either intradural or extradural. Carcinomatous metastases, lymphomatous or leukemic deposits, and myeloma are most often extradural lesions. Tumor involvement may lead to pathological fracture or direct cord compression. Spinal cord dysfunction may be the result of ischemia secondary to tumor causing arterial or venous obstruction.

Vertebrae are a common location for primary and metastatic neoplasm. Primary neoplasms of the spine may present as benign lesions, such as the osteoid osteoma, osteoblastoma, or spinal osteochondroma, and are often found in patients between 10 and 40 yr of age. Typically, the tumor forms a nidus and grows by creating a surrounding zone of sclerosis or becoming expansile. More often these tumors are found in the neural arch and pedicle than in the vertebral body.

Multiple myeloma and lymphoma represent the more aggressive lesions of the spine and are permeative in presentation. Multiple myeloma and lymphoma can grow through the vertebrae in a diffuse manner and cause marrow replacement. The weakened bone is prone to form compression fractures that can narrow the central canal and recesses, and be the source of radicular symptoms or focal or referred pain. Multiple myeloma is one of the most common primary bone tumors and most often involves the spine. Lymphoma is often found in the spine as a metastasis in up to 30% of patients with primary systemic disease. Although in fewer than 5% of cases, lymphoma presents as a primary bone lesion. Metastases to the spine occur in 10–40% of cancer patients and the most common primary sites are lung, breast, prostate, and kidney neoplasms.

History The symptoms of spinal tumors may develop insidiously. Pain is commonly the presenting symptom and generally precedes the neurological symptoms. Pain is often conspicuous with extradural lesions. The pain can be radicular and can be aggravated by stretching, coughing, or straining *(22)*. Commonly discomfort may be localized to the back or may be felt in the extremities. Neoplasms of the spine can also compress and irritate the dura to create referred pain such as headaches. Motor deficits, paresthesias, and numbness in the legs are also associated with tumors of the spine. Invasion of the posterior elements can cause focal tenderness but neurological symptoms are often absent. Lesions that are destructive to the bone of the spine can cause pathological fractures that result in cord compression. Tumor causing cord compression or epidural extension along the nerve root can create spinal pain, myelopathy, and/or radiculopathy. Primary benign lesions, such as osteoid osteoma, are often symptomatic at night and present with spinal stiffness, torticollis, and scoliosis. Therefore, because of the varied presentations, the most obvious cause of the pain or neuropathy from tumors and metastases may not be specific.

Physical Examination On physical evaluation a segmental lower motor neuron deficit or dermatomal sensory change (or both) are sometimes found at the level of the lesion. An upper motor neuron deficit and sensory disturbance may be demonstrated below the level of the lesion. The deep tendon reflexes can be hyperreflexic. If hyperreflexic symptoms and other upper motor neuron signs, such as clonus or a positive Babinski test, are found the cervical and thoracic spine should be evaluated to exclude a spinal cord lesion. Palpation of the spinous processes can localize the vertebrae that are affected by tumor.

Diagnostic Imaging Plain film radiographs are commonly unremarkable. In the setting of metastatic disease the films may show evidence of sclerotic, lytic, or permeative bony destruction. CT scans and CT myelography help to reveal the site of cord compression and gross bony change.

MRI with gadolinium enhancement is better for the evaluation of cord involvement and its surrounding soft tissues. At times intramedullary and extramedullary lesions may be differentiated only by MRI. The size, shape, and extent to which the normal anatomy is compromised can also be characterized on MRI, which is also the best tool for evaluating the response to therapy.

Other tests may include evaluation of the CSF, which can reveal greatly increased protein with normal cell count and glucose levels.

COMPRESSION FRACTURES

Compression fractures in the cervical and upper thoracic regions are most often traumatic in origin. In the middle, lower thoracic, and lumbar regions, the fractures are related to axial loading as has been seen in elderly and osteoporotic patients. Commonly the patient is an elderly

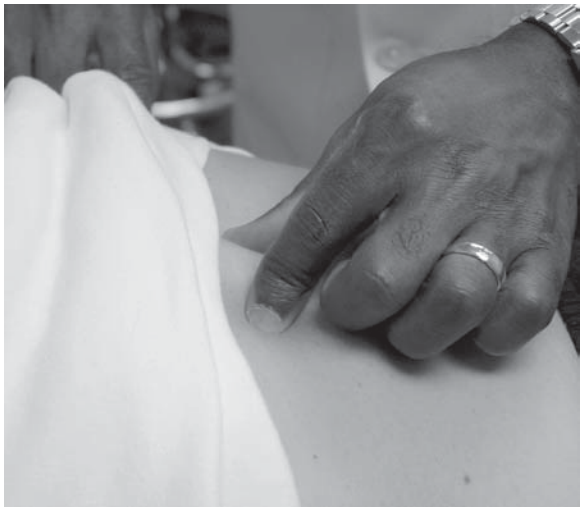

Fig. 8. Paraspinous palpation localizes area of pain.

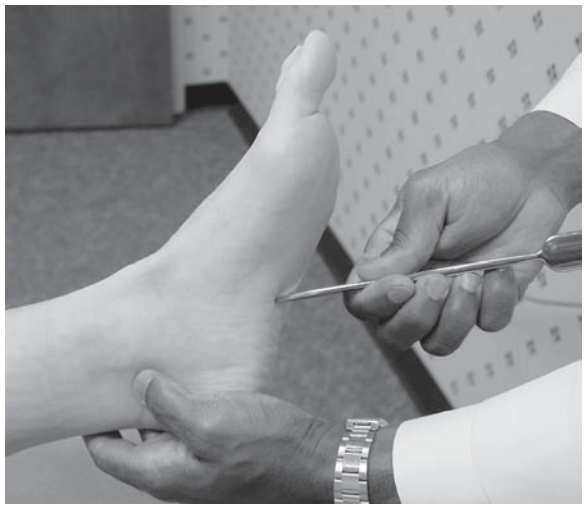

Fig. 9. Stroke plantar surface of foot to produce Babinski reflex.

post-menopausal woman aged 60 or older *(23)*. Osteoporosis is a disease characterized by low bone mass and microarchitectural deterioration of bone tissue that leads to pronounced bone fragility and increased fracture risk. The compression fracture of the osteoporotic patient can reduce vertebral height and can also cause lateral displacement of the bone. The fracture may extend into the lateral masses and posterior arch. The compression fractures of the spine often produce wedging of the vertebral body, which may also be associated with retropulsion of bone fragments and posttraumatic disc herniation. Other fracture types include burst or vertical shear fractures. Anterior to posterior dislocations may result from disruption of the anterior or posterior longitudinal ligaments.

History In most cases, the patient can recall the exact moment he or she developed symptoms. In the acute phase, the fragments may compromise nerve fibers in the central canal or foramen, causing pain that may be severe, disabling, and lasting up to 6 wk. When the pain extends beyond 6 wk this indicates poor healing, and the patients may experience a persistent dull ache. With movement the pain is aggravated and may become excruciating. Additional fractures or refracturing of the initial injury may occur *(24)*. Fractures may result in loss of height, kyphosis, and chronic pain. In the chronic phase, bone overgrowth with remodeling into the posterior or lateral canals can compromise the lateral recesses, central canal, or foramen.

Physical Examination The patient presents with focal tenderness over the compressed vertebra. The evaluation consists of a thumb compressing the spinous process of the vertebra in the region of tenderness. Alternatively the index and third finger can palpate the tissues lateral to the spinous process in a deep or rocking motion (Fig. 8). This latter maneuver may be more specific when the patient's discomfort is too diffuse. The pain may be dull in the subacute or chronic phase.

Often the patient complains of a dull persistent ache that is acute and sharp only during activity, especially exacerbated with rising from the supine or sitting position. This can be tested by having the patient flex and extend the spine.

Mild weakness may persist for days or weeks. If the fracture compromises the cord, reflex changes from corticospinal tract dysfunction can follow and include hyperreflexia, sensory loss, loss of sphincter control, and weakness of the lower extremities. Deep tendon reflexes can be helpful in clinical assessment. Absence of deep tendon reflexes implies dysfunction at the peripheral nerve or root level. In the setting of diffuse reduction of the deep tendon reflexes, the test for Babinski's sign of upper motor neuron involvement may help determine whether there is brain or cord involvement. Stroking along the plantar surface of the foot may cause dorsiflexion of the great toe and fanning of the others (Fig. 9).

Diagnostic Imaging Plain films of the spine are an excellent first imaging technique that can reveal a collapse, fracture, or associated dislocation of the spine. Despite an unrevealing initial evaluation, repeat radiographs in 7–10 d are appropriate when a fracture is suspected because callus formation or abnormal alignment may become evident.

Changes in the matrix of bone lead to osteoporosis and increased fracture risk, which can be detected by bone mineral densitometry. The bone mineral density is a noninvasive measurement of the bone mineral content in grams per square centimeter. The bone mineral content is

considered normal if it is no lower than 1 standard deviation (SD) below the mean. Bone mineral density between 1.0 and 2.5 SD below the mean indicates osteopenia or low bone mass. A bone mass and density below 2.5 SD indicates osteoporosis *(25)*. The fracture risk increases with each SD decline in the bone mineral density.

CT scans from an axial view are helpful to assess compromise of the central canal. CT may not clearly show associated disc herniations or the impingement of the lateral recesses and foramen. However, three-dimensional reconstruction can assist in visualization of the neural foramen. CT can characterize anterior to posterior dislocations and is also the best modality for finding teardrop fracture and fractures of the cervical spine.

MRI can show the fracture line as a low signal on T1 and T2. A high signal of marrow edema can be seen on T2 images. Encroachment of the cord and effaced epidural and foramen fat can be depicted on T1 images when the normal high signal of fat is displaced. A high signal in the cord from edema or hemorrhage on T2 images has been associated with a significant cord injury. Cord compromise is uncommon in osteoporotic compression fractures.

In the hyperacute phase the radionuclide bone scan may not show any change in activity. By 24 h there should be increased activity at the fractured vertebra. A linear, horizontal fracture line is shown by radiotracer uptake. In the setting of trauma or multiple fractures the intensity of the activity differentiates the more acute fractures from the older ones.

SUMMARY

The manifestation of back pain and neuropathy is complex and varies in individual patients. This chapter serves as a guide for the clinician when evaluating patients with such symptoms. The patient's history, physical examination, and diagnostic tools discussed will help the clinician identify the cause of the pain or neurological deficit, distinguish referred from local symptoms, and differentiate a neuropathy from pain of musculosketal origin. Treatment can be initiated after a thorough clinical evaluation.

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Interventional Spinal Procedures

II

6 History and Overview of Spinal Procedures

J. KEVIN MCGRAW, MD

THE DISCOVERY OF X-RAYS

The specialty of interventional radiology would not exist had it not been for the work of Wilhelm Conrad Roentgen. On November 8, 1895, Roentgen observed a bright fluorescence of barium platinocyanide crystals while experimenting with the Hittorf–Crookes tube. He assumed that the fluorescence might be caused by cathode (β) rays. Using a fluorescent screen he filtered out cathode rays but the phenomenon persisted; he became aware that the effect was produced by a new kind of ray that he called X-rays. Roentgen then replaced the screen with a recording photographic plate. One of the results of this experiment was an image of the bones of his wife's hand. After 8 wk of investigation, he delivered the manuscript reporting his discovery of X-rays to the Physical Medical Society of Wurzburg *(1)*. Medical science was forever changed.

NEEDLE AND SYRINGE DEVELOPMENT

Needles and syringes are used everyday by interventionalists and are two of the more common tools of our trade. In 1665, Oxford University architect and astronomer Christopher Wren performed the first recorded intravenous injection. Wren was convinced that substances could be injected directly into veins instead of being administered orally or rectally. He injected crocus metallorum (a mixture of antimony oxysulfide and antimony oxide) and opium into dogs. The dogs injected with crocus metallorum vomited to death while those injected with opium fell into a stupor *(2)*.

Johann Daniel Major decided to advance the work of Wren. In 1667, Major described the technique of intravenous injections in humans. His equipment consisted of a silver cannula connected to a bag that could be compressed by hand. An incision had to be made into the skin because the cannula was blunt *(3)*.

In 1841 Zophar Jayne patented the forerunner of the modern hypodermic needle and syringe. The device was created to inject an irritant solution into a hernia sac to produce inflammation. The device was the size of a tuberculin syringe, made of metal, and had a permanently attached needle with side holes *(4)*. The first use of the modern steel hypodermic needle and syringe was by the Scottish physician Alexander Wood in 1850. His earliest syringe was used to inject morphine to relieve pain in patients suffering from neuralgia *(5)*. The all-glass syringe was developed by Karl Schneider in 1896 at the Wulfing-Luer plant in Paris. The new syringe came with a "boiling box" and was the only "truly sterilizable" syringe *(4)*. The modern sterilizable syringe and needle were available at the beginning of the 20th century. Percutaneous entry needles appeared shortly thereafter. However, the process of matching glass pistons and barrels, resharpening needles, and sterilizing the equipment soon became expensive and time consuming. These drawbacks led to the development of prepackaged, sterilized, disposable needles and plastic syringes that we use today.

ANGIOGRAPHY

In January 1896, 1 mo after the announcement of Roentgen's discovery, Haschek and Lindenthal injected a radiopaque mixture into the blood vessels of an amputated hand showing remarkable detail of the vascular anatomy *(6)*. In his 1907 textbook, *Roentgen Rays and*

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Electrotherapeutics, Kassabian describes the vascular anatomy of the thorax, abdomen, kidney, heart, brain, spleen, liver, and stomach in cadavers *(7)*. An X-ray atlas devoted only to the systemic arteries of the body was published in England in 1920 *(8,9)*. In 1923, Berberich and Hirsch reported the first arteriograms and venograms obtained in humans with an injection of 20% strontium bromide. The radiographs of Berberich and Hirsch showed adequate quality of the arteries and veins in the upper extremity and vessel detail was surprisingly good *(10)*. In 1924, Brooks reported the first use of intraarterial sodium iodide as a means of demonstrating the vessels of the lower extremity in humans *(11)*. He reported that his technique was useful for defining the anatomy of the arteries as well as for showing plaque formation and indicating when an amputation of an extremity needed to be performed for compromise of blood supply *(11)*. In 1928, Moniz described the technique of carotid angiography and its application in the study and evaluation of cerebral lesions *(12)*. The use of compliant intravascular catheters occurred in 1929 when Werner Forssmann wanted to develop a method to inject drugs directly into the heart. After practicing a technique on a cadaver, Forssmann used a dissection kit and made an incision in his own antecubital fossa. He then inserted a Dechamps aneurysm needle into his antecubital vein, opened it, and pushed a urethral catheter into his bloodstream. He then had a chest radiograph taken to show that the catheter was within his right atrium. In 1931, Forssmann published a paper describing this event. He is credited with the first heart catheterization *(13)*.

In 1929, Santos described translumbar aortography and showed that satisfactory visualization of the abdominal aorta and its branches could be accomplished *(14)*. The study of the abdominal aorta depended on the translumbar approach of Santos until 1941, when Farinas described the retrograde passage of a catheter from the femoral artery into the aorta for purposes of aortography *(15)*. It was not until 1953 when the work of Sven Ivar Seldinger revolutionized modern angiography. Seldinger devised a method of percutaneous transfemoral catheterization that is currently in use today. In the May 1953 edition of the Scandinavian medical journal Acta Radiologica, Seldinger reported, "This technique is simpler than it appears on paper and after a little practice should present no difficulties" *(16)*. Seldinger was born in Mora, Sweden in 1921, and was only 32 when he developed his famous technique.

INTERVENTIONAL RADIOLOGY

The father of interventional radiology is Dr. Charles Dotter, from the United States. Under Dotter's leadership, diagnostic angiography moved into interventional medicine. In the early years, it was necessary for angiographers to learn catheterization procedures; in the Dotter years, the most important objective of catheterization became interventional therapy. It troubled Dotter that many conditions could be diagnosed by radiology but could not be treated. This changed after Dotter performed his first percutaneous transluminal angioplasty (PTA) on January 16, 1964 at the University of Oregon Medical School. The patient he treated was an 83-yr-old woman who had been bedridden for 6 mo because of severe pain and infection in her left foot due to peripheral vascular disease. A vascular surgeon advised amputation of the patient's extremity. When the woman refused the surgery, Dotter had the opportunity to prove the value of PTA. After Dotter's angioplasty, the patient's pain disappeared and healing of her ulcer began. She was able to walk using her own legs without difficulty until her death 3 yr later. In the 1964 edition of Circulation, Dotter described his technique.

> *The actual procedure is begun with downstream or antegrade femoral catheterization and control angiography. A preliminary injection of 2,000 units of heparin is given into the artery, and under fluoroscopic control an ordinary coil spring catheter guide of about 0.05 inch O.D. is passed down the lumen beyond. A tapered, radiopaque, Teflon dilating catheter of approximately 0.1 inch O.D. is then slipped over the guide and advanced until it too has traversed the block, thereby enlarging the pre-existing or newly opened lumen. The guide is passed across the atheromatous block without going through the wall more by the application of judgment than of force; both are often needed to effect the subsequent dilatation. Where desirable and possible, a second dilating catheter of nearly 0.2 inch O.D. is passed over the first.* (17)

European radiologists embraced the technique and referred to the new procedure as "dottering." Despite the acclaim Dotter enjoyed in Europe and elsewhere, "dottering" did not catch on in the United States until the mid-1970s. An additional decade would pass before Dotter received due recognition from peers in the United States. Many predicted that dottering was just a fad and cardiovascular surgeons in general would not refer their patients to radiologists for these "radical" procedures. As time went on, Dotter's unconventional methods were proven correct with the help of Andreas Gruentzig.

Andreas Gruentzig based his work on Dotter's methods. After Gruentzig shared his results with the medical community, Dotter's achievements in dilatation began to be appreciated. Dotter's contributions resulted in near

elimination of exploratory surgery and brought about one of the greatest advances in medical history. Following Charles Dotter's lead, Andreas Gruentzig changed the face of vascular catheterization, bridging the gap between diagnosis and therapy using a novel catheter. Gruentzig developed and refined percutaneous transluminal coronary angioplasty in Switzerland. Gruentzig announced his groundbreaking technique in the following letter to the editor, published in the February 4, 1978, issue of Lancet.

> *Sir: In November 1977, we introduced a technique for percutaneous transluminal coronary angioplasty (PTCA). This technique consists of a catheter system introduced via the femoral artery under local anesthesia. A pre-shaped guiding catheter is positioned into the orifice of the coronary artery and through this catheter a dilatation catheter is advanced into the branches of the artery. The dilatation catheter has a sausage-shaped distensible segment (balloon) at the tip. After traversing the stenotic lesion, the distensible segment is inflated with fluid to a maximum diameter of 3.0–3.8 mm by a pump-controlled pressure of 5 atmospheres. This pressure compresses the atherosclerotic material in a direction perpendicular to the wall of the vessel thereby dilating the lumen.* (18)

By 1979, Gruentzig and his colleagues reported in the New England Journal of Medicine, "Over the last eighteen months we have used this technique on 50 patients. The technique was successful in 32 patients, reducing the stenosis from a mean of 84 to 34% and the coronary pressure gradient from a mean of 58 to 19 mm Hg" *(19)*.

The pioneering work of Dotter and Gruentzig helped interventional radiology develop as a distinct subspecialty of radiology. Today, many vascular and nonvascular procedures are expertly performed by interventional radiologists who have acquired and mastered the skills necessary to perform image-guided procedures.

DISCOGRAPHY

Lumbar discography developed as a complementary modality for studying the lumbar intervertebral discs at a time when oil-based myelography was associated with high false-negative rates, particularly at the lumbosacral junction. Radiographic contrast was first injected into a normal disc in 1941 by Lindgren in Scandinavia. In 1948, Knut Lindblom, a radiologist in Stockholm, Sweden, was the first to publish in vitro studies on discography by using a posterior transdural approach and coined the term discography *(20)*. Also in 1948, Karl Hirsch employed the procedure to identify painful discs in patients with radiculopathy. Hirsch's diagnostic parameter of the procedure was the pain response, which led to the concept of provocative discography *(67)*. Lindblom continued to modify the technique to utilize the injection of contrast to visualize the radial structures of the disc, and the diagnostic criteria were expanded to include the radiographic appearance of the disc as well as the patient's response to the injection *(20)*.

Wise and Weiford were the first in the United States to visualize and study internal disc morphology in the early 1950s at the Cleveland Clinic *(21)*. Cloward and Busade continued the work and described the technique and indications for discography in their 1952 paper on the evaluation of normal and abnormal discs *(22)*. Ulf Fernstrom suggested mechanical and biomechanical causes for symptoms, based on cases of back and leg pain in which no nerve compression was detectable *(23)*.

The diagnostic merits and applications of discography have been challenged frequently and the modality remains highly controversial. In 1968, Holt questioned the validity of discography, reporting a 36% rate of positive findings in asymptomatic subjects *(24)*. His study, however, had flaws that included using prison inmates as his study subjects, using a very irritating contrast (sodium diatrizoate), and failing to include a positive pain response as a criterion for a positive result. Positive results in his study were based primarily on radiographic appearance of the discogram *(24)*. Walsh and co-workers refuted Holt's findings in a well designed study demonstrating a zero rate of false-positive results in 10 asymptomatic volunteers *(25)*. Walsh incorporated fluoroscopy and postdiscography CT scanning, which helped establish the standards of modern-day discography *(25)*.

EPIDURAL INJECTIONS

Epidural injections have been used in the management of neck and back pain for almost 100 yr, although they still remain quite controversial. The first reported epidural injection for pain management was in 1901 in Paris. M. A. Sicard injected cocaine for the treatment of sciatica *(26)*. The description of the paramidline approach to the lumbar epidural space was proposed by Pagés in 1921 *(27)*. Pagés' technique used the tactile feedback from the needles touching and passing through the ligamentum flavum as a means of identifying the epidural space. Confirmation of needle placement in the epidural space was based on absence of free flow of spinal fluid from the needle and the lack of resistance to injection of local anesthetic *(27)*. This approach was technically demanding and was associated with a significant failure rate.

The problems inherent in Pagés' technique led to further refinements in the loss of resistance technique.

Forestier and Sicard advocated attaching a fluid-filled syringe to a needle and injecting continuously while advancing the needle through the ligaments of the spine *(28)*. Sicard envisioned that the injectate served as a fluid trocar that atraumatically pushed the dura away from the advancing needle. Using a different approach, injecting through a sacral foramen, Evans reported the use of epidural anesthetics and saline for the treatment of sciatica in a 1930 Lancet paper *(29)*.

In 1933, drawing from the work of Sicard and Forestier, Dogliotti introduced the loss of resistance technique into clinical practice *(30)*. Dogliotti's technique relied on the sudden loss of resistance to injection when the needle bevel passed from the dense ligamentum flavum into the fat-containing epidural space. Independently, in the same year, Gutierrez suggested that the negative pressure of the epidural space might be used to identify the epidural space and devised the hanging drop technique *(31)*. This technique involves placing a drop of local anesthetic into the hub of a needle, and the needle is then advanced toward the epidural space. Gutierrez postulated that, as the needle bevel passes through the ligamentum flavum into the negative pressure of the epidural space, the drop of local anesthetic is sucked through the needle into the epidural space *(31)*. Measurements of epidural pressure have caused this mechanism to be called into question *(32)*.

In spite of these technical advances, many considered epidural anesthesia an unreliable anesthetic technique as compared with spinal anesthesia. For this reason, epidural anesthesia remained popular with a limited number of practitioners. Interestingly, it was the development of the Tuohy needle rather than a new drug that renewed interest in epidural anesthesia. The Tuohy needle not only reduced the incidence of inadvertent dural punctures but also allowed the practitioner to maintain analgesia for prolonged periods through the use of indwelling catheters placed through the needle *(33)*. The introduction of lidocaine into clinical practice in the early 1950s added a greater margin of safety for epidural anesthesia and led to increased use of epidural anesthesia in obstetrics. Bupivacaine, introduced in the early 1960s, enabled physicians to provide long-lasting neural blockade from a single injection and made epidural nerve block an option in a variety of new clinical situations. The first epidural steroid administration was reported in 1952, which was performed through the first sacral foramen *(34)*. The discovery of the clinical utility of epidural steroid administration in the management of radiculopathy and other painful conditions and of opioids in the management of cancer-related pain brought epidural nerve block into the mainstream of pain management *(35)*.

FACET JOINT INJECTIONS

In 1911, Goldthwait first stated that the facet joints were responsible for cases of low back pain and instability *(36)*. Like many clinicians of that time, he was struck by the asymmetry of the facet joints seen on radiography. He believed that the joint asymmetry could cause pain from nerve root pressure *(36)*. An Italian surgeon, Putti, published an article in 1927 that supported Goldthwait's findings and focused specifically on articular facet degeneration as a cause of back pain *(37)*. In 1933, Ghormley was the first to describe facet syndrome, which he defined as lumbosacral pain with or without sciatic pain, particularly occurring suddenly after twisting or rotatory strain of the lumbosacral region *(38)*. In addition, his initial discussion focused on the role of facet joints, not the intervertebral discs, in creating nerve pressure and sciatica. In 1934, however, Mixter and Barr described protrusion of lumbar discs as the most likely cause of low back pain *(39)*. This description then overshadowed the role of the facet joints as a source of low back pain and sciatica.

In 1941, Badgley encouraged clinicians to again focus attention on the facet joints to explain the large numbers of patients with low back pain whose symptoms are not due to a ruptured disc *(40)*. He showed that facet joint pathology could cause symptoms, including radiation of pain into the lower extremity. Badgley was the first clinician to associate facet arthritis with nerve root irritation as a cause of low back pain and sciatica *(40)*. Hirsch and colleagues, in 1963, were the first to demonstrate that low back pain distributed along the sacroiliac and gluteal areas with radiation to the greater trochanter could be induced by injecting hypertonic saline in the region of the facet joints *(41)*. These findings were confirmed by Mooney and Robertson, who in 1976 performed intraarticular facet injections with hypertonic saline and noted that the pain produced could be relieved by intraarticular injection of local anesthetics *(42)*. In addition, Pawl reported the reproduction of pain in patients after injecting hypertonic saline into their cervical facet joints *(43)*.

PERCUTANEOUS DISC DECOMPRESSION

CHEMONUCLEOLYSIS

After Mixter and Barr established the relationship between intervertebral disc disruption and back pain *(39)*, investigators attempted to find ways to treat this pervasive problem. By far, the most widely used and studied procedure for percutaneous disc decompression is chemonucleolysis. Chemonucleolysis was first per-

formed by Lyman W. Smith in 1963 *(44)*. The procedure involves the chemical dissolution of the nucleus pulposus via a percutaneous injection into the nucleus of the disc. This most commonly involves the enzyme chymopapain, a proteolytic enzyme derived from the papaya fruit. This enzyme cleaves the proteoglycan of the nucleus into muco-protein and glycosaminoglycan *(45)*. To date, more than 400,000 chemonucleolysis procedures have been performed *(46)*. Chemonucleolysis has also been associated with a number of problems that has limited the procedure. First, it is difficult to predict the amount of nucleus that will be digested, leading to cases of overdecompression, disc collapse, and instability. Chymopapain is indiscriminate in the proteins that it will digest, and it may cause irreversible nerve damage if it comes into contact with neural elements. There have been a number of rare, but serious, complications associated with chemonucleolysis. In the first year of commercial use, there were 55 catastrophic events out of 100,000 cases performed *(47)*. Complications included transverse myelitis and paraplegia. In addition, there is an estimated 0.35% incidence of anaphylactic reactions to this enzyme, leading to a number of deaths *(48)*. Because of these complications, use of chemonucleolysis has decreased to approx 1200 cases per year, primarily outside of the United States *(47)*.

AUTOMATED PERCUTANEOUS LUMBAR DISCECTOMY

Hijikata first described a manual percutaneous decompression of the nucleus pulposus in 1975 *(49,50)*. He utilized a 5-mm cannula and surgical rongeurs to remove disc material *(49,50)*. In 1985, Onik and his co-workers developed a blunt-tipped, reciprocating, suction-cutting probe for automated percutaneous lumbar discectomy (APLD) *(51)*. Their device was placed into the disc through a 3-mm cannula utilizing fluoroscopic guidance. Research utilizing APLD demonstrated that decompressing the disc centrally also decompresses herniation at the disc periphery by reducing intradiscal pressure *(52)*. The popularity of APLD has diminished because of a combination of clinical, design, and cost issues. However, the concept of decompressing the nucleus led to the development of other nuclear-reducing procedures such as laser discectomy and nucleoplasty.

PERCUTANEOUS LASER DISCECTOMY

Choy et al. introduced the yttrium–aluminum–garnet (YAG) laser to vaporize the nucleus pulposus in 1991 *(53)*. Again, it has been hypothesized that the drop in intradiscal pressure may be a factor in symptomatic relief. In a large series of patients treated over many years, the overall success rate was reported as >75% *(54)*.

NUCLEOPLASTY

Nucleoplasty also utilizes a percutaneous approach to decompress disc material. This is accomplished by a multifunctional bipolar radiofrequency device that features Coblation technology to ablate, or remove tissue, while alternating with thermal energy for coagulation. Coblation technology has been used in more than 1 million procedures since 1997, primary in orthopedic arthroscopy *(55)*. With nucleo-plasty, a curved wand is introduced into the nucleus via a 17-gauge needle. At least six passes are made through the nucleus to create channels in the disc. Nucleoplasty with the Perc-D Spine Wand was developed in 2000.

INTRADISCAL ELECTROTHERMAL THERAPY

Intradiscal electrothermal therapy (IDET) entered the procedure arena in 1998 and represented a deviation from the evolution of nucleoplasty. Drs. Jeffrey Saal and Joel Saal put forth a new theory of "annuloplasty." IDET is thought to relieve pain by three mechanisms: (1) thermal destruction of annular nociceptive nerve fibers (pain fibers); (2) disruption of heat-sensitive hydrogen bonds in the annular collagen which leads to shrinkage of the disc; and (3) the concept that thermal heating of the annulus could seal and stabilize annular tears. The literature shows that type C afferent nerve fibers (nociceptors) are destroyed by temperatures above 45°C *(56,57)*. Collagen fibers are typically arranged in a triple helix. At 70°C, the collagen fibers denature and form random coils of intermittent cross-lengths. In essence, they shrink *(58,59)*. The IDET technique requires threading a curved resistance heating wire around the posterolateral annulus under fluoroscopic guidance. The catheter is then heated to 90°C, in theory accomplishing an annuloplasty.

SELECTIVE NERVE ROOT BLOCKS

The history of selective nerve root blocks dates back to the turn of the previous century. Shortly after the manufacturing of procaine, Sellhiem described a paravertebral block *(60)*. In 1922, Lawen described the use of procaine to perform a diagnostic paravertebral block, which was the first report of using an anesthetic to perform a diagnostic block *(60)*. In 1930, White performed landmark work using procaine to define pathways of peripheral pain *(61)*. The use of lidocaine for nerve blocks started in the early 1950s after Erdtman synthesized it in 1943 *(60)*. When corticosteroids were synthesized and became available in the 1950s, they were combined with anesthetics to attempt to provide a longer lasting result. It has more recently also been proposed to combine this technique with an epidural injection using a transforaminal approach as a more effective means of treating radicular back pain *(62)*.

VERTEBROPLASTY

Acrylic cements have been used for the augmentation of weakened or partially destroyed bones for decades *(63)*. The term *vertebroplasty* originally described an open surgical procedure that introduces bone graft or acrylic cement to mechanically augment weakened vertebral bodies. Polymethyl methacrylate (PMMA) is the acrylic most commonly used as a bone filler. The first image-guided percutaneous vertebral augmentation or percutaneous vertebroplasty (PVP) was performed in France in 1984, when Deramond and Galibert injected PMMA into a C2 vertebra that had been partially destroyed by an aggressive hemangioma *(64)*. The procedure relieved the patient's chronic pain. Shortly thereafter, PVP was used to treat vertebral compression fractures caused by osteoporosis *(65)*. The interest in PVP has continued to grow since its introduction in Europe and its subsequent introduction in the United States *(66)*. In 1993, the first vertebroplasty procedure in the United States was performed at the University of Virginia on a patient with a breast cancer metastasis *(66)*.

CONCLUSION

A thorough understanding of the history of interventional radiology and interventional spinal procedures will allow us to develop new and innovative treatments for our patients.

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7 Pharmacology of Medications Used in Spinal Injection Procedures

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OVERVIEW

Spinal injection procedures employ many different techniques to provide pain relief for a myriad of medical conditions. Interventional pain management strategies and techniques have grown exponentially; nevertheless, many of the medications used for these procedures are quite similar.

Pain is defined in terms of acute and chronic. There is no precise definition of pain, which is often loosely defined as an unpleasant sensory and emotional experience, and typically includes psychosocial experiences such as the patient's culture, prior pain experiences, and to some degree the patient's motivation. Acute pain is a natural physiologic response designed to remove the subject from harm, and generally resolves as the offending stimulus is removed. Chronic pain is defined in a variety of terms, but typically is defined as a pain that continues for more than 1 mo beyond the usual recovery period for an illness or injury. Obviously in the setting of a chronic condition, pain may last for months or years. Pain represents the single most common reason for seeking medical attention. More than 50 million people in the United States suffer from severe chronic pain, and an additional 25 million people experience acute pain from injuries or surgery *(1)*. Each year, more than 4 billion work days are lost secondary to pain. Pain is therefore an important public health issue. Pain results in an annual financial loss to the economy in the United States of approx $79 billion, and does not include the immeasurable costs associated with reduced quality of life and patient suffering *(2)*.

Despite access to healthcare, pain remains largely undertreated in the United States. Poorly managed pain often exacerbates the suffering and decreased quality of life, ultimately impairing healing and contributing to the development of chronic pain. Many treatment options exist for the management of pain, including pharmacologic therapies, behavioral interventions, and other therapies such as transcutaneous electrical nerve stimulation, acupuncture, and massage. Pharmacologic therapies include aspirin, acetaminophen, nonsteroidal antiinflammatory agents, opioid analgesics, and other classes of medications such as anticonvulsants, antidepressants, and antiarrhythmics for specific types of neuropathic pain. Opioids represent the most effective analgesic agents for virtually all types of pain, but are frequently underutilized. Despite these readily available therapies, many patients with pain receive no treatment or inadequate treatment, representing an important healthcare problem *(3)*. Although most pain can be effectively treated with medications, it is estimated that only about one quarter of pain patients receive adequate analgesia *(4)*.

Many appropriately selected patients are candidates for percutaneous spinal injection procedures following failure of conservative treatment measures, often consisting of rest, immobilization, analgesic therapy, antiinflammatory therapy, and physical therapy. This chapter focuses on the pharmacology of the medications used in such procedures, and includes their mechanism of action, route of administration, dosage, and potential adverse effects. Obviously, the management of these patients would require additional treatment modalities, often including treatment of their underlying precipitating condition, behavioral modification, and counseling.

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THE PATHOPHYSIOLOGY OF PAIN PRODUCTION

The sensation of pain represents a complex series of events designed to protect the central nervous system (CNS). The integration of multiple components of the neuroaxis begins with activation of specific nociceptors, signaling potential injury to sensory fibers and potential damage to the CNS. This type of neuropathic pain is considered maladaptive, yielding harmful sequelae. Nociceptive pain is, however, more of a warning to the rest of the body, indicating some form of injury, signifying that further investigation and action is warranted *(5)*. Nociceptors are not specialized pain receptors, but rather they are simply bare nerve endings in the periphery. In 1965, Melzack and Wall first described the gate control theory of pain, which integrates the anatomic pain pathways and several psychological pain models *(6)*. The gate control theory of pain proposes a neural mechanism in the dorsal horn of the spinal cord that acts like a gate, blocking or allowing the transmission of pain impulses from the periphery to the brain. The smaller unmyelinated fibers transmit impulses slowly and result in dull pain such as burning and aching. The large myelinated fibers transmit impulses quickly and are associated with acute, sharp types of pain. The large fibers typically produce the acute initial pain sensation, but small fiber stimulation can produce chronic pain that worsens with time. The magnitude of the response is proportional to the intensity of the stimulus and thus proportional to the magnitude of the injury. In addition, the two types of impulses can be antagonistic. For example, mild stimulation of the large fibers can greatly diminish the pain produced by the stimulation of small fibers, which is the gating mechanism used to explain the effectiveness of topical counterirritants as well as electrical and physical pain treatment modalities. The autonomic nervous system is integrally related in the pain experience as the afferent sympathetic chain ganglia fibers connect with the same spinal cord cells that receive input from the peripheral nociceptive fibers. Although the normal dorsal root ganglion demonstrates minimal sympathetic innervation, it demonstrates a marked enhancement in the levels of sympathetic innervation following peripheral injury.

Although the first intrathecal injection of morphine was reported in 1901, it was not until the 1960s and 1970s that the effects of opioids on the CNS were studied extensively *(7)*. The first proposal of a descending system of pain modulation was proposed in 1906 by Sherrington *(8)*. The description of stereospecific opioid receptors was first made in the early 1970s, helping to characterize further the suggestion that the analgesic effects of opioids involve a descending inhibitory system originating in the brain stem and affecting dorsal horn nociceptive transmission *(9)*. Just half a decade after the discovery of specific opioid receptors, it was shown that opioids exert their effects by binding selectively to and altering the conformation of stereospecific opioid receptors *(10)*.

In the periaqueductal gray, substance P neurons from the ascending nociceptive system stimulate cells that contain the opioid enkephalin. These enkephalin-containing cells then inhibit interneurons, which are also inhibited by β-endorphin-containing cells in the hypothalamus *(11)*. These interneurons inhibit the main outflow neuron of the periaqueductal gray to the rostral ventral medulla. The inhibitory interneurons then result in increased transmission from the outflow neurons in the periaqueductal gray to the rostral ventral medulla *(12)*. The input from the periaqueductal gray then stimulates an output cell in the rostral ventral medulla, which may contain norepinephrine, enkephalin, and substance P as its neurotransmitters. The norepinephrine-containing neurons inhibit the main outflow neuron, but neurons containing a local opioid, such as enkephalin or dynorphin, can inhibit the norepinephrine neuron. The outflow neurons appear to be inhibitory via receptors on thalamic-projecting neurons. These nociceptor neurons are targets of the spinothalamic, spinoreticular, and spinomesen-cephalic tracts and interneurons in the spinal cord *(13)*.

The nociceptors may be stimulated by compression, stretching, or a physical or chemical insult, and the painful stimulus is then transmitted. Noxious chemicals such as bradykinin result from inflammation, anoxia, and other pain-producing stimuli, and are likely involved in initiating the pain impulses. Prostaglandins are also involved in the sensitization of nociceptors. In the dorsal horn, small-fiber afferent nociceptors release substance P, calcitonin gene related peptide, and glutamate. The second-order nociceptive neurons then project into the spinothalamic, spinoreticular, and spinomesencephalic tracts. While these thalamic-projecting neurons are stimulated by input from the rostral ventral medulla, these neurons are also inhibited by local neurons in the dorsal horn containing opioid. Thus, the pain impulse terminates in the thalamus, where conscious pain perception may be localized, and is then transmitted to the cerebral cortex, where the pain is recognized and interpreted. The limbic system, which is anatomically very close to these structures, is likely responsible for the emotional component of the pain. The junction of primary afferent fibers, second-order nociceptive neurons, and local opioid-containing neurons represents the integration of the entire system of nociceptive transmission and analgesia, serving as the basis for multiple theories including the gate control theory *(6)*, postsynaptic inhibitory balance theory *(14)*, and the diffuse noxious inhibitory control theory *(15)*. Following 20

yr of intense research, the nociceptive and antinociceptive receptors can be grouped into several general classes, including opioid peptides, substance P, noradrenergic receptors, serotoninergic receptors, γ-aminobutyric acid (GABA) receptors, and other peptide receptors.

Pain impulses are transmitted from the periphery via the A-δ and C fibers to the dorsal horns of the spinal cord, where substance P is the primary neurotransmitter. Spinal gating is postulated to occur in the substantia gelatinosa of the dorsal horns. Stimulation of A-δ and C fibers within the dorsal horn has been shown to be reduced by opioid peptides or endogenous endorphins. The endogenous endorphins include met-enkephalin, dynorphin, and β-endorphin. Opioids have been shown to diminish the neuronal activity evoked by somatic and visceral stimuli, proven to cause pain in animals *(16)*. The action of opioid peptides is always inhibitory on target neurons. Opioid receptors in the superficial dorsal horn have synaptic contacts with spinothalamic tract neurons *(17)*. In fact, five distinct subclasses of endorphin receptors have been described, specifically μ, κ, σ, δ, and ε receptors. The μ receptors are largely responsible for analgesia by most natural and several synthetic opiates. Agonist–antagonist opiate analgesics tend to block the μ receptor and stimulate the κ receptor, which produces spinal analgesia. Stimulation of the σ receptor results in the undesirable effects of opioid administration, notably dysphoria, hallucinations, and vasomotor stimulation. Enkephalins are located in the dorsal horn, periaqueductal gray, and nucleus raphe magnus, and bind to κ, μ, and δ receptors *(18)*. Small-diameter, high-threshold primary afferent fibers of the spinothalamic tract, spinoreticular tract, and spinomesencephalic tract have been shown to contain large numbers of presynaptic enkephalin-binding sites. The enkephalins inhibit neuronal activity in dorsal root ganglia and reduce the terminal activity of the primary afferent neurons *(19)*. Enkephalins and enkephalin agonists have demonstrated naloxone-reversible inhibition of substance P release from primary afferent neurons *(20)*.

Dynorphins are found in the hypothalamus, periaqueductal gray, and the spinal dorsal horn, where they bind to κ receptors *(21)*. The dynorphin levels within the dorsal root neurons increase significantly in the setting of peripheral inflammation *(22)*. κ agonists have been shown to produce analgesia, and are most responsive to mechanical and low-intensity thermal stimulation.

Substance P is synthesized in the cell bodies of small cells (type B) of spinal ganglia and is found in C-fiber primary sensory neuron cell bodies. Substance P is not released during stimulation of A-β fibers. More than half of the quantity of substance P produced is transported in a peripheral direction *(23)*. Protracted pain states, particularly those associated with chronically inflamed or injured tissues, result in an augmented peripheral release of active factors. In the presence of substance P, there is a substantial increase in the release of several different neurotransmitters in the dorsal horn of the spinal cord. Substance P facilitates nociceptive transmission in neurons activated by noxious cutaneous stimuli. It also promotes nociceptive transmission by enhancing the effectiveness of other neurotransmitters through slow progressive depolarization in the dorsal horn neurons *(24)*. Because substance P has receptors both centrally and peripherally, axonal reflexes can trigger the peripheral release of substance P causing degranulation of mast cells, plasma extravasation, and vasodilatation *(25)*.

Both α_1- and α_2-noradrenergic receptors are located in the descending antinociceptive pathway. Noradrenergic transmitters are found in cerebrospinal fluid and are located within the axonal terminals of interneurons making synapses with spinothalamic tract neurons involved in nociception. Both pre-synaptic and postsynaptic noradrenergic terminal connections are found in neurons responsible for nociception. The presynaptic binding is avid on small-diameter, high-threshold (nociceptive) primary afferents. α_2-Noradrenergic transmitter release is inhibitory to nociceptive transmission and critical for opioid-induced analgesia *(26)*. In fact, the application of norepinephrine to the dorsal horn will produce analgesia. The locus ceruleus in the pons is the key part of the noradrenergic pathway in the neural control of antinociception of the brain and spinal cord, sending inhibitory axons containing norepinephrine to the periaqueductal gray and to dorsal horn neurons *(27)*.

Nociceptor sensitization is also a result of the actions of multiple second messenger systems, activated by the release of inflammatory mediators such as bradykinin, prostaglandins, serotonin, and histamine. Serotonin creates an activation pathway in the descending system of antinociception, located in the descending axons of the nucleus raphe magnus neurons. The serotoninergic axons make axosomatic and axodendritic connections on receptors on the spinal cord. Although there is significant presynaptic binding of serotonin on small primary afferent neurons, there is no significant decrease in the release of substance P.

A prominent excitatory response to glutamate is present in motor horn and dorsal horn cells, which are activated by the larger myelinated A-β fibers *(28)*. Both glutamate and aspartate are associated not only with synapses of small-diameter primary afferents but also with larger diameter afferents. The dorsal horn neurons contain a large pool of glutamate, where postsynaptic activation of the dorsal horn nociceptive neurons occurs, and includes a large number of receptors for both the released peptides as well as for the excited amino acids. The amino acid

receptors affect central and peripheral neuropathic pain transmission more than the nociceptive transmissions of tactile or thermal stimuli *(29)*.

Major functions of the periaqueductal gray include pain, analgesia, fear, anxiety, vocalization, and cardiovascular control. The foremost intrinsic circuit of the periaqueductal gray is the GABA receptor network. The GABAergic system is critical to ascending pain transmission, and is responsible for receiving afferents from all of the nociceptive neurons in the spinal cord, and has projections to the thalamic nuclei and other nociceptor sites. GABA is another transmitter that acts primarily as an inhibitor to stop the outflow neuron in the descending nociceptor pathway. However, GABA can also function as a major excitatory neurotransmitter in the CNS. GABA found in the dorsal horn likely causes inhibition of small-diameter primary afferents. Receptors for GABA on interneurons may cause inhibition of second-order nociceptors as well as inhibition of thalamic-projecting neurons *(30)*. Nociceptors have been demonstrated to become excited with inflammation and other pathologic conditions *(31)*. Adenosine triphosphate (ATP) and GABA are coreleased in 70% of GABAergic neurons, which may help to explain a possible reversible switch between the inhibitory and excitatory roles of a given synapse without anatomic reorganization of the neural circuitry.

Despite the complex interaction of numerous neural pathways, the medications used in spinal injection procedures result in a simple localized effect. Certainly, given the fact that the biological activity of medications used in spinal injection procedures last far longer than the chemical activity of the agent, the entire pain production pathway is affected with drug administration. The method by which the pharmacologic agent is introduced into the tissues also plays a critical role in its clinical effect, bioavailability, duration of action, elimination, and potential adverse effects.

MEDICATIONS USED IN SPINAL INJECTION PROCEDURES

LOCAL ANESTHETICS

Local anesthesia can be produced with the direct administration of any of the following agents: 1.0% lidocaine (Xylocaine, AstraZeneca Pharmaceuticals), 0.25% bupi-vacaine (Marcaine, AstraZeneca Pharmaceuticals, and Sen-sorcaine, AstraZeneca Pharmaceuticals), 0.5% ropivacaine (Naropin, AstraZeneca Pharmaceuticals), and 1.0% mepi-vacaine (Carbocaine, Sanofi-Winthrop Pharmaceuticals). The administration of these agents into the epidural space or perineural space is capable of producing adequate sensory block of the adjacent nerve roots or ganglia. With increasing drug concentrations, the onset of action shortens dramatically and the degree of motor block increases. Systemic drug absorption decreases with the coadministration of epinephrine, which also slightly prolongs the duration of action *(32)*. On average, a total of 5–10 mL of any one of the aforementioned medications is sufficient in the adult patient population for most pain management applications *(33)*. The operator needs to ensure that any agent administered into the epidural route has been appropriately formulated for epidural use *(34)*.

For diagnostic and prognostic purposes, a short-acting agent such as 1.0% preservative-free lidocaine is most appropriate *(33)*. For therapeutic purposes, longer acting regimens such as 0.25% preservative-free bupivacaine or 0.5% ropivacaine in combination with a long-acting steroid such as 80 mg of depot methylprednisolone (Depo-Medrol, Pharmacia & Upjohn) are more appropriate *(33)*.

The frequency of administration is variable between institutions and specific patient requirements. Acute painful conditions may require daily lumbar epidural nerve blocks with both local anesthetics and steroids *(35)*. Lumbar radiculopathy and diabetic neuropathy are examples of chronic pain syndromes treated on various schedules, from every other day, to once a week, to every few weeks, and are dictated by the results and the patient's clinical status.

Mechanism of Action Local anesthetics completely block electrical impulse conduction in excitable neural tissues such as peripheral nerves, spinal roots, and autonomic ganglia when applied locally in appropriate concentrations. By blocking sodium channels, electrical impulses are halted both proximally (pain) and distally (motor). The resulting effect is the particular nerve, whether it has a sensory, motor, or autonomic function, is blocked. The concomitant pain sensation, muscle contraction or autonomic effect is interrupted in the area exposed to the local anesthetic as well as the tissues innervated distal to the site of application. Unlike the effects of neurolytic agents, the impulse conduction block produced by local anesthetics is painless and completely reversible. The nerve block dissipates as the drug is released from its bonds to the sodium channel receptors *(36)*. The unique effect of a local anesthetic block is provision of a transient neural quiescence. This transient period of relaxation is frequently sufficient to allow spontaneously discharging hyperactive neurons to decrease gradually their level of activity, and thereby produce pain relief that extends far beyond the few hours duration of the local anesthetics' pharmacologic blocking action.

The thin lipoprotein nerve membrane contains voltage-responsive ion transmitting channels that render the membrane excitable, and therefore capable of generating and

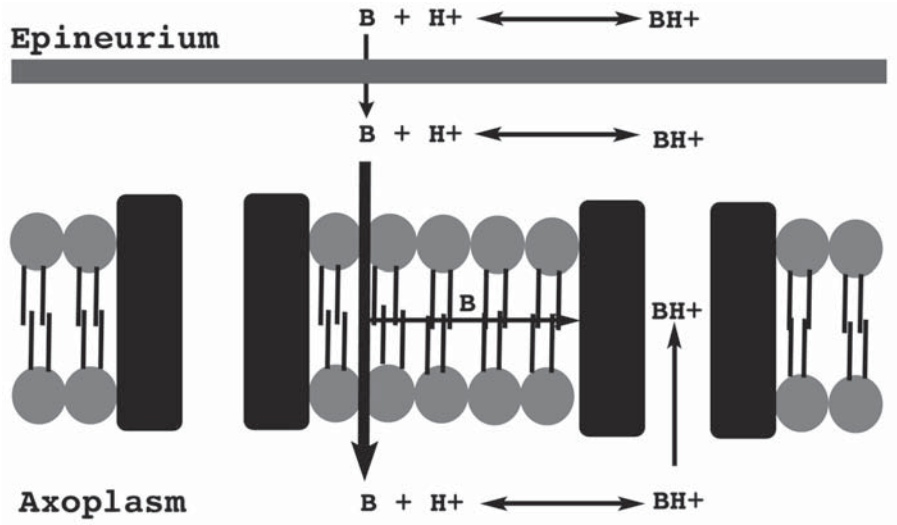

Fig. 1. Local anesthetic molecules' access to the membrane sodium channel. The uncharged lipophilic tertiary amine (B) diffuses across lipid membrane barriers and interacts with the channel through the axolemma interior. Within the axoplasm, the charged quaternary amine (BH^+) is formed. The charged molecule then binds to a specific receptor via an open sodium channel pore.

conducting tiny electrical currents or impulses. The nerve's resting potential is generated by the cross-membrane potassium ion concentration gradient, and the action potential is maintained across the membrane by the sodium ion concentration. These cross-membrane ionic gradients, which govern nerve excitability, are maintained by metabolically fueled sodium-potassium pumps. The stabilization and deactivation of the sodium channel is the key mechanism of action of local anesthetics *(37)*. The first step in the initiation of a nerve action potential is the generation of a sodium current resulting in bidirectional signal propagation. This impulse generation is suppressed by local anesthetics, which act to block and thus close the transmembrane sodium channels, preventing the inward membrane-depolarizing surge of sodium ions *(36)*. The resting membrane potential is maintained, but the nerve is completely inexcitable. The positively charged local anesthetic binds to negatively charged fatty acid tails in the transmembrane gate, locking the movement of the protein subunits and blocking sodium ion flow. The local anesthetic must be lipophilic because it can enter the sodium channel only from inside the axoplasm. Therefore, the highly lipid-soluble agent will first traverse the lipid nerve membrane, dissociate into a local anesthetic cation, and then ascend into the sodium channel to lock up the mobile gating structures (Fig. 1).

Relative therapeutic potency is measured by the minimum blocking concentration, defined as the lowest drug concentration necessary to halt impulse traffic and to block the nerve and thus relieve pain. Bupivacaine is severalfold more potent than lidocaine, which in turn is severalfold more potent than procaine. The degree of anesthetic block is also affected by the state of the sodium channel. The receptor accessibility status of the channel, whether open, inactivated, closed, or resting, will determine the depth of the nerve block in response to local anesthetic administration (Fig. 2). In addition, the frequency of stimulation will also determine the degree of block. As the frequency of nerve stimulation is increased, the membrane channels are more likely to be open and more accessible to local anesthetic for a greater proportion of time, and thus the more profound the degree of block will be noted in nerves that fire faster. The size of the nerve fiber can also play a role in the degree of block. The thin A-δ and C fibers are more easily blocked at lower drug concentrations than are the larger, A-α, motor fibers *(38)*. This unique differential nerve block is the basis for treatment of pain syndromes. At appropriate doses, the patient will experience no pain sensation, but would be able to perceive touch and pressure as well as voluntarily contract muscles. Because preganglionic autonomic axons, spinal B fibers, are similar in size to the smallest sensory (cold) fibers, most epidural local anesthetic injections result in a local sympathetic block that often extends several segments higher and lasts longer than the desired nociceptive block. As nerve impulses can skip over one or two consecutively blocked nodes, at least 5 mm, and preferably 8 mm, of nerve length must be immersed in local anesthetic to ensure nerve blockade (Fig. 3). Thus larger volumes of diluents, such as preservative-free saline, are necessary to ensure adequate penetration of local anesthetic agent to the nerves undergoing blockade.

Local anesthetics are organic amines, which are lipid soluble but water insoluble and unstable. The lipophilic ringed head of the molecule is separated from its hydrophilic hydrocarbon tail by an intermediary ester or amide

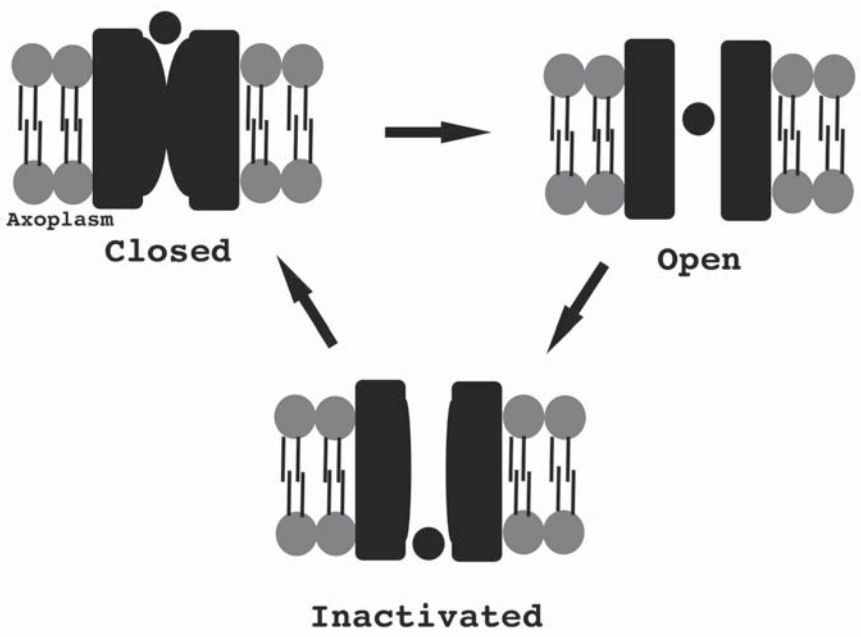

Fig. 2. The sodium channel. The channel may exist in three distinct states. The closed or resting state is impermeable to sodium ions but does remain voltage responsive. The open state represents a transmembrane channel that is permeable to an inward sodium ion flux. The inactivated state is in an open channel configuration but has been rendered impermeable to sodium ions because a local anesthetic molecule is bound to the gating receptor site. Because local anesthetic renders the membrane impermeable to sodium ion and thus inexcitable by local action potentials, the nerve is blocked. The sodium channel cannot reopen until the original resting membrane potential is reestablished and the channel first returns to its closed or resting state.

linkage (*36*) (Fig. 4). The crystalline acidic salts, most often the hydrochloride, of the local anesthetic base are both stable and water soluble, but lipid insoluble. The drug dissolves in water to yield an anesthetic cation and a chloride or other acid anion. The anesthetic cation, a positively charged quaternary amine, is then in dissolution equilibrium with the anesthetic base, an uncharged tertiary amine, that is lipid soluble and can penetrate neural membranes *(36)*. Within the neural cell axoplasm, the molecule again dissociates into the local anesthetic cation, which then migrates into the sodium channel and binds to its receptor site.

Drug absorption delivers local anesthetic to the bloodstream, where it is highly protein bound, resulting in low plasma drug levels *(39)*. The extravascular component represents a high-capacity storage reservoir. Highly vascular tissues can result in much higher drug absorption. Local vasoconstriction, as seen with the coadministration of epinephrine, slows absorption, allowing more anesthetic to be retained in the target tissues longer, enhancing and prolonging the local anesthetic properties of the agent *(32)*.

Local anesthetics depend on hepatic blood flow for clearance. Although extensively protein-bound, the plasma free fraction of drug is cleared by the liver. The metabolites and conjugates are excreted renally *(36)*. Biliary elimination of drug is minimal.

As a class of drugs, local anesthetics are very homogeneous in molecular structure and biological properties. Most local anesthetics are weak basic tertiary amines. All are structurally similar, containing an aromatic lipophilic head and a hydrophilic amino alkyl tail, separated by an ester or amide carboxy linkage. These agents are extensively bound to plasma proteins, controlling the spread, penetration, duration of activity, and toxicity. The dissociation constant represents a physical principle that governs the proportions of diffusible lipid-penetrating mobile local anesthetic base with the neurally active but nonmobile cation given the surrounding pH *(36)*. The intermediate linkage controls the molecule's planar orientation, affecting its unique affinity for sodium channel receptors. The linkage influences the molecule's risk of an allergic reaction. This linkage chain also plays a major role in the meta-bolism of the agent. Ester-linked local anesthetics, such as procaine, are readily hydrolyzed in plasma to the parent aromatic acid and amino alcohol. In contrast, the amide-linked tertiary amines such as lidocaine resist direct plasma hydrolysis and require one or more preliminary steps before eventual hepatic hydrolysis *(36)*. In fact, amino amides with a nonlinear cyclic amino tail such as bupivacaine are more resistant to hydrolysis than the linear-chain ones such as lidocaine. The distinction is so sharp that local anesthetics are divided into two classes known as amino ester and amino

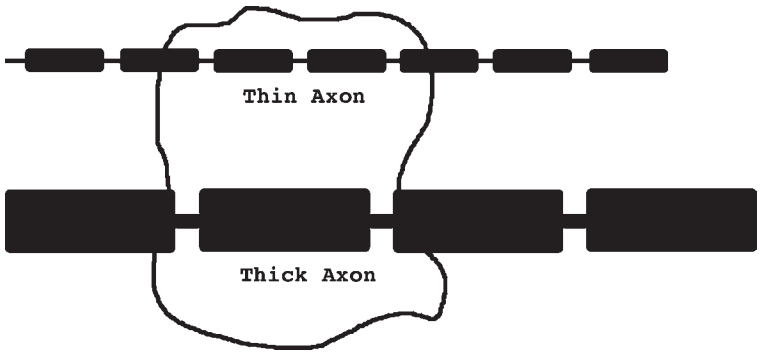

Fig. 3. Basis of nerve fiber size and differential nerve block. A thin and thick axon are placed side by side in a local anesthetic bath at the minimum blocking concentration. The internodal interval of the thick fiber is twice that of the thin fiber. The local anesthetic solution covers three successive nodes of the thin axon but only one node of the thick axon. Impulses can easily skip over one and even two inexcitable nodes; thus, impulse conduction along the thick fiber continues uninterrupted while impulse conduction in the thin fiber is halted. A sufficient volume of local anesthetic should be injected to coat at least three successive nodes, about 1 cm in the thickest axons.

amide for ester-linked and amide-linked compounds, respectively. The molecular structure is fundamental to the key clinical characteristics of each agent such as potency, biotransformation, duration of action, and drug allergy.

The amino ester local anesthetics consist of agents such as cocaine, tetracaine, 2-chloroprocaine, and procaine (Novo-caine, Sanofi-Winthrop Pharmaceuticals). These amino ester compounds are easily hydrolyzed and have a very short duration of action, thus limiting their clinical usefulness in pain management. Lidocaine metabolism is hepatic blood flow-limited with a larger than 70% hepatic first-pass extraction. The molecule is hydrolyzed by liver microsomal mixed-function oxidases and amidases, largely by the cytochrome P_{450} enzymatic system. The amino amide local anesthetics consisting of lidocaine, mepivacaine, ropivacaine, and bupivacaine have marked clinical usefulness in pain management. These agents are resistant to hydrolysis and have a significant longer duration of action.

Administration Lidocaine has replaced procaine as the standard local anesthetic based on its properties of faster and farther diffusion, a more potent and longer-lasting block, and less allergenicity. With the addition of a vasoconstrictor such as epinephrine to lidocaine, drug absorption can be slowed sufficiently to prolong the duration of block as long as 50%. The block also tends to be more intense as there is less dilution with tissue fluid. The optimal concentration of epinephrine is 5 μg/mL or a 1:200,000 solution.

Although the duration of action might be slightly longer, mepivacaine resembles lidocaine in the clinical aspects of potency and toxicity. The rapid onset of profound analgesia, predictable diffusion, moderate motor block, and a duration of action desirable for outpatient procedures makes the agent a popular choice for major nerve blocks.

Bupivacaine represents a second-generation modification of long-acting local anesthetics. Bupivacaine analgesia lasts two to three times longer than that provided by lidocaine or mepivacaine. Repeated administration, however, can lead to the accumulation of drug and metabolites, resulting in a higher risk of toxicity. Bupivacaine is more than 97% protein bound and is highly lipid soluble. Higher concentration solutions such as 0.75% bupivacaine have been limited to local ophthalmologic use given its cardiotoxicity. Intermediate concentrations of 0.5% bupivacaine have been reserved for cases requiring profound muscle relaxation. For pain management procedures, 0.25% bupivacaine is the preferred concentration, providing both adequate anesthesia as well as minor to moderate motor block. The manufacturers' recommendation is to limit the bupivacaine dose to 1–2 mg/kg, generally 150–200 mg for most adults. High drug–tissue binding allows for slower consistent peak blood levels and for a longer duration of action. The onset of action of bupivacaine is relatively slow, requiring up to 15–20 min to achieve epidural blockade. When used for perineural analgesia, bupivacaine blocks typically last for 4–6 h or longer. With the epidural administration of bupivacaine, the duration of action is normally 2 h or less. The synergistic response of the combined administration of bupivacaine and an opioid is highly useful and may allow for profound pain relief without the drawbacks of orthostatic hypotension or respiratory depression of either drug alone *(40)*.

The volume of solution, both medications and diluent, administered into the epidural space will influence the vertical spread of anesthesia. In one study, for example, 30 mL of 1% lidocaine produced a level of analgesia 4.3 dermatomes higher than that achieved with 10 mL of 3% lidocaine administered at the same lumbar epidural level *(41)*. Studies with bupivacaine demonstrated that increas-

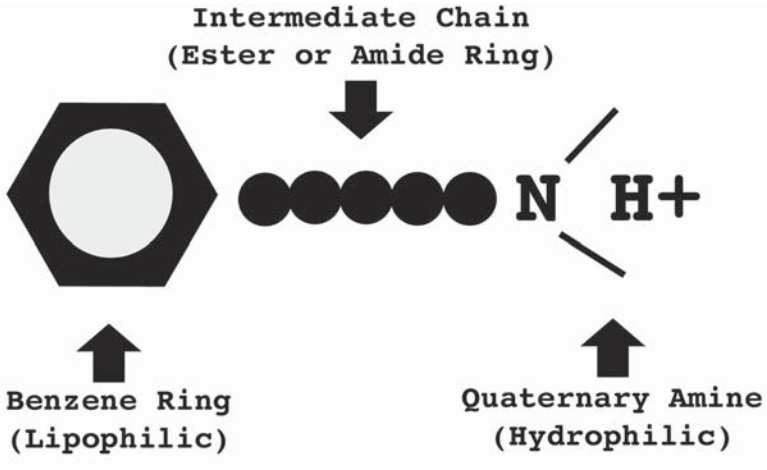

Fig. 4. Fundamental structure of a local anesthetic molecule. The lipophilic aromatic (head) and hydrophilic amino (tail) segments are joined together by a five-carbon amino ester or amino amide linkage chain.

ing the concentration from 0.125% to 0.25%, while maintaining the same volume of epidural injectate, shortened the latency time, improved the rate of effective analgesia, and increased the duration of sensory analgesia *(42)*.

Epinephrine is often added to epidural solutions of local anesthetic in an effort to prolong the duration of action and increase the depth of sensory blockade. The effects of epinephrine are thought to be due to its effects on the local vasculature and limitation of local drug absorption. This results in increased local drug exposure to the spinal roots and spinal cord, generally with epinephrine doses of 1:200,000 or 5 μg/mL *(42)*.

In the setting of epidural injections, a total of 5–10 mL of local anesthetic in the concentrations described is generally administered. Given the smaller target and potential space, the volume of local anesthetic solution injected for nerve blocks is typically 1–3 mL. This overall volume is then expanded locally with the injection of preservative-free saline. The volume of epidural injectate in the midthoracic spine is reduced to 3–5 mL, given the relatively narrow thoracic epidural space. The lumbar epidural space is more capacious and thus requires larger injectate volumes. Cephalad spread of epidural solution occurs more easily than caudal spread, likely due to the negative intrathoracic pressures and the high resistance produced by narrowing of the epidural space at the lumbosacral junction *(43)*. In fact, very little medication administered via a caudal epidural injection extends superior to the lumbosacral junction secondary to narrowing of the epidural space at this level and the thickness of spinal roots in this area. Greater volumes of caudal epidural injectate preferentially will extend through the anterior sacral foramina where it is absorbed rather than extend superior to the lumbosacral junction. The rate of epidural injection has virtually no effect on the level of epidural anesthesia or duration of effect *(44)*. Rapid injection of solutions into the epidural space can result in significant patient discomfort, which abates with stopping or decreasing the rate of injection.

Injections of similar volumes and solution concentrations of local anesthetics are employed for peripheral nerve blocks. Given the proximity to the intercostal artery and vein, intercostal nerve blocks can result in the highest systemic drug levels, and thus the highest risk of potential adverse effects. However, other peripheral nerve blocks with a very poor adjacent blood supply, such as blocks of the sciatic nerve, can result in a substantially longer duration of action. For example, an equivalent dose of anesthetic delivered into the epidural space may last for 3–4 h, but may last for 24–36 h if delivered to the sciatic nerve *(45)*. The injection volume depends greatly on the route of administration. Given the size of the retroperitoneum and the need to diffuse to all adjacent ganglia, a celiac plexus blockage generally requires the administration of 20–25 mL of a local anesthetic such as 0.75% lidocaine or 0.25% bupivacaine.

The volume of injectate is significantly limited in facet joint injections. As the facet joint is contained within a synovial capsule, high-volume, high-pressure injections may result in capsular rupture. Therefore, intraarticular injections in the lumbar facets are typically limited to 1–2 mL of injectate, including not only the volume of anesthetic and/or steroid, but also the volume of radiographic contrast *(46)*. To improve the local anesthetic's effects, the concentration of local anesthetic solution is generally increased for facet blocks. Given their smaller size, the injectate volumes are limited to 0.4–0.6 mL for thoracic facet joint blocks. Similarly, the injectate volume for cervical facet joint blocks is decreased to 0.8–1.0 mL. Additional administration of local anesthetic solu-

tion can be performed in the periarticular tissues for therapeutic purposes. Periarticular injections can result in blockade of adjacent nerve roots. It is unclear whether facet capsular rupture results in exacerbation of the patient's chronic back or neck pain.

Adverse Effects The majority of complications are related to procedural technique rather than to pharmacological effects. Certainly, potential drug-related events would include a contrast reaction in patients with allergy to radiographic contrast media. Vasovagal reactions are often procedurally mediated. Hemorrhage, infection, and vessel or nerve root injury are related to the performance of the procedure. Headaches occur much less commonly than with myelography, and result only from inadvertent puncture of the subarachnoid space during attempts to access the epidural space. Arachnoiditis is a rare complication related to intrathecal drug injection. Most local anesthetics in the concentrations used for epidural injection are without significant local neural irritation, and thus the risk of localized nerve damage is very low.

Adverse reactions to local anesthetics may be characterized as local or systemic. Systemic reactions occur at a site distant to the injection site and correlate with plasma drug concentrations. Local reactions occur when the agent injures the structures it contacts. Other than allergic reactions, systemic reactions are dose dependent. Because these reactions are directly proportional to the plasma drug concentration, measures utilized to decrease the local blood level, which include using the weakest solution and minimizing local absorption with a vasoconstrictor, help to reduce the incidence of significant toxicity *(36)*. Systemic side effects most often occur from injection of more than a prudent or maximum dose or from unintentional intravascular drug administration. Cerebrotoxicity ranges from mild symptoms such as drowsiness to grand mal seizures. Inadvertent intrathecal injection can result in serious and permanent neurotoxicity. The subtle early symptoms of a rising local anesthetic blood level are tinnitus, drowsiness, metallic taste in the mouth, paresthesias, disorientation, and confusion *(36)*. More severe manifestations of neurotoxicity include shivering, muscle twitching, and tremors, which first involve the face and distal parts of the extremities. The physical expressions of toxicity may progress to generalized tonic–clonic seizures. Cardiotoxicity may result with the formation of refractory arrhythmias, which are more often seen with bupivacaine than lidocaine. Cardiac tissue, like nerves, is rendered less excitable owing to the limitation of inward flowing sodium currents. The blocking action of bupivacaine increases with each successive heart beat, and thus opens the door for potentially malignant reentrant cardiac arrhythmias *(47)*. The administration of topical local anesthetics and opioids to the lumbar and sacral nerve roots can result in urinary retention, particularly in elderly men, multiparous women, and in patients who have undergone inguinal or perineal surgery *(48)*.

Allergy represents a different form of a systemic reaction to the administration of a local anesthetic. This results from a sensitization to the drug, viewed as an antigen, and the body's response to it. An immunoglobulin E (IgE)-mediated antibody response represents a true allergic reaction with mast cell degranulation and histamine release. A slower, delayed, type of response results in a localized reaction, with the skin and soft tissues being the primary target. Fortunately, true allergies to the amino amide local anesthetics are exceedingly rare. In addition, more than 90% of reported allergies to local anesthetics are due to the preservatives and additives in commercially prepared solutions.

Local adverse reactions include myotoxicity and neurotoxicity. High local concentrations of anesthetic can be toxic to muscle and irritating to subcutaneous tissues. However, the doses required for these side effects are not used in daily interventional pain management practice.

The vast majority of complications are related to the spinal injection procedure rather than the administered pharmacological agent. Certainly, the most significant complication is the incorrect route of drug administration. If the needle or catheter is inadvertently positioned in the subarachnoid space rather than the epidural space, and the problem is not recognized, the patient will undergo injection of epidural doses of medications into the cerebrospinal fluid. Epidural doses of local anesthetics into the subarachnoid space can result in total spinal anesthesia with associated loss of consciousness, hypotension and apnea. The profound systemic side effects of local anesthetics occur as a result of high blood concentrations of drug. Although this may rarely occur because of excessive local drug absorption, it most commonly occurs with inadvertent intravascular injection or the administration of an excessive amount of local anesthetic.

NEUROLYTICS

Although neurolytic blocks are an important tool in the management of pain in patients with terminal cancer, certain neuralgias, and vascular occlusive disorders, only about 30% of cancer patients with intractable pain require neurolysis as a means to obtain effective analgesia *(49)*. A diagnostic or prognostic block prior to neurolysis may be helpful to evaluate the patient and to help familiarize the patient with the possible side effects, but does not predict the exact outcome of neurolysis.

Mechanism of Action The peripheral nerve lacks lymphatic innervation, which can lead to increases in endoneural fluid pressure as a result of any toxic, metabolic, or traumatic insult. This initiates mast cell degen-

eration and the release of vasoactive substances, increasing the permeability of the blood–nerve barrier and subsequent accumulation of fluid in the endoneurial space. The elevated endoneurial pressure results in stretching of the perineurium and compression of perineurial vessels, leading to nerve fiber ischemia. The entire process peaks in 6–7 d and reverts to normal in about 30 d.

Although a wide variety of compounds can produce neurolysis, only absolute alcohol and phenol remain useful in clinical practice. Increasing efforts at neurolysis are being performed by mechanical means such at cryoanalgesia and radiofrequency ablation. Absolute alcohol, in a commercially available concentration of >95%, remains the mainstay of chemical neurolysis. Alcohol is also a local irritant and can cause considerable pain during injection, which can be limited with a preceding injection of a local anesthetic. Alcohol extracts cholesterol, phospholipids, and cerebrosides from nerve tissue, thereby causing precipitation of lipoproteins and mucoproteins *(50)*. The topical application of alcohol to peripheral nerves produces changes characteristic of wallerian degeneration. When injected near the sympathetic chain, alcohol destroys the ganglion cells and thus blocks all postganglionic fibers to all effector organs *(51)*.

Phenol has the unique property of acting as a local anesthetic at lower concentrations and as a neurolytic agent at higher concentrations. Thus, a potential advantage is that phenol produces minimal pain on injection. Phenol causes nonselective neurolysis by denaturing proteins of axons and perineural blood vessels *(52)*. The degeneration process characteristically occurs in about 14 d, and regeneration is completed in about 14 wk after injection

Administration Neurolytic blocks with alcohol are commonly used for cranial neuralgias with blocks of the trigeminal and glossopharyngeal nerves, epidural and intrathecal interruption of neuraxial transmission, lumbar sympathetic block, and celiac plexus neurolysis. There is a 95% dehydrated absolute alcohol solution commercially available for medical use. The volume of injectate is often small; thereby, none of the effects of ingested ethanol are seen. Extreme caution is taken at the time of injection to avoid local tissue necrosis and cellulitis. After the therapeutic injection, the needle should be first flushed with remaining local anesthetic or saline prior to removal to avoid the application of residual alcohol along the needle tract.

Phenol is less commonly used in injection procedures as it is not commercially available in an injectable form. A phenol solution can be prepared by the hospital pharmacy. Phenol is a potent neurolytic in its aqueous form at concentrations usually of 6–8%. Phenol in glycerine diffuses out very slowly. Compared to alcohol, phenol produces a shorter lived and less intense blockade. The typical duration of pain relief lasts for 2–6 mo in patients with chronic pain.

Adverse Effects Despite adequate and effective analgesia, many patients experience painful, annoying, and psychologically distressing neuralgias following alcohol neurolysis. The neuralgia is most commonly a dull to severe pain, which can occasionally result in a burning sensation or even a sharp, shooting pain sensation. Recovery from the pain can occur as soon as a few weeks or may take many months to resolve. The incidence of this complication is higher with a thoracic paravertebral sympatholytic injection than in a lumbar injection, possibly owing to the closer proximity of the somatic fibers of the sympathetic chain in the thoracic region. The dermatomal distribution of hypesthesia or anesthesia of the nerve roots treated is a rare but distressing complication. Fortunately, the recovery from this symptom is usually quick. Lumbar or sacral neurolysis can result in loss of bowel or bladder sphincter tone and thus bowel or urinary incontinence. Celiac plexus neurolysis can result in increased gastrointestinal peristalsis, which may lead to the development of diarrhea. Lumbar sympathetic neurolysis has been associated with the development of severe groin pain secondary to genitofemoral neuralgia. The referred pain is related to degeneration of the L2 nerve root, which gives rise to the genitofemoral nerve *(53)*. A rare complication is paraplegia, which can occur if the alcohol injection results in significant vasospasm in the artery of Adamkiewicz.

Phenol has demonstrated a high affinity for vascular tissues, generating concerns regarding its use in celiac plexus neurolysis, where major vessels are in close proximity to the injection site. Neuritis is uncommon with phenol injection. In patients with intractable pain, both alcohol and phenol have equivalent analgesic efficacy *(54)*.

OPIOIDS

The first report regarding the analgesic properties of intrathecal morphine in animals was not made until 1976 *(55)*. Within 3 yr, both the intrathecal and epidural administration of morphine was shown to provide effective pain control. Opioids have been shown to produce a powerful and selective reduction in humans' and animals' responses to pain and other noxious stimuli. Opioids not only block spinally mediated reflexes, but also block supraspinally organized responses. The intrathecal administration of opioids has a powerful and dose-dependent effect on nociceptive thresholds. Opioid analgesics provide pain relief as a result of binding to their specific receptors in the spinal cord, and inhibiting nociceptive responses via reducing the spinal neuronal activity evoked by a noxious

stimulus *(56)*. Unfortunately, the oral dose of opioid required to achieve a therapeutic concentration at the spinal cord level and thus provide adequate pain relief must be relatively large, which can result in concomitant adverse effects such as constipation, sedation, and respiratory depression. Thus, the potential goal of the intrathecal or epidural administration of opioids is to provide local, targeted, effective analgesia with lower doses and avoid the potential systemic side effects resulting from the indirect route of administration of high-dose opioids.

Mechanism of Action Morphine, and its related semisynthetic and completely synthetic congeners, produce their major effects on the CNS and bowel. Despite the chemical variability and a variety of special properties, all opioids are capable of producing the diverse biological effects of analgesia, drowsiness, changes in mood, respiratory depression, decreased gastrointestinal motility, nausea, vomiting, and alterations of the endocrine and autonomic nervous systems *(57)*. Although each opioid has its own unique properties, none have been proven to be clinically superior to morphine for pain relief, and thus each new analgesic agent is compared to morphine with regard to its properties and effectiveness *(56)*.

There are four major types of specific opioid receptors in the CNS, specifically the μ, κ, δ, and σ receptors, which may also possess a variety of subtypes. There is considerable variation in the binding characteristics and anatomical distribution among the variety of opioids *(58)*. Morphine-like agents behave as agonists and act preferentially at the μ receptors. The primary opioid analgesic receptors in the spinal cord are the μ receptors, located in the substantia gelatinosa of the dorsal horn, where the spinal neuron discharge in response to a noxious stimulus is suppressed without changing the responses to other sensory inputs *(59)*. Regardless of the route of administration, the opioid eventually binds to the dorsal horn μ receptor. If the opioid is administered epidurally, it must first pass through the dura to reach its receptor sites. To cross the dura, the agent must be lipophilic; however, this will result in increased absorption by the epidural fat and surrounding tissues, thus reducing the desired effects of epidurally administered opioids *(60)*.

Although opioids do not alter the threshold or responsiveness of afferent nerve endings to noxious stimulation or impair the conduction of the nerve impulse along peripheral nerves, they may decrease conduction of impulses of primary afferent fibers when they enter the spinal cord and decrease activity on other sensory nerve endings *(56)*. Morphine in the brain stem inhibits spinal nociceptive reflexes, reducing the level of spinal neuronal activity evoked by noxious stimuli. Opioids acting in the substantia gelatinosa of the dorsal horn are thought to decrease the release of neurotransmitters, in particular substance P, which mediates the transmission of pain impulses *(56)*. Thus, opioids selectively inhibit the release of excitatory neurotransmitters from the terminals of nerves conducting nociceptive impulses, thereby reducing both the spontaneous discharge and physiological responses evoked by noxious stimuli.

Opioid administration results in the biological effects of analgesia, drowsiness, changes in mood, and mental clouding. In therapeutic doses, analgesia can occur without loss of consciousness. Patients experience pain that is less intense, less discomforting, or entirely resolved. The relief of pain by opioids is relatively selective, in that other sensory stimuli such as touch, vibration, vision, and hearing are not obtunded *(56)*. Opioid analgesics not only suppress the sensation of pain, but the patient's affective response is also altered. Typically, the pain sensation is still present, but the patient feels more comfortable. Continuous dull aching pain is relieved more effectively than sharp intermittent pain at comparable analgesic dosages. With increasing doses, feelings of drowsiness, inability to concentrate, difficulty in mentation, apathy, lessened physical activity, reduced visual acuity, and lethargy may develop. Also at larger doses, the adverse effects of nausea, vomiting, and respiratory depression may become more pronounced. The localized administration of intrathecal opioids is capable of producing profound segmental analgesia without eliciting a significant alteration in motor or sensory functions or subjective effects *(61)*.

Administration Commonly used opioids for epidural injection include morphine sulfate, hydromorphone (Dilau-did, Knoll Pharmaceutical Co.), fentanyl (Sublimaze, Taylor Pharmaceuticals), meperidine (Demerol, Sanofi-Winthrop Pharmaceuticals), and methadone (Dolophine, Roxanne Pharmaceuticals). The epidural administration of morphine is 5–10 times more potent than that administered intravenously. Morphine in the epidural space has a slow onset of action, ranging from 30 to 60 min, but a more sustained duration of effect, lasting from 12 to 24 h. Hydromorphone has an intermediate onset of action, ranging from 20 to 30 min, and an intermedi-ate duration of effect of 6–12 h. Fentanyl administered into the epidural space has equivalent potency to intravenous administration. Although fentanyl has a rapid onset of action of only 5–15 min, its duration of effect is short, lasting only 2–4 h. Meperidine is one to two times more potent via the epidural route than the intravenous route of administration. Meperidine has a rapid onset of action of 10–20 min, but a short duration of action, lasting 4–8 h *(62)* (Table 1). The intrathecal route provides better long-term pain relief at a lower dose with less pump refills than the corresponding epidural route *(63)*. Options for the delivery of epidural or intrathecal opioids for pain relief include percutaneous infusion catheters, tunneled cath-

Table 1
Comparison of Opioids for Epidural Use

Medication	*Relative lipid solubility*	*CSF solubility and spread*	*Time to onset*	*Duration of action*	*Potency relative to IV dosing*
Morphine	1 Hydrophilic	High	Slow, 30–60 min	Long, 12–24 h	5–10 times greater
Hydromorphone	1.4 Intermediate	Intermediate	Intermediate, 20–30 min	Intermediate, 6–12 h	5 times greater
Fentanyl	580 Lipophilic	Low	Rapid, 5–15 min	Short, 2–4 h	Equivalent potency
Meperidine	28 Lipophilic	Low	Rapid, 10–20 min	Short, 4–8 h	1–2 times greater
Methadone	82 Lipophilic	Low	Rapid, 10–20 min	Short, 4–8 h	Less potent

eters, and implantable programmable pumps, with pumps being more cost effective if spinally administered opioids are to be given for 3 mo or longer *(64)*.

If the patient undergoes the administration of opioids via the epidural route, 4–5 mg of morphine sulfate formulated for epidural use is most appropriate as an initial dose, which can be increased based on the patient's level of pain relief and tolerance. Highly lipid-soluble opioids, such as fentanyl, require administration via an infusion catheter. Again, all opioids administered via an epidural route should be formulated for epidural use *(34)*.

Adverse Effects Adverse effects related to opioids include minor sedation, nausea, urinary retention, constipation, and pruritus. Nausea and vomiting are unpleasant side effects caused by the direct stimulation of the chemoreceptor trigger zone for emesis in the area postrema of the medulla *(56)*. At higher doses, hyperalgesia, myoclonus, and respiratory depression may occur (Table 2). All phases of respiratory activity such as respiratory rate, minute volume, and tidal exchange can be diminished, thereby leading to respiratory failure. Epidural doses of opioids administered inadvertently into the subarachnoid or subdural spaces can result in significant respiratory and CNS depression, often requiring immediate supportive care. Therapeutic doses of opioids can result in peripheral vasodilatation, reduced peripheral vascular resistance, and an inhibition of baroreceptor reflexes, which can lead to orthostatic hypotension with possible fainting *(56)*. There is, however, no significant effect of opioids on blood pressure or cardiac rate and rhythm in therapeutic doses. Both biliary and pancreatic secretions are diminished by opioids, delaying digestion of food. Throughout the small and large intestine, opioids increase resting tone and diminish or abolish propulsive peristaltic contractions, thereby resulting in fecal desiccation and constipation. The development of tolerance and physical dependence is a characteristic feature of all opioids. The possibility of the development of psychological dependence is a major concern with opioid administration.

CORTICOSTEROIDS

Epidural steroid injections were first noted to alleviate pain of spinal etiology in the early 1900s by Sicard. Many investigators have evaluated the mechanism of action and clinical efficacy. The majority of these reports have proposed the mechanism of action to be a decrease in nerve root inflammation and swelling at the nerve–disc interface. Some authors have proposed that the fluid alone in the epidural space interposes itself between the nerve root and disc, mechanically influencing the pressure on the disc. Many experts have stated that epidural injections, particularly with the addition of an anesthetic, help to break the acute pain cycle, thereby allowing the patient to begin to recover from the primary insult and respond to more conservative treatment measures, hoping to obviate the need for surgery.

Mechanism of Action Adrenocortical steroids have numerous and widespread effects, influencing carbohydrate, protein, and lipid metabolism; electrolyte and water balance; and the functions of the cardiovascular system, the kidney, the skeletal muscle, and the nervous system *(65)*. A given dose of a corticosteroid may have physiological or pharmacological effects depending on the environment and the activities of the organism. The corticosteroids can be divided according to their degree of mineralocorticoid vs glucocorticoid effects, which are present within varying degrees in all agents. Like all other steroid hormones, their mechanism of action is achieved by controlling the rate of protein synthesis. Cortisol, a natural adrenocortical steroid, and its synthetic analogs have the ability to prevent or suppress the local warmth,

Table 2
Adverse Effects of Spinal Opioid Administration

Central nervous system
- Sedation
- Dizziness
- Light-headedness
- Euphoria
- Dysphoria
- Agitation
- Delirium
- Disorientation
- Drowsiness
- Lethargy
- Visual disturbances
- Hallucinations
- Coma

Gastrointestinal
- Nausea
- Vomiting
- Anorexia
- Constipation
- Biliary tract spasm

Cardiovascular
- Flushing
- Tachycardia
- Bradycardia
- Peripheral circulatory collapse
- Chest wall rigidity
- Orthostatic hypotension
- Syncope

Genitourinary
- Ureteral spasm
- Urinary retention
- Oliguria
- Antidiuretic effect

Dermatologic
- Pruritus
- Urticaria
- Edema

Major hazards
- Respiratory depression
- Apnea
- Respiratory arrest
- Laryngospasm
- Bronchospasm
- Circulatory depression
- Shock
- Cardiac arrest

Other
- Diaphoresis
- Hyperalgesia
- Myoclonus
- Physical tolerance
- Physical dependence
- Psychological dependence

erythema, swelling, and pain that are associated with inflammation. Corticosteroids inhibit both the early and late phenomena of the inflammatory response. The early effects include edema, fibrin deposition, capillary dilatation, migration of leukocytes into the area, and macrophage phagocytic activity. The later manifestations of the inflammatory response include capillary proliferation, fibroblast proliferation, deposition of collagen, and, finally, cicatrization *(65)*.

Corticosteriods inhibit the inflammatory response regardless of the inciting agent, whether it is radiant, mechanical, chemical, infectious, or immunological. Therefore, the administration of corticosteroids is palliative therapy for its antiinflammatory effects, and the underlying disease process remains untreated. The antiinflammatory effects depend on the direct local action of the steroid hormone. The most important of these effects is likely the inhibition of the recruitment of neutrophils and monocyte-macrophages into the affected area *(66)*. In addition, glucocorticoids inhibit the ability of these inflammatory cells to adhere to the capillary endothelial cell in areas of inflammation *(67)*. Glucocorticoids block the effect of lymphokines such as the macrophage migration inhibitory factor, preventing local accumulation of nonsensitized macrophages as seen in delayed sensitivity reactions. Glucocorticoids also inhibit the formation of plasminogen activator, which converts plasminogen to plasmin, also known as fibrinolysin, which is thought to facilitate the entrance of leukocytes into areas of inflammation by hydrolysis of fibrin and other proteins *(68)*. Glucocorticoids also induce the synthesis of a protein that inhi-bits phospholipase A_2, decreasing the release of arachidonic acid from phospholipids. This decreased formation of prostaglandins, leukotrienes, endoperoxides, and thromboxane plays a critical role in the prevention of chemotaxis and inflammation *(69)*.

Cortisone was the first corticosteroid used for its antiinflammatory properties. Its chemical structure has been modified to increase its antiinflammatory to sodium-retaining potency ratio. Thus, more modern day synthetic glucocorticoids have high antiinflammatory effects with minimal if any undesirable electrolyte, mineralocorticoid, effects. The changes in molecular structure have brought about changes in biological potency through alterations in absorption, protein binding, rate of metabolic transformation, rate of excretion, ability to traverse membranes, and the intrinsic effectiveness of the molecule at its site of action.

Administration Corticosteroids can be administered by virtually any route including orally, parenterally (intra-

Table 3
Comparison of Commonly Used Corticosteroids

Medication	*Relative antiinflammatory potency*	*Relative sodium-retaining potency*	*Duration of action*	*Approximate equivalent dosate (mg)*
Cortisol	1	1	Short	20
Prednisone	4	0.8	Intermediate	5
Methylprednisolone	5	0.5	Intermediate	4
Triamcinolone	5	0	Intermediate	4
Betamethasone	25	0	Long	0.75
Dexamethasone	25	0	Long	0.75

venous, intramuscular, subcutaneous, intrasynovial, perineural, and intralesional routes), and topically (dermal ointments, creams, and lotions; ophthalmic ointments and solutions; respiratory aerosols; and enemas). With all forms of topical administration, there is some systemic absorption of steroid.

There are a wide variety of commercially available corticosteroids; however, a limited number of injectable formulations exist for spinal injection procedures. Cortisol is available in several different injectable forms, including hydrocortisone (Cortef, Pharmacia & Upjohn, and Hydrocortone, Merck), hydrocortisone acetate (Cortef acetate, Merck, and Hydro-cortone acetate, Merck), hydrocortisone sodium phosphate (Hydrocortone phosphate, Merck), and hydrocortisone sodium succinate (A-Hydrocort, Abbott, and Solu-Cortef, Pharmacia & Upjohn). The naturally occurring cortisol products have moderate antiinflammatory potency but also some sodium-retaining potency. Injectable forms of methylprednisolone include methylprednisolone acetate (Depo-Medrol, Pharmacia & Upjohn, and Medrol acetate, Pharmacia & Upjohn) and methylprednisolone sodium succinate (A-Methapred, Abbott, and Solu-Medrol, Pharmacia & Upjohn). Methylprednisolone has approximately five times the antiinflammatory potency of cortisol and slightly decreased sodium-retaining potency. The synthetic corticosteroids, namely triamcinolone, betamethasone, and dexamethasone, have substantially higher antiinflammatory activity and essentially no mineralocorticoid effects. Triamcinolone acetonide (Kenalog, Westwood-Squibb) and triamcinolone diacetate (Aristocort, Fujisawa USA, and Kenacort diacetate, Westwood-Squibb) have approximately five times the potency of cortisol. Betamethasone sodium phosphate and acetate (Celestone Soluspan, Schering-Plough HealthCare Products) and dexamethasone acetate (Decadron-LA, Merck) possess 25 times the relative antiinflammatory potency of cortisol *(65)* (Table 3).

Given their ease of use and high antiinflammatory potency, triamcinolone and betamethasone are the primary medications used in spinal injection procedures. Triamcinolone acetonide is available as a 40 mg/mL suspension for injection. Typical injection volumes for triamcinolone acetonide are 2–4 mL for the epidural route of administration and 1–2 mL for the peripheral nerve block or facet block route of administration. The betamethasone preparation is a 6 mg/mL suspension for injection. The same injectate volumes of 2–4 mL for epidural blocks and 1–2 mL for peripheral nerve or facet blocks are used with betamethasone administration.

The distribution of drug throughout the epidural space depends on its flow. The volume and speed of drug injection; the epidural space anatomic variations; prior back surgery; the degree of epidural venous dilatation; and the position, age, and height of the patient all affect drug distribution in the epidural space *(70)*. During injection into the epidural space, the patient may experience temporary pain or a dull ache radiating down the lower extremities, which customarily abates when the injection rate is decreased or the injection discontinued.

The therapeutic effects of the injection are not felt imme-diately, but gradually develop with some relief beginning in 2–3 d. The extent and duration of pain relief are individualized and difficult to predict prior to the injection.

Adverse Effects The majority of adverse effects related to corticosteroid use are not experienced by those undergoing spinal injection procedures, as they are not subjected to prolonged exposure and concomitantly do not experience corticosteroid withdrawal and acute adrenal insufficiency. The synthetic agents, particularly in the doses used for spinal injection procedures, rarely result in hypokalemic metabolic alkalosis or edema *(65)*. Given their local administration and limited absorption, the synthetic corticosteroids used in spinal injection procedures uncommonly cause increased susceptibility to infection, peptic ulceration, myopathy, and behavioral disturbances. Although hyperglycemia can be seen in diabetics with systemic glucocorticoid administration, this condition is uncommonly noted after local epidural or perineural injections. As there is no prolonged systemic administration,

osteoporosis and vertebral body compression fractures would be highly unlikely adverse events given the local drug administration.

OTHER

Radiographic contrast media is used in virtually all spinal injection procedures. While it is beyond the scope of this chapter, most interventional pain management specialists use low osmolar contrast media for needle tip localization and verification of needle position at the target injection site. In addition, the small injection of contrast material is utilized to confirm an extravascular location prior to injection of many of the agents discussed in this chapter, particularly local anesthetics and neurolytics. As with any contrast injection procedure, the patient should be appropriately premedicated with a corticosteroid and antihistamine regimen in the setting of a known contrast allergy *(71)*.

Conscious sedation is often not required for most spinal injection procedures. However, those patients who are extremely anxious or are experiencing severe acute pain would likely benefit from intravenous conscious sedation. Given the severe pain incurred with alcohol neurolytic injections, heavy conscious sedation or general anesthesia is often utilized in these procedures. The pharmacology of conscious sedation is also beyond the scope of the chapter, but is generally accomplished with short-acting benzodiazepines such as midazolam (Versed, Roche) and a short-acting opioid such as fentanyl (Sublimaze, Taylor Pharmaceuticals). Conscious sedation administration does require the supplemental resources of continuous monitoring, risks of respiratory depression, the need for a recovery area, and additional nursing resources.

FUTURE DIRECTIONS

Neurospecific ultralong-acting local anesthetics with prolonged yet nondestructive and painless neural blockade would represent the ideal spinal injection agent. Rather than a new pharmacological compound discovery, this goal will likely be met through modification of a delivery vehicle, which would allow for the steady and sustained release of drug directly into the desired location. The most obvious goal would be that of providing a long-lasting yet reversible agent capable of producing sustained pain relief.

SUMMARY

The local administration of opioids, anesthetics, and steroids into the epidural or perineural space is utilized to treat a variety of acute and chronic pain syndromes. The spine injection specialist must have a strong basic understanding of the pathophysiology of pain to employ proper treatment modalities. In addition, a sound pharmacologic foundation will assist the interventional pain management physician to make appropriate choices in their pharmaceutical treatment regimens.

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8 Selective Nerve Root Blocks

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INTRODUCTION

The selective nerve root block (SNRB) is a procedure utilized in pain management both for its diagnostic and therapeutic advantages. It has a history dating back to the turn of the previous century. Shortly after the manufacturing of procaine, Sellhiem described a paravertebral block *(1)*. In 1922, Lawen described the use of procaine to perform a diagnostic paravertebral block, the first report of using an anesthetic to perform a diagnostic block *(1)*. In 1930, White performed landmark work using procaine to define pathways of peripheral pain *(2)*. The use of lidocaine for nerve blocks started in the early 1950s, after Erdtman synthesized it in 1943 *(1)*. When corticosteroids were synthesized and became available in the 1950s, these were combined with the anesthetics to attempt to provide a longer lasting result. It has more recently also been proposed that this technique be combined with an epidural injection using a transforaminal approach as a more effective means of treating radicular back pain *(3)*.

ANATOMY

The neural foramen provides a passageway for the spinal nerve as it exits from its intradural position to its extraspinal course. The intervertebral disc and the vertebral body form the anterior boundary. The posterior boundary is the zygapophyseal joint formed by the inferior and superior facets (Fig. 1). The superior and inferior boundaries are the pedicles (Fig. 2). The foramen communicates medially with the epidural space. The dura mater has extensions that follow the exiting spinal nerves into the neural foramen. The extensions tend to be shorter in the cervical and upper thoracic vertebrae and become longer more caudally.

There is variation in the length of the dural sleeve (Fig. 3). The dura continues as the epiradicular tissue as the nerve becomes extraspinal *(4)*. This variation in the length of penetration of the dural sleeve into the neural foramen becomes quite critical if a diagnostic nerve block is attempted. Inadvertent access to the epidural space can occur and an associated epidural injection will result.

The content of the neural foramen includes the spinal nerve, made up of the dorsal and ventral roots, the spinal ganglion, a small branch of the spinal artery, and a venous plexus. The ganglion, which is part of the dorsal root, is usually found lateral to the end of the dural sleeve within the foramen and medial to the joining of the ventral and dorsal roots. After formation of the spinal nerve by the joining of the ventral and dorsal roots in the lateral aspect of the foramen, the dorsal ramus arises supplying the zygaphoseal joints. A spinal nerve block in the lateral aspect of the foramen will therefore block the dorsal ramus as well as the nerve.

The cervical spinal nerves tend to have a more horizontal course through the neural foramen, with the first seven cervical nerves exiting on top of the similarly numbered pedicle. The eighth nerve exits underneath the associated pedicle as do the thoracic and lumbar nerves.

The sacral foramina are oriented in the anteroposterior plane and provide an exit point for the five sacral spinal nerves. There are foramina on both the anterior and posterior aspects of the sacrum and these nerves are approached taking advantage of the posterior opening (Fig. 4). More prominent and longer dural sleeves can be

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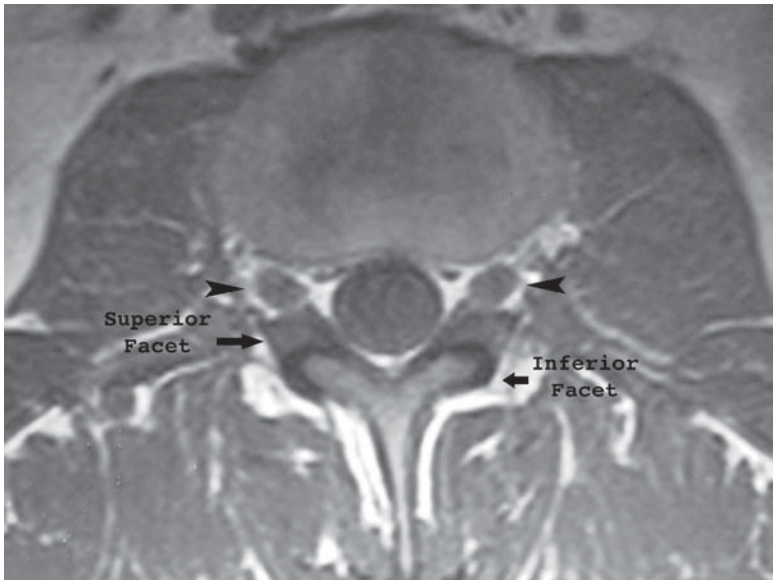

Fig. 1. Axial MRI. The superior facet lies more anterior with the nerve root exiting between the facet and the lateral annulus (*Arrowhead*: nerve root).

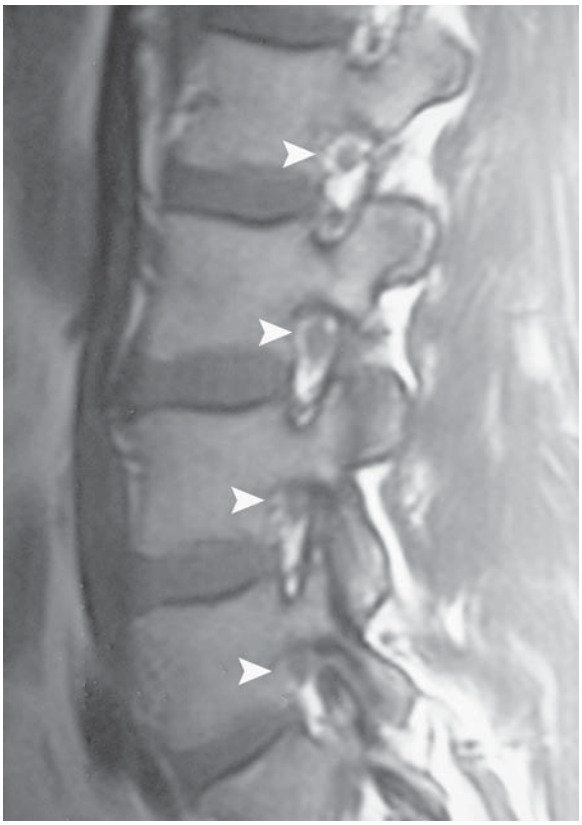

Fig. 2. Parasagittal MRI shows the bony boundaries of the neural foramen and its content.

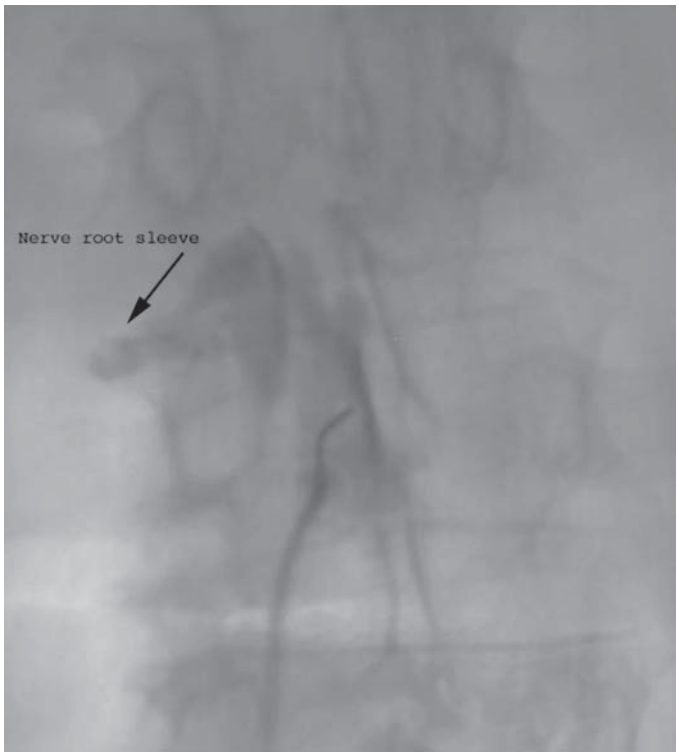

Fig. 3. ESI, which shows a prominent epidural sleeve during epidurography.

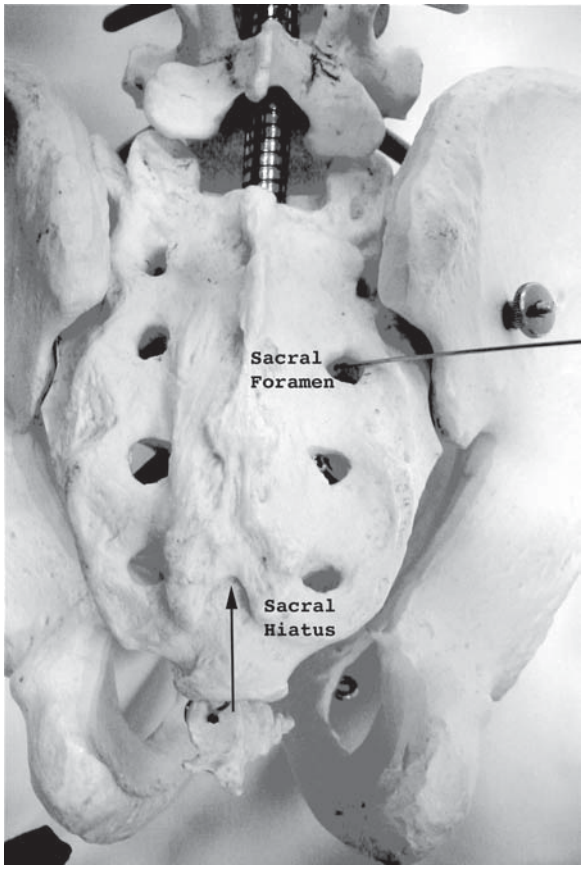

Fig. 4. The sacral foramen is accessed from a directly posterior approach. The orientation of the sacrum may necessitate craniocaudal angulation of the C-arm to identify the posterior sacral foramen.

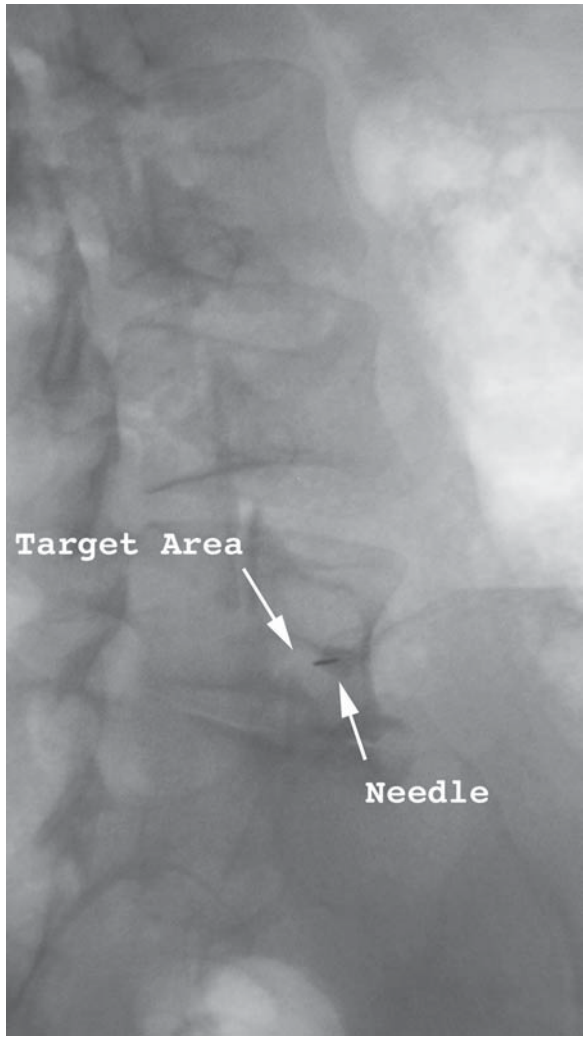

Fig. 5. SNRB using a "down the barrel" technique directed toward the infrapedicular target area.

seen in the sacral foramina and it is helpful to review imaging studies to avoid an inadvertent subarachnoid puncture.

INDICATIONS

SNRB is useful in the diagnosis of radicular pain, particularly when imaging is confusing. If a patient clearly suffers from radicular pain (shooting pain in the limb along a narrow band), relief of that pain by a SNRB implicates the treated nerve root as the source of pain. SNRB is also useful as a therapeutic modality following a successful diagnostic block. Local anesthetics and steroids are commonly used for treatment as outlined in the following.

CONTRAINDICATIONS

Contraindications for SNRB include an allergy to contrast (relative since the patient can be premedicated), infection along the intended needle trajectory, uncorrectable coagulopathy, and a contralateral pneumothorax (thoracic block).

TECHNIQUE

SNRB is traditionally performed with fluoroscopic guidance to facilitate accurate needle placement. The basic technique is to position the patient in an appropriate position to allow visualization of the neural foramen en face. Using C-arm fluoroscopy, final adjustments can be made to best view the foramen. After marking the skin entry site and prepping, local anesthetic is used at the needle entry site. Using a "down the barrel" technique, the needle is advanced into the foramen (Fig. 5). The target area within the foramen is a perineural placement of the needle, avoiding puncture of the nerve root itself. The acceptable location of the needle in or adjacent to the foramen will vary slightly, depending on the anatomic level and the need for diagnostic specificity. The ideal needle placement will vary for cervical, thoracic, lumbar, and sacral roots.

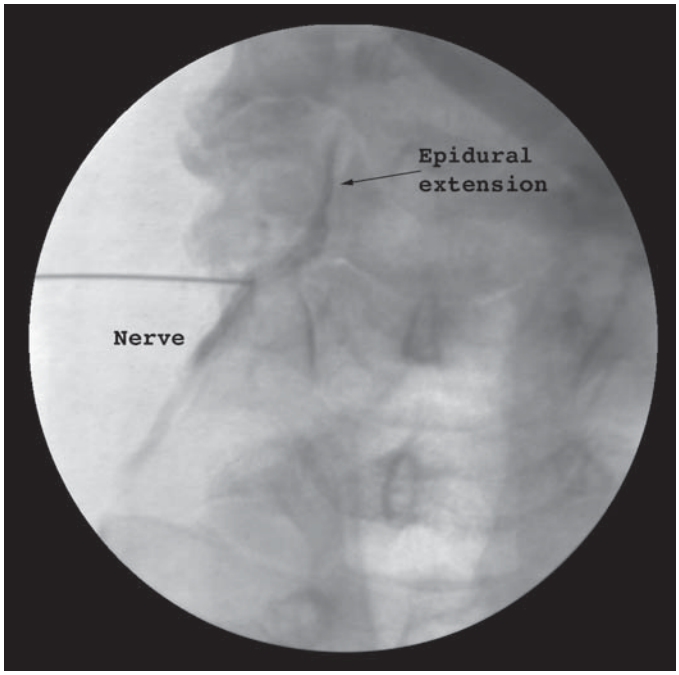

Fig. 6. Prominent spread to the adjacent epidural space during a cervical selective nerve root block.

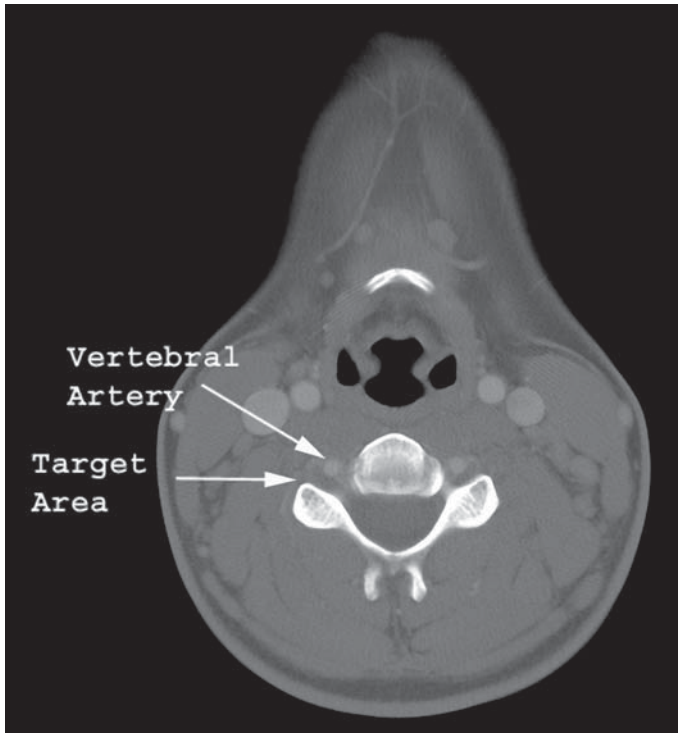

Fig. 7. Axial image of the cervical spine. The vertebral artery lies anterior to the neural foramen. The intervertebral segments of the artery are not protected by the vertebral canal.

As the needle is advanced, its depth is monitored with fluoroscopy in a perpendicular projection or anteroposterior and lateral fluoroscopy. At all levels, a bony landmark can provide a very accurate depth gauge to avoid excessive advancement into the foramen. On entering the neural foramen, care should be exercised to not pierce the nerve root itself. In the lumbar levels, the needle is advanced into the area immediately inferior to the pedicle forming the superior border of the foramen. Because of the downward slope of the exiting nerve root, this target area is less likely to contain the nerve root itself. A small contrast injection (1–2 cc) is made to identify the nerve root *(4)*, and confirm the absence of epidural spread and lack of intravascular flow of contrast (Fig. 6). Corticosteroid and anesthetic solution is then injected around the nerve root sleeve. A typical injected solution would include 80 mg of methylprednisolone (1 cc) (Depo-Medrol, Pharmacia Upjohn), 1 cc of 0.5% lidocaine, and 1 cc of 0.5% bupivacaine. Partial epidural spread of contrast can be seen with a medial position of the needle. If the injection is to have diagnostic value, an epidural injection should be avoided because of the risk of extension to adjacent roots. Most operators will use a 22-gauge needle with a beveled tip, which allows some steering. The needle will tend to track away from the beveled face on the needle tip. This allows for minor adjustments in position as the needle is advanced into the foramen. The 22-/25-gauge blunt-tipped needle (Whitacre Needle, Becton Dickinson & Co.) is also used. The blunt tip may also reduce the risk of piercing the nerve.

SNRB of the cervical segments has unique anatomic considerations. The nerve root has a more horizontal course and a close proximity to the vertebral artery (Fig. 7). Both computed tomography (CT) and fluoroscopic approaches have been described *(2,5,6)*. When fluoroscopy is used, the patient is placed supine on the table with the head turned toward the contralateral shoulder (Fig. 8). Sometimes an angled wedge sponge can be used to elevate the ipsilateral side to better visualize the neural foramen en face without needing steep angulation of the C-arm. After the site is prepped and infiltrated with a short-acting local anesthetic, a 22- or 25-gauge needle is advanced toward the base of the superior articulating facet at approx the 6–7 o'clock position in the neural foramen. This bony landmark can function as a depth gauge for needle placement. The needle can then be redirected slightly anterior into the lateral aspect of the neural foramen adjacent to the base of the superior process. Care should be taken to avoid the anterior aspect of the foramen and to remain in the lateral aspect of the foramen because of the close proximity of the vertebral artery. A contrast injection (1–2 cc) is used to confirm the location of the nerve root, which will be outlined with contrast, and to avoid an intravascular injection.

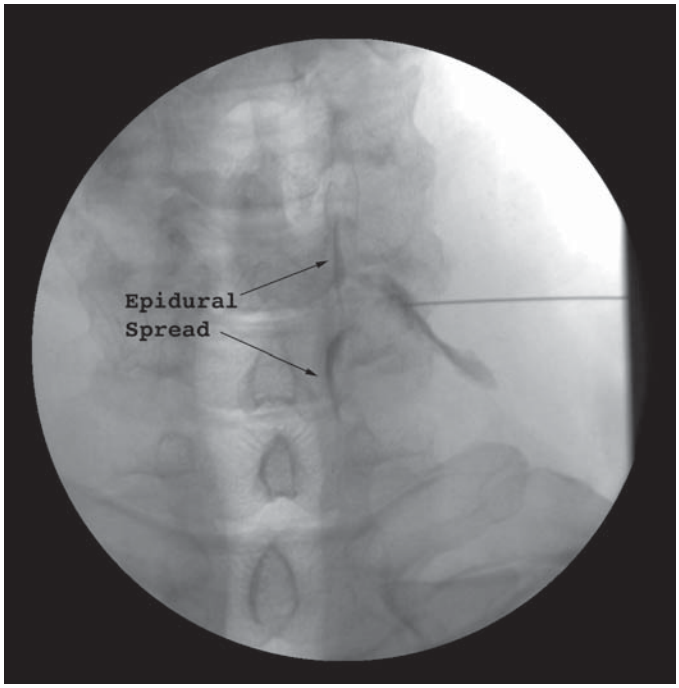

Fig. 8. Cervical SNRB using the fluoroscopic technique. The nerve is outlined by an epineurogram. Note also the epidural extension of contrast in spite of the lateral position of the needle.

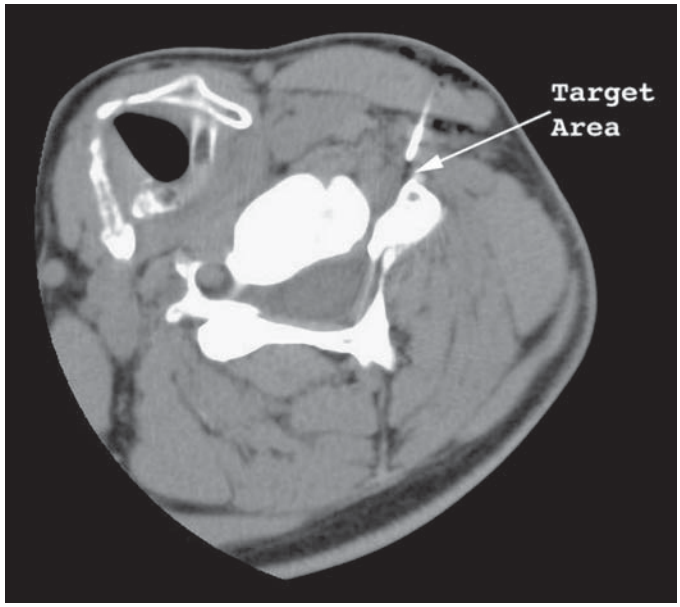

Fig. 9. Cervical SNRB using CT guidance.

Table 1
Structures Innervated by the Nerve Root

Ventral ramus	*Dorsal ramus (medial branch)*	*Sinovertebral nerve*
Intervertebral disc	Facet joint	Posterior longitudinal ligament
Longitudinal ligament	Interspinous ligament	Posterior outer annulus
Anterior dura		Anterior dura

When CT guidance is utilized, the landmarks for needle place-ment will remain the same but must be appreciated in the axial plane (Fig. 9). Although the procedure may be more time consuming, the axial visualization will clearly define the relationship of the vertebral artery to the exiting nerve root. It is important to review magnetic resonance (MR) images of the cervical spine prior to performing a selective nerve root block to avoid puncturing an aberrant or tortuous vertebral artery.

The least common level to block is the thoracic spine. The approach used for the thoracic spine is similar to that for the lumbar spine, but the incident angle used must be reduced to avoid the pleural reflection. The target area is slightly more lateral than in the lumbar spine (Fig. 10). Paravertebral thoracic blocks are described using a palpation technique *(7)*. Fluoro-scopy can be used and is helpful if specific levels are to be blocked. As the nerve exits the neural foramen, it will enter its subcostal location. The target area is inferior to the costovertebral articulation.

The sacral roots also have unique consideration for access. With the patient prone, craniocaudal angulation of the C-arm will usually allow for visualization of the sacral foramen en face (Fig. 11). After identifying the appropriate level, a 22-gauge needle can be advanced to the posterior superior margin of the neural foramen. This provides a depth gauge to the nerve root. The needle can then be advanced slowly into the foramen in close proximity to the nerve root. A contrast injection can identify the foraminal position and most likely also outline the nerve root. The block can then be performed with the usual medications.

COMPLICATIONS

Very few reports of complications are found in the literature. The risk of infection or bleeding appears to be very rare. There is also a risk of allergic reaction to the contrast or medication. Corticosteroids will elevate serum blood sugars in the diabetic patient. Some patients will experience short-term side effects from the steroid including insomnia, an increased appetite, and headache. Pain exacerbation should also be considered a very rare event. The risk of a dural puncture is present, mainly with a puncture into the medial aspect of the foramen or in a patient with dural ectasia. This is most commonly seen on the sacral segments. This could precipitate a spinal headache. The cervical SNRB has the additional risk of puncture of the vertebral artery, which can result in dissection

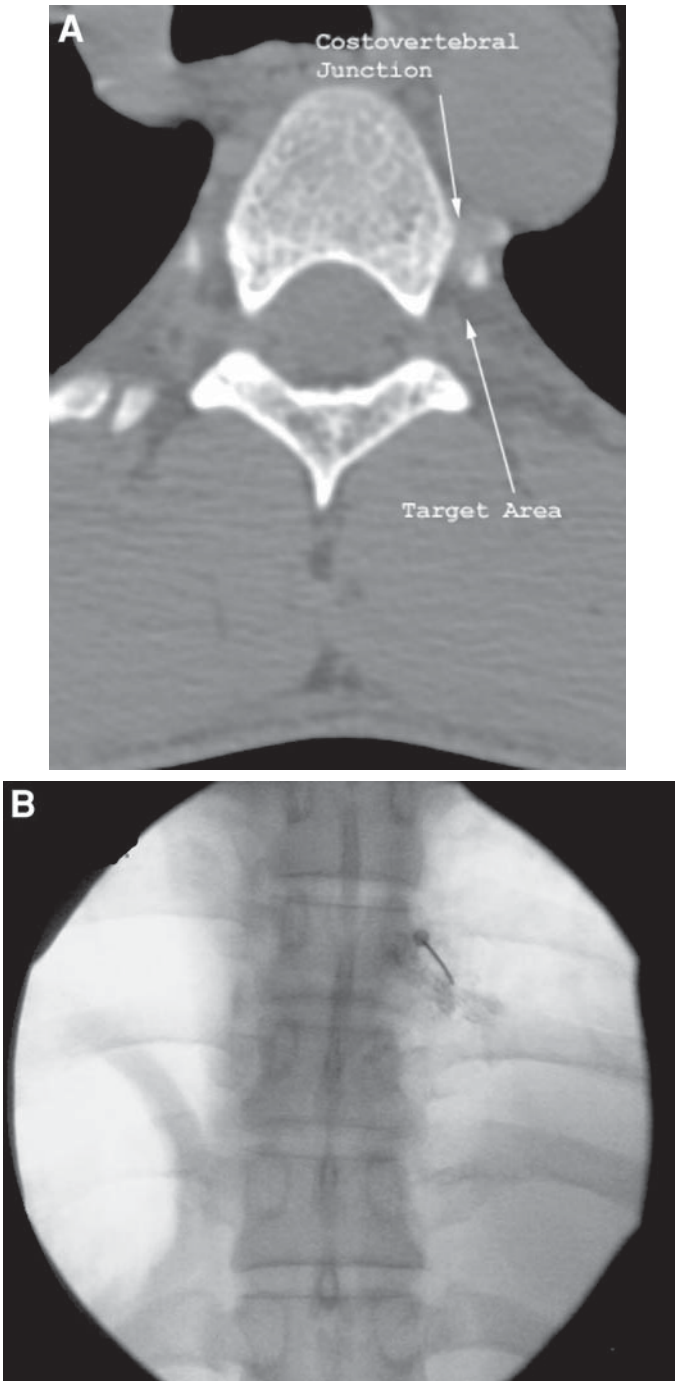

Fig. 10. Thoracic SNRB with a contrast epineurogram. Note the close proximity of the pleural reflection. The costovertebral junction borders the target area anteriorly.

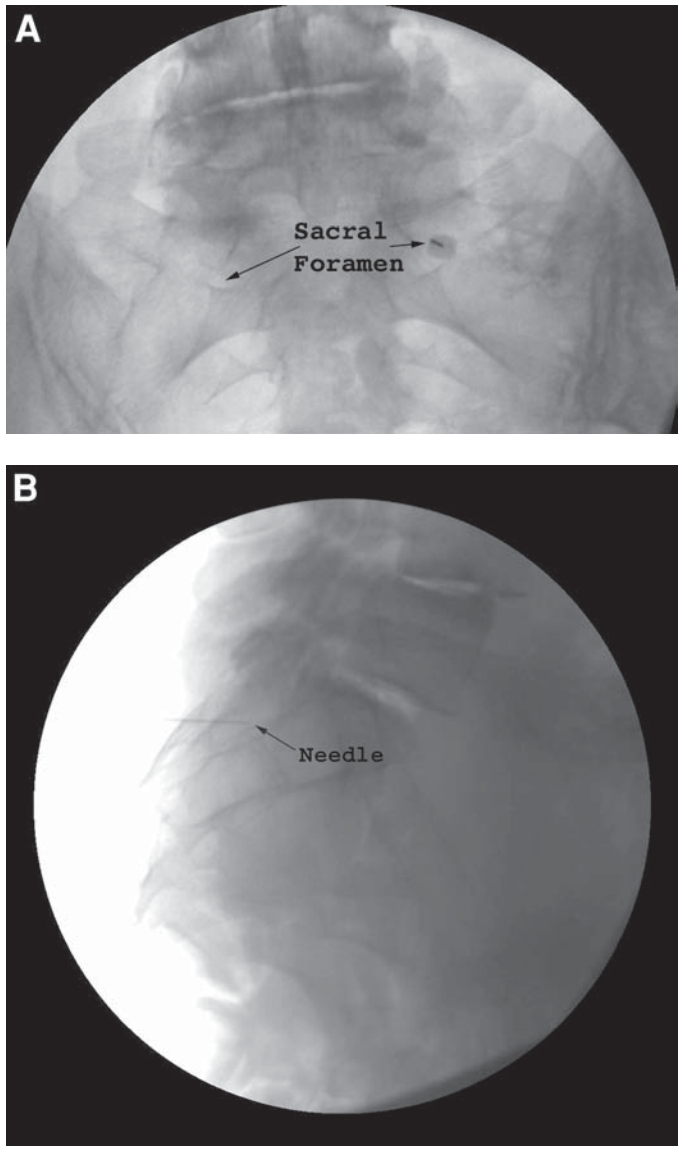

Fig. 11. Sacral SNRB accessing the S1 foramen.

or occlusion. The epidural spread of medication at the cervical level can at least theoretically result in intraspinal medication because of the small risk of epidural to intradural communication. This could result in a risk of temporary spinal anesthesia. This complication is more frequently seen, although also rare, with cervical epidural injections. There is also the devastating risk of inadvertent injection of medications intracranially with an unrecognized vertebral artery puncture. The thoracic nerve block carries the additional risk of pleural puncture and an associated pneumothorax.

RESULTS

As is the case with epidural steroid injections, there is contro-versy concerning the benefit of SNRB. The value is questioned as a diagnostic tool, considering the close proximity of the ventral ramus, the dorsal ramus, and the sinovertebral nerve to the neural foramen. These nerves supply numerous structures that could contribute to the pain complex seen in patients with acute or chronic back pain (Table 1)*(8)*. Care must be taken to block the nerve in a paravertebral position for diagnostic purposes. The frequency of epidural spread with a medial injection will also potentially cloud diagnostic information *(9–11)*. The

difficulties associated with the interpretation of pain response were well studied by Wolff et al. *(12)*. They evaluated the effect of a selective nerve root block, by mapping hypesthesia, on pain elicited from nerve stimulation and pain control. They found overlap of two and sometimes three derma-tomal areas when mapping hypesthesia. Less overlap was present when mapping paresthesias. By creating an adapted dermatomal map based on this overlap and mapping several criteria, there was however good correlation with the segmental level blocked. In spite of these criticisms, there are data to support its role as a diagnostic test. As imaging has improved and demonstrated many patients with multilevel disease with varying degrees of root compression, it has become important to better identify the symptomatic level *(13)*. In addition, studies have shown that pharmacological effects of degenerative disc disease and foraminal stenosis contribute to periradicular inflammation causing pain *(6,14)*. Imaging findings may not correlate accurately with the degree of inflammation present. MRI will often show multilevel disease in a patient with complex pain. The efficacy of SNRB has been studied in this setting *(15)*. Pang et al. used it to infiltrate lumbar roots for diagnostic evaluation of radicular pain to help identify the implicated level *(16)*. They reported on 104 patients. This series looked at patients with obscure or difficult back pain. Forty-four percent were found to have a radicular component to their pain when studied with SNRB *(16,17)*. As a diagnostic tool, SNRB has been studied for its predictive value. Seventy-one patients studied by Derby et al. showed that a positive response to SNRB predicted a positive surgical outcome in patients with chronic symptoms *(11)*. Several other authors also have used the predictive value of the test, offering surgical decompression to patients with a positive short-term and long-term response to the injection of a corticosteroid and a longer acting anesthetic *(18,19)*. The positive predictive value has reported to between 85% and 100% *(9,10,20)*. Only limited literature is available for the negative predictive value, because of the difficulty in correlating negative injection results with negative surgical findings, but it has also been shown to be a valuable tool *(18)*. North et al. also studied the diagnostic value of SNRB prospectively but found little advantage in using SNRB. They concluded that positive blocks were nonspecific, but that a negative block may provide beneficial data. They also concluded that there may be a therapeutic application in spite of the lack of specificity of the block *(19)*. Herron et al. had surgical follow-up in 78 patients out of 215 patients studied with SNRB *(21)*. The test had good positive predictive value in the patients who did not have a previous history of surgery, but the previously operated group had only a 53% correlation with the SNRB findings.

Besides its diagnostic value, SNRB is offered as part of a therapeutic pain management regimen. Many operators have anecdotal cases of significant long-term relief from SNRB, but few prospective studies exist. One author recently found only short-term benefit in a prospective randomized trial, but when stratifying the patients into subgroups found one subgroup that had significant long-term benefit and found the treatment to be cost effective for the management of radicular symptoms *(22,23)*.

Very recently, Narozny et al. studied 30 patients retrospectively with 26 patients reporting significant pain reduction at 2–3 wk and 18 patients (60%) reporting permanent pain reduction *(24)*. Berger et al. looked at 160 patients treated with SNRB and reported that 63.8% of the patients had significant pain reduction *(25)*. Sixty-seven percent of these patients had long-term relief. CT guidance was used in this series. The benefit of CT image guidance in comparison to fluoroscopy has also been examined and at least one author felt it was superior. This same author also found SNRB to be a beneficial long-term therapeutic tool *(26)*. Another series included a control group receiving an intramuscular injection to exclude a systemic effect and also found SNRB to be beneficial *(27)*. One of the few articles that specifically looked at cervical disease showed SNRB to be an effective treatment for cervical radicular pain, although this was a small study, retrospective in design *(28)*. It did have a mean follow up of 21 mo.

CONCLUSION

It is clear that there continues to be controversy concerning selective nerve root block, but it is widely used and many believe that it has diagnostic value in the complex patient and may provide both short-term and long-term benefit. There needs to be continued research in this area, as it will continue to be a commonly used tool in the management of radicular pain.

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9 Epidural Steroid Injections

DENNIS J. GRIFFIN, MD

INTRODUCTION

Back pain is a frequent and costly problem in modern society. In the United States alone, back pain is estimated to cost nearly $100 billion annually in lost productivity and health care resources. It affects at least 2% of the workforce as measured by workman's compensation. The cost of treating this group alone almost tripled from 1977 to 1999, reaching almost $12 billion *(1)*. Low back pain will affect 70–85% of the population, most prevalent in people under the age of 45 *(1)*. This problem has significant impact on the working population, considering the average age of the patient. Conservative management of acute low back pain is still the mainstay of treatment. Most patients will improve with standard conservative management, with 90% recovering within 3 mo *(2)*.

Epidural injection has been used as an adjunct in the management of neck and back pain for almost 100 yr, although it still remains quite controversial. The first reported epidural injection for pain management was in 1901, when there was a report of epidural cocaine administration for the treatment of sciatica, performed by M. A. Sicard in Paris *(3)*. In 1930, Lancet reported the use of epidural anesthetics and saline for the treatment of sciatica *(4)*. The first administration of epidural steroid injection (ESI) was reported in 1952 *(5)*. This was performed through the first sacral foramen. During the 1960s, clinical studies were published debating the clinical value of this treatment *(6–14)*. ESIs have been used in the acute phase to minimize pain and increase mobility *(15–17)*. Numerous articles have argued the benefits of epidural steroids in the treatment of chronic back pain as well *(18–21)*. Although there continues to be an ongoing debate concerning the value of ESI for the treatment of back pain, it remains a commonly used procedure today. One large epidemiological study that looked at almost 26,000 patients in the United States with spinal or radicular pain showed that ESI was recommended in 12.9% of cases of lumbar pain, to 3.7% of patients with cervical pain, and 1.8% of patients with thoracic pain (22). Considering the frequency of these symptoms in the general population, this is a commonly recommended treatment. The majority of patients treated with steroids had symptoms of pain for longer than 7 wk, with a minor percentage of patients in the acute stages being offered steroid therapy (16.4%) *(22)*. The most frequent diagnoses found in the treated population were herniated disc and spinal stenosis and radicular pain, while sprain, strain, instability, and chronic pain syndrome were infrequent diagnoses. The group of patients least offered treatment was patients with symptoms for <4 wk. This correlates well with the natural history of acute back pain.

ANATOMY

The epidural space lies circumferentially around the dural sac and extends from the foramen magnum to the sacrococcygeal membrane at the sacral hiatus (Fig. 1). Its anterior boundary is the posterior longitudinal ligament. Posteriorly, it is limited by the ligamentum flavum, the laminae, and pedicles. It is connected to the paravertebral space through the intervertebral foraminae, which contains the exiting nerve roots. This communication is utilized in the transforaminal epidural approach. The content of the space includes nerve roots as they exit from their intradural course to the neural foramen, lymphatic tissue,

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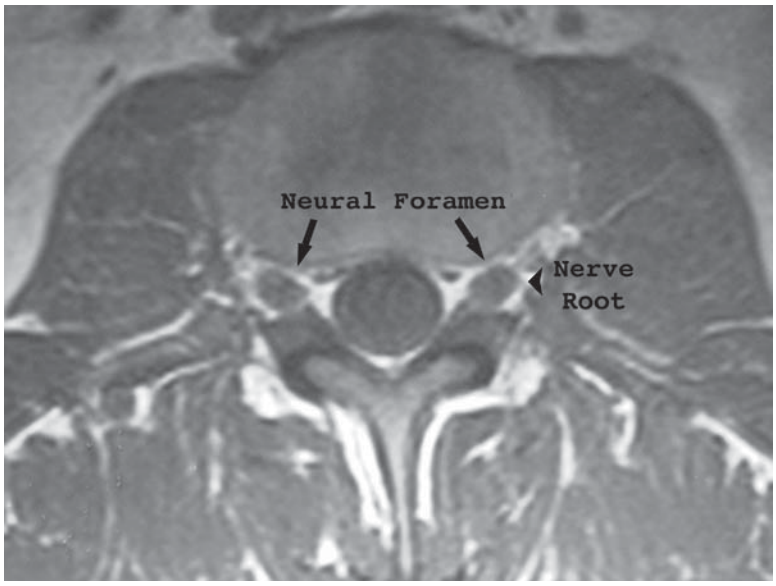

Fig. 1. The transverse anatomy of the lumbar spine.

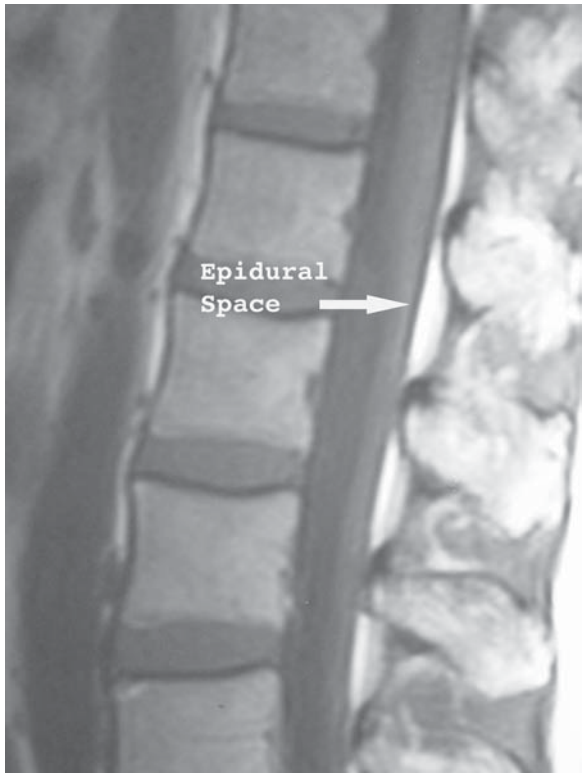

Fig. 2. Sagittal MRI of the epidural space. The epidural space is triangular in shape viewed in this sagittal plane, and most prominent in the sublaminar region.

fatty tissue, loose connective tissue, and arteries and veins. It varies from a potential space up to 5–6 mm, measured in the midlumbar spine, and varies in depth *(23)*. The epidural space is narrowest at the rostrale lamina and widest at the caudal lamina and the adjacent interlaminar space. Reynolds *(23)* described a sawtooth appearance along its posterior margin that accounts for this variation (Fig. 2). The epidural space is circumferential when looked at in cross section. There is a posterior raphe in the midline formed by the dorsal median fold of the dura mater, which may occasionally divide the posterior compartment. This can be seen as a midline lucency during epidurography. In the majority of cases, the space is contiguous, surrounding the spinal cord and cauda equina and dural membranes. The epidural space does increase slightly in depth in the prone position *(24)*. The epidural space has a pressure, which is slightly less than the ambient pressure, explaining the so-called "loss of resistance" technique used for epidural punctures.

INDICATIONS

ESI is commonly used for relief of upper and lower back pain secondary to spinal stenosis, disc herniation with or without radicular pain, and refractory back pain of unknown etiology. ESI may help delay or prevent surgical treatment because many patients receive pain relief that allows them to endure an acute exacerbation of pain. ESI when combined with physical therapy and antiinflammatory medications can provide satisfactory pain relief in patients who are not surgical candidates.

CONTRAINDICATIONS

Absolute contraindications include a bleeding diathesis. Patients who are on anticoagulants should discontinue usage and clotting parameters should be checked prior to the procedure. Aspirin is not an absolute contraindication, however, newer antiplatelet medications such as Plavix should be discontinued. Other absolute contraindications include major hypersensitivity (anesthetic solutions and steroids), local infec-tion at the site of the proposed injection, systemic infection, and contraindication to steroid therapy (active bleeding from gastritis or peptic ulcer disease, resistant diabetes mellitus, severe congestive heart failure, and severe hypertension).

Contrast allergies are a relative contraindication because, with experience, a fluoroscopically guided injection can be performed without contrast with a high degree of accuracy. Gadolinium-based contrast agents are available, but these are not approved for intrathecal usage and are therefore not recommended.

THE TECHNIQUE

The basic technique for accessing the epidural space is the same for access to the cervical, thoracic, or lumbar areas. Atthe same time, there are specific anatomic con-

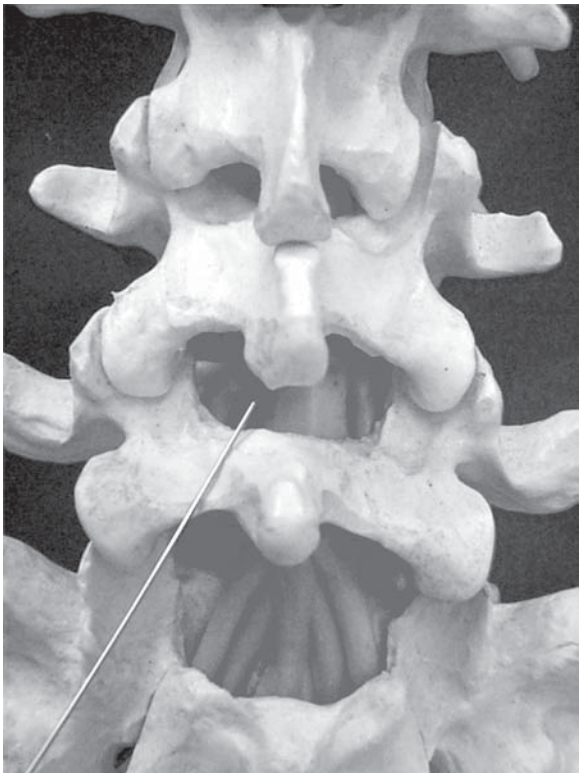

Fig. 3. The needle is directed across the medial aspect of the lamina into the epidural space.

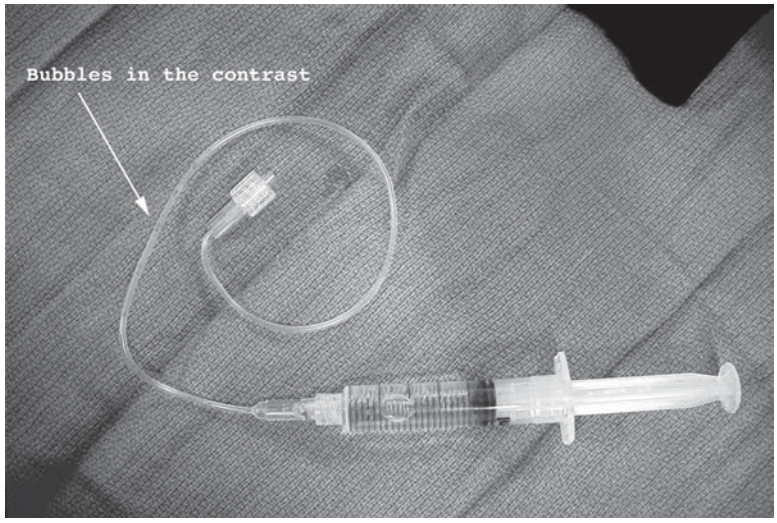

Fig. 5. Contrast syringe with small air bubbles, which allow the recognition of a change in pressure when entering the epidural space. These bubbles will allow the recognition of the pressure change by a sudden limited movement toward the needle.

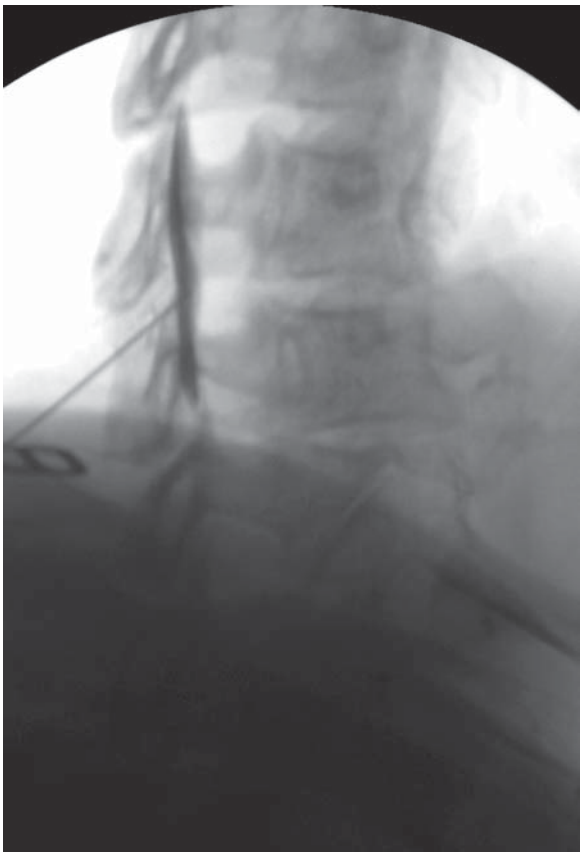

Fig. 4. Note the typical linear spread of contrast in the cervical epidural space.

siderations that are important in each area and are addressed separately. The epidural space is accessed from a posterior or posterolateral approach most frequently. It can also be accessed from the caudal and the transforaminal approach but these methods are specific to the lumbar spine.

Using the posterior or posterolateral approach, the patient is placed in the prone or prone oblique position. The fluoroscopic landmark for this approach is the lamina (Fig. 3). Identifying this structure allows for a sublaminar approach. The midline can be palpated, identifying the posterior spinous process. A needle is then advanced from the paramedian location until the interlaminar ligament is encountered. The needle is then slowly advanced until the epidural space is entered. The epidural space can typically be identified by one of two techniques. Some operators will slowly inject contrast as they advance the needle through the interlaminar ligament and ligamentum flavum, monitoring the advance with fluoroscopy. This is commonly done when accessing the cervical epidural space (Fig. 4). The contrast will spread in a characteristic linear appearance outlining the epidural space. There is usually also a discernible loss of resistance as the needle advances through the ligament into the epidural space. Many will use this loss of resistance technique to find the epidural space and only then confirm the needle location with contrast. To use the loss of resistance, a drop of fluid is placed on the hub of the needle or small bubbles are created in a connector tubing attached to the needle (Fig. 5). The needle is then advanced slowly through the ligament. On encountering the epidural space, the bubbles in the connector tubing will abruptly move forward in the

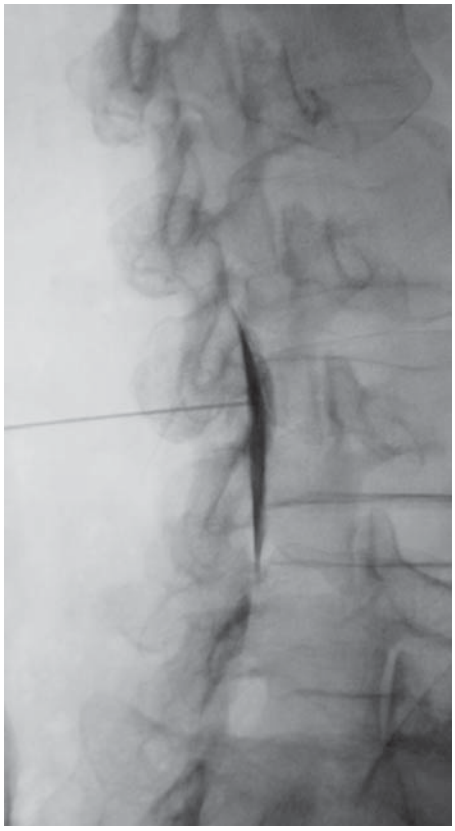

Fig. 6. Lumbar ESI using the sublaminar approach with the typical spread of contrast.

tubing or the drop of saline in the needle hub will be drawn into the needle. This technique can be used blindly or with the aid of fluoroscopy. Studies have shown that fluoroscopic guidance will increase the accuracy of placement by as much as 17–25%, even when an experienced operator is performing the procedure *(25,26)*. The risk of an inadvertent injection has been shown to be even higher with less skilled operators *(27)*. Many will aspirate to confirm that epidural veins have not been punctured, thereby avoiding an intravenous injection of steroids. Following placement of the needle, an epidurogram is often obtained. Many perform a limited contrast injection to simply document the location of the needle tip in the epidural space, identifying any inadvertent subarachnoid or intravenous injections. This is typically performed with 3–6 cc of nonionic contrast, injected under fluoroscopic monitoring, with spot film images often being obtained (Fig. 6). Epidurography is often used to confirm the location of the needle tip, because aspiration alone can be negative with inadvertent placement into an epidural vein *(27)*. Some will perform a diagnostic epidurogram, trying to identify compartmentalization, adhesions, or loculations that would limit the spread of anesthetic and steroid to the intended treatment area. There have also been reports of performing postinjection epidurograms to better identify compartmentalization problems that would limit the effectiveness of the therapeutic injection *(19)*.

The injection of the therapeutic agents can be painful, especially when the injection of the agent is performed rapidly. It is often necessary to inject small aliquots over 1–5 min to avoid or reduce this discomfort. Many centers will require a recovery period of 20–40 min and patients are often asked to have transportation so they are not required to drive after the procedure. This is especially important when local anesthetics are used epidurally in conjunction with the steroid injection. The local anesthetic can occasionally also affect motor fibers, thereby reducing motor function temporarily.

AGENTS

The injected agents reported in the literature include saline, local anesthetics, corticosteroids, and combinations of these agents. The therapeutic solution is often a combination of a local anesthetic and a corticosteroid. The local anesthetic most frequently reported for ESI is preservative-free 1% lidocaine *(8,11,20,21)*. Bupivacaine 0.5–0.75%, a longer acting anesthetic, is also commonly used. The anesthetic used should be preservative free, to avoid inadvertent subarachnoid injection of the preservative (paraaminobenzoic acid). The basis for adding a local anesthetic to the injectant is its ability to reduce the firing frequency of the smaller diameter fibers, which transmit pain impulse *(28)*. This often will provide some short-term relief before the corticosteroid effect can develop. There may be an intrinsic antiinflammatory effect attributable to the local anesthetic as well *(29)*.

The corticosteroid derivatives used most commonly for epidural injections include betamethasone (Celestone Soluspan-Schering-Plough) and methylprednisolone (Depo-Medrol-Pharmacia & Upjohn). For a sublaminar lumbar injection, 2–4 cc of Celestone or 40–80 mg of Depo-Medrol is typically mixed with 3–5 cc of preservative-free 1% xylocaine.

There continues to be a major controversy concerning the safety of the injection of Depo-Medrol either intrathecally or into the epidural space. Depo-Medrol is currently associated with a risk of arachnoiditis. Depo-Medrol contains polyethylene glycol. This agent has been shown to cause meningitis, arachnoiditis, and pachymeningitis when injected intradurally *(30–33)*. The intrathecal use of Depo-Medrol has largely been abandoned because multiple studies have demonstrated concern for its intrathecal use *(34–36)*. The risk from epidural injections is not as well established, and this drug continues to be commonly used for epidural injections. Celestone does

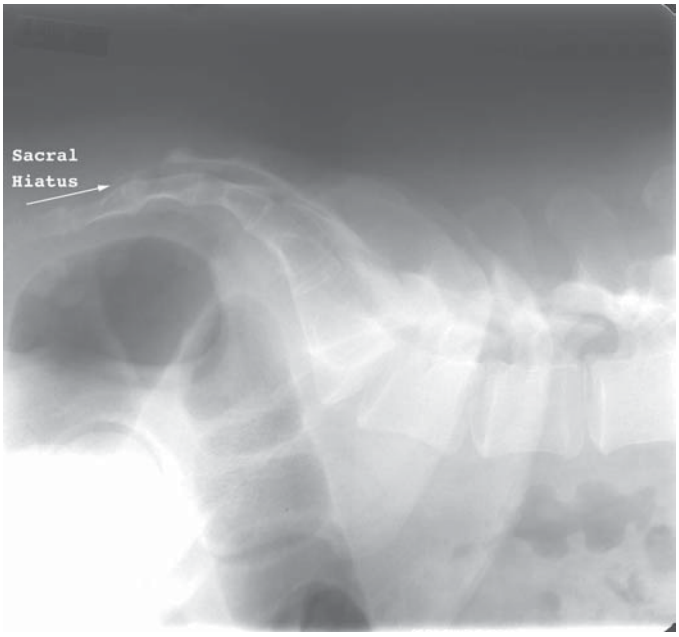

Fig. 7. Lateral radiograph of the sacrum shows the sacral hiatus, which is the access for the caudal technique.

not contain the carrier, polyethylene glycol, and has not been associated with the same controversies.

THE CAUDAL TECHNIQUE

It is not always feasible to perform an ESI using the sublaminar approach. Previous surgery can limit access. Scarring of the epidural space can also limit the flow of medication to the appropriate levels.

Many physicians prefer using the caudal approach as their primary route of delivery. This is a very helpful access in the operated patient and in patients with extensive interlaminar degenerative change, which may make the sublaminar approach more difficult. To use the caudal approach, the patient is placed in the prone position and the sacral hiatus is palpated (Fig. 7). This area is prepped and a fenestrated sterile drape is placed over the field. After the infiltration of local anesthetic, a 22-gauge needle is introduced through the sacral hiatus into the sacral epidural space. This is typically done with the needle almost parallel to the sacrum (Fig. 8). C-arm fluoroscopy can be used to identify the needle tip entering the sacral epidural space through the sacral hiatus, by viewing in the anteroposterior and lateral planes. The needle can be advanced up to S2–S3. Beyond this level, the inadvertent puncture of the thecal sack can occur. Epidurography is performed in a similar fashion, although a larger volume of contrast may be necessary to identify and predict the effective spread of the therapeutic solution. A larger volume of agent is typically required when using the caudal approach, especially when the intended treatment area is above the lumbosacral junction *(21)*. One recent study using nonionic contrast and fluoroscopy showed that an 8-cc volume reached the L4–5 level only 85% of the time when the needle was placed at the S2–3 level *(37)*. Earlier studies have used larger volumes, 20–40 cc, when treating patients from the caudal approach *(4,8,11,12,14)*.

THE CERVICAL ESI

The cervical epidural space is more variable in size. The most consistent finding is a relatively prominent epidural space at the C7–T1 level. On sagittal magnetic resonance imaging (MRI) T1 sequencing, the epidural space is often identified by the bright signal in the epidural fat (Fig. 9). The C6–7 space is more variable and above this level the space is most frequently smaller or only a potential space. Because of this anatomic finding, ESIs are safest when performed at the C7–T1 interlaminar space. As with the lumbar approach, the superior aspect of the lamina is an important landmark, which can be seen fluoroscopically and palpated with the needle. This landmark is more important in the cervical approach because of the close proximity of the spinal cord to the epidural space in the cervical region. As the needle is advanced from its posterior parasagittal approach toward the lamina just off midline, the superior margin is encountered and is clearly palpable. The needle is then redirected toward the midline and slightly superior to enter the epidural space. The bony margin provides an important measure of the required depth for entering the epidural space. The interlaminar ligament is often felt as well. Once the needle tip is at the laminar ridge, perpendicular fluoroscopy or steep contralateral oblique fluoroscopy is used with contrast injections to monitor the advance of the needle into the epidural space. The operator will often encounter the typical loss of resistance and see the characteristic spread of contrast as the space is entered. The loss of resistance is not as prominent in the cervical region as that of the lumbar epidural space.

Typically a 2- to 4-cc volume of steroid solution will be injected. It is generally recommended that local anesthetics not be used in the cervical injections because of the risk of subarachnoid absorption and cervical anesthesia. Although rarely reported, the author knows of cases of temporary respiratory compromise when these agents have been utilized. As can be seen with the contrast epidurogram, there will be substantial cephalad flow of the injected agents, thereby allowing treatment of the affected levels. It is important to always review correlative imaging studies prior to cervical epidural injection to guarantee adequate space at the intended injection level.

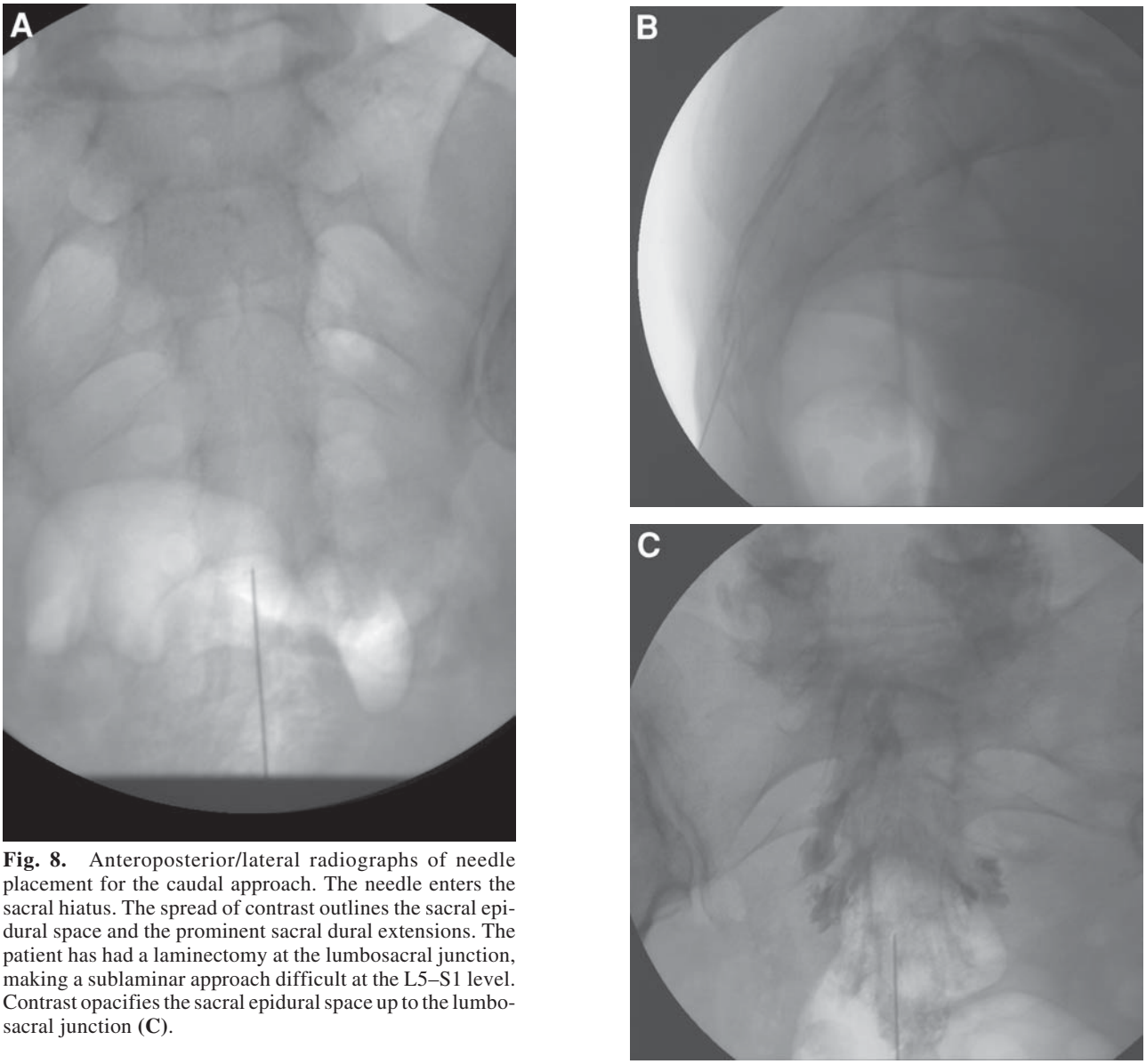

Fig. 8. Anteroposterior/lateral radiographs of needle placement for the caudal approach. The needle enters the sacral hiatus. The spread of contrast outlines the sacral epidural space and the prominent sacral dural extensions. The patient has had a laminectomy at the lumbosacral junction, making a sublaminar approach difficult at the L5–S1 level. Contrast opacifies the sacral epidural space up to the lumbosacral junction **(C)**.

MRI of the cervical spine is generally the most useful for this pretreatment evaluation.

TRANSFORAMINAL ESI

The transforaminal approach to the epidural space is very similar to the approach used for selective nerve root blocks. With the patient in the prone or prone oblique position, fluoro-scopy is used to identify the appropriate neural foramen. Using C-arm equipment, the fluoroscope can be angled to "open" the neural foramen. This usually requires 30–40° ipsilateral angulation. The needle is then advanced through the neural foramen immediately inferior to the pedicle (Fig. 10). The epidural space can be encountered at the medial margin of the pedicle as seen on the anterior–posterior plane. Contrast epidurogram can be obtained to confirm the epidural location, the lack of subarachnoid puncture, and to document that there is adequate epidural spread for the intended treatment area. If the needle is not in the epidural space, one can see a perineural injection, with the contrast outlining the exiting nerve root sleeve. This sleeve will many times communicate with the epidural space, so it is possible to see both the exiting nerve root and the epidural space. Mixtures similar to those used in the interlaminar technique are used for the transforaminal approach, typically 40–80 mg of Depo-Medrol or 2–3 cc of Celestone with 3–5 cc of local anesthetic. The transforaminal approach is most frequently used in treating radicular pain, especially in patients with previous back surgery and thereby limited access to the epidural space using the easier sublaminar approach.

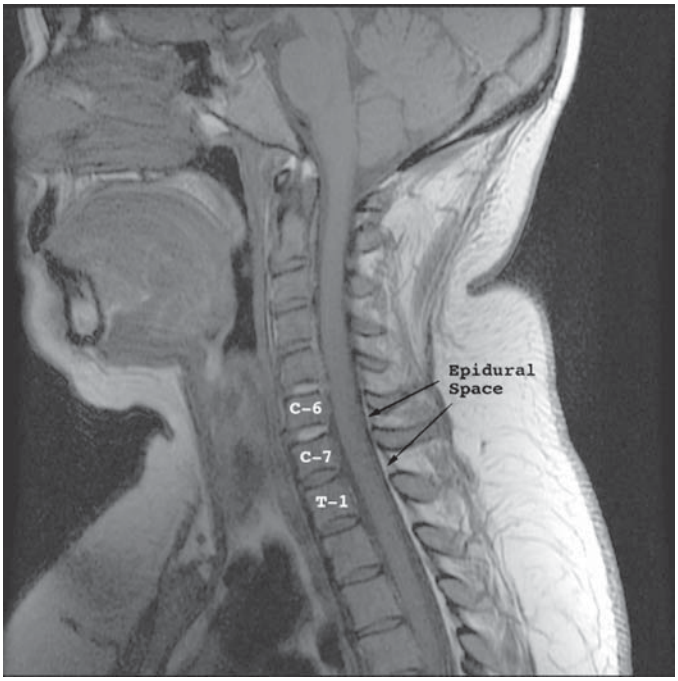

Fig. 9. This sagittal MRI of the cervical spine shows the more prominent epidural space at the C6–7 and C7–T1 interspaces.

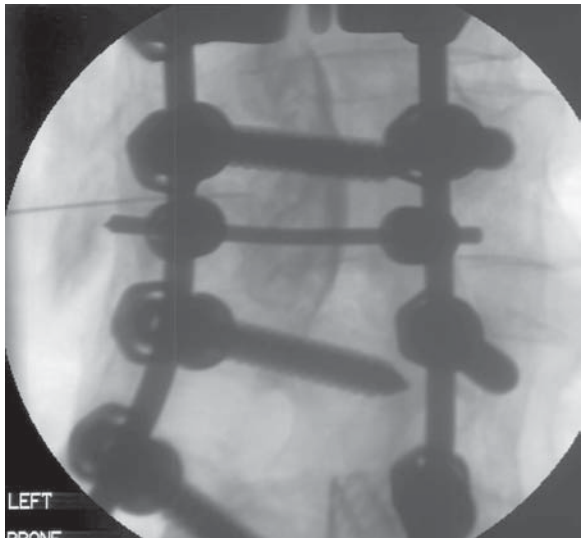

Fig. 10. Transforaminal ESI in a postoperative patient.

COMPLICATIONS

The problems seen with epidural injections can be divided into two categories: true complications and side effects. The side effects are related to the medications used while the complications are related to the procedure itself.

The side effects of intrathecal steroids have already been addressed. When injected into the epidural space, corticosteroids can and do cause systemic effects, although these are generally much less prominent than those seen when systemic treatment with steroids is used. There is a depression of the hypothalamic–pituitary–adrenal access with ESIs. There is depression of plasma cortisol levels up to 3 wk after an epidural administration of the commonly used doses of steroids *(38)*. Insomnia, anxiety, fluid retention, and headache have all been recorded as complaints by patients following epidural steroid injections, but these are limited in time and severity in almost all cases. Diabetic patients can experience a transient elevation of their blood sugar although this has been rarely reported *(39)*.

Complications seen with ESIs include: dural puncture with resulting spinal headache, epidural hematoma, infection, epidural abscess, worsening of pain, nerve injury, intravascular injection of medication, allergic reaction to medications or contrast medium, and vasovagal reactions during the initial needle placement and intradural or intramedullary injection of medications *(39,40)*.

The overall complication rate is below 1% in experienced hands *(41)*, but will be higher for the inexperienced operator *(11)*. There are numerous studies that have reported no major complications from ESIs *(17,40,42–44)*. The incidence of inadvertent dural puncture has been reported at 2.5% when using the sublaminar approach in the lumbar region and is the most commonly reported complication *(45)*. It has also been reported when performing cervical sublaminar injections *(46)*. The risk of dural puncture has been reported to be less when using the caudal technique *(47)*. Major complications have rarely been reported with the caudal technique. The transforaminal route of delivery also has a reported risk of dural puncture, which is lower than the rate reported for the sublaminar approach *(39)*. No major complications have been reported with this technique. The complications specifically related to cervical or thoracic epidural injections have not been studied as extensively. In one series, the leading complication was minor and self-limited. This complaint of a stiff neck was reported in 13% of the patients *(46)*. Dural puncture has also been reported and in isolated cases required treatment with a blood patch *(46,48)*. Injury to the spinal cord or an inadvertent injection into the cord has been rarely reported *(49)*. Meticulous attention to needle placement, adequate fluoroscopy, and careful choice of the puncture site will all help to avoid this serious complication. This reinforces the importance of reviewing the preprocedure imaging for areas of significant spinal stenosis when choosing the site of the injection.

Table 1
Results of Epidural Steroid Trials

Year	*Author*	*Study design*	*No. of patients*	*Patients improved*	*Comments*
1969	Sayle-Creer and Swerdlow *(8)*		320	87%	
1970	Burn and Langdon *(11)*		138	92 (66%)	
1970	Cho *(10)*		7	5	All postop laminectomy
1971	Beliveau *(12)*		24	Improved with Depo-Medrol	Caudal
1973	Dilke et al. *(53)*		35	21 (61%)	Statistically significant improvement
1977	Snoek et al. *(54)*	R	51	No difference in treatment groups	
1984	Klenerman et al. *(42)*	R		No difference	Four treatment groups
1991	Bush and Hillier *(16)*	DB, R	23	Improvement @ 4 wk Slight improvement @12 mo	Statistically significant improvement in treated group
1999	Buchner et al. *(15)*	DB, R	36	Improved @ 2 wk No difference @ 6 mo	Statistically significant improvement @ 2 wk
2001	Papagelopoulos *(18)*		50	80%	

R, Randomized; DB, double blind.

RESULTS

The literature of ESIs over the last 30–40 yr is controversial. There have been studies that have shown both short-term and long-term benefit to statistically significant groups of patients as well as studies that have shown little if any benefit (Table 1). In the early 1970s, Burns reported a series *(11)*. He reviewed the results of the first 138 patients treated in the first year. Sixty-six percent of patients were "cured" or improved at a 6-mo evaluation. The patients who responded best had short-term symptoms (<1 yr). He later reviewed 1000 patients treated over 5 yr for lumbar disc derangement. At 6 mo, 65% had complete or near complete relief and approx 10% had partial relief *(14)*. More recent, Papagelopoulos et al. studied 50 patients with disc herniation or spinal stenosis (18). Ninety percent of patients obtained early relief of symptoms within 1 wk and only 12% eventually required surgery. There have been very few controlled double-blind randomized studies and many studies have been flawed in design owing to the difficulties of performing investigations in this patient population in many clinical settings. In 1995, Watts et al. published a meta-analysis of 11 trials that encompassed 907 patients *(45)*. They demonstrated that the odds ratio was significantly improved in both the short-term and the long-term management of pain when epidural steroids were utilized as part of the treatment regimen. Another review of the literature by Benzon revealed success rates up to 75% with four out of five studies reporting positive treatment results in a majority of patients (60–75%) *(38)*. Most patients who will respond to epidural steroids will begin to experience a reduction in symptoms within 6 d following the injection *(17)*.

Many of these studies are using ESIs in conjunction with other conservative measures such as bed rest, analgesics, and muscle relaxants acutely, and physical therapy, water therapy, and education for more chronic injuries. Several studies have shown epidural injections to be more effective in the early stages of radicular pain. This treatment should be used in addition to the less invasive measures for treating radicular pain and not used as a stand-alone therapy. The difficulty in determining the efficacy of ESIs is best demonstrated in the study of two major systematic reviews, which pooled the literature and attempted to define the benefits of this treatment *(45,50)*. Watts and Silagy published a meta-analysis of the ESI literature in 1999 *(45)*. Koes et al. reviewed similar literature at the same time *(50)*. Both performed a meta-analysis of the literature. Their conclusions were disconcordant. Watts and Silagy found that ESIs were beneficial and Koes et al. concluded that the efficacy could not be substantiated by the literature. The two sets of authors had nine major studies in common in their reviews. A recent analysis of these reviews attempts to explain the discordance and reveals the difficulties associated with reviews and studies of this treatment *(51)*. Another difficulty found

in evaluating this literature became evident when a large-scale randomized trial was prematurely terminated after 6 mo for lack of patient enrollment *(52)*. These trials are difficult to design. It has been difficult to enroll patients and many studies falter in methodology and referral physician participation. The role of ESI in the treatment of radicular and nonradicular back pain will continue to be scrutinized. Those of us involved in the treatment of back pain should continue to strive for studies to define efficacy and better identify the patient subgroups who might benefit from spinal injections.

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10 Facet Joint Injections

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INTRODUCTION

The facet joints, as true synovial joints, were first postulated as an etiology of low back pain and sciatica more than 90 yr ago *(1–3)*. It was not until 1933, however, that the facet joints themselves were reported to be the source of the back pain, at which time the term "facet syndrome" was coined by Ghormley *(4)*. More recent studies have provided physiologic evidence that the facet joints do indeed cause back pain as well as referred pain to the buttocks and lower extremity in the lumbar region and the head and shoulder girdle in the cervical region *(5–7)*. Back pain presumed caused by facet syndrome has been attributed to distension and inflammation of the synovial capsule, resulting in stimulation of nociceptive nerve fibers *(6)*. Nerve root compression in the neural foramen or in the spinal canal may be caused by expansion of the synovial recesses *(6,8)*. Many studies have now described the successful relief of back pain after facet joint blocks *(9–12)*.

The lumbar facet joints act biomechanically to withstand both axial compressive and shearing stresses *(13)*. Disease states that cause degeneration of the intervertebral disc space with concomitant narrowing cause further increased axial loading and shear stresses on the joint *(14–16)*. As the facet joints at all spinal levels are continuous with the posterior border of the adjacent neural foramen, facet joint degenerative changes frequently can be associated with neural foraminal narrowing and concomitant radiculopathy. Trauma, inflammation, infection, degeneration, arthritis, synovial impingement, meniscoid entrapment, segmental instability, and chondromalacia are purported etiologies of facet pain *(17,18)*. Extension and rotation injuries can cause sudden and acute facet joint derangement.

ANATOMY

Zygapophyseal (apophyseal) or facet joints are found paired throughout the spine between the third cervical level and the first sacral level. Facet joints are diarthrodial synovial joints between the posterior elements of the spine with articular surfaces lined by hyaline cartilage, with marked variability in the size, shape, and position of the joint capsule *(19,20)*.

The facet joint is comprised of the superior articular facet originating from the caudad vertebral body and inferior articular facet from the craniad vertebral body. In the lumbar spine the superior articular facets are directed anterolaterally, with the inferior articular facets facing posteromedially. The orientation of these structures is further such that the anterior portions of the joint are directed closer to the midline than the posterior portions (Figs. 1 and 2). This allows for flexion and extension, with minimal opportunity for rotation. In the cervical spine, the facet joints are oriented in an oblique axial plane, allowing for maximal flexion and extension and rotation, with lesser opportunity for lateral flexion. In the thoracic spine, flexion, extension, and lateral flexion are much more available than rotation secondary to the oblique coronal orientation of the facet joints *(19,21,22)*.

The source of innervation of the facet joints of the spine includes the median branch of the dorsal ramus from the level of the joint as well as from the level above. In addition to this bisegmental innervation, autonomic nerves have been reported to exist in the joint as well, reportedly contributing to back pain *(23,24)*.

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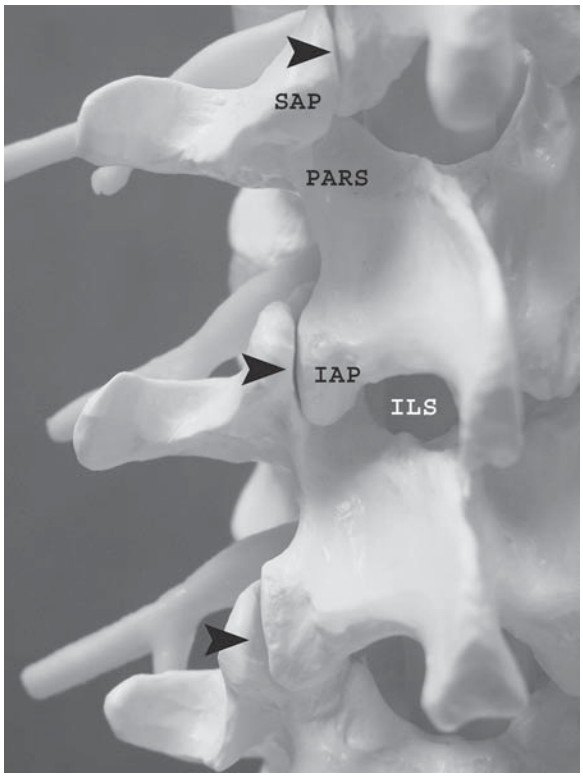


Fig. 1. Model showing the relationship of the facet joints in the lumbar spine. Notice how the orientation of the facet joints (*arrowheads*) changes as you move down the lumbar spine. A facet block at L4–5 would be at a steeper oblique than the facet joint above. SAP, superior articular process; IAP, inferior articular process; PARS, pars interarticularis; ILS, interlaminar space.

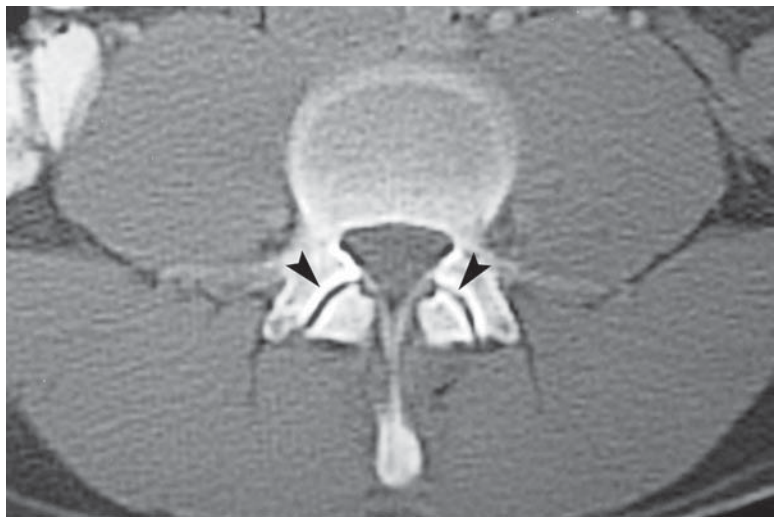


Fig. 2. Axial CT image using bone window algorithm revealing normal appearing facet joints at the L4 level in an asymptomatic volunteer (*arrowheads*).

CLINICAL FEATURES

As degenerative changes of facet joints are commonly found on plain radiographs, computed tomography (CT) examination, magnetic resonance imaging (MRI) examination, and even nuclear medicine skeletal examinations in otherwise asymptomatic patients, careful and insightful patient selection is necessary when considering facet joint injection therapy. Facet joint asymmetry, joint space narrowing, subchondral sclerosis, erosions, and facet hypertrophy have all been found in patients with facet syndrome, but are not pathognomonic *(9,25,26)* (Figs. 3 and 4). For patients with back pain, evaluation for other etiologies must be made prior to consideration of the facet joints. Such considerations must include the frequently encountered etiologies of pain including herniated nucleus pulposus, spinal stenosis, and arachnoiditis. Persistent back pain following a successful stable spine fusion suggests that the facet joint might be the etiology of the pain *(27)*. Thus, for patients presenting with a deep, dull, aching pain in the back, possibly with referred pain into the buttocks, posterior or anterior thigh, leg, head, or shoulder girdle, the suspicion that the facet joint is the etiology requires confirmation by complete symptomatic relief following successful anesthesia of one or more facet joints.

Lumbar facet joint pain can present as an acute or a chronic chief complaint. It can be secondary to degenerative disease of the joint or may present secondary to an acute traumatic event, such as a motor vehicle or skiing accident *(28,29)*. The appearance of the joint by radiography does not correlate with the joint's relationship as the pain generator. Chronic disc degeneration can result in disturbances of the facet joints including loss of height, hypertrophic bone formation, synovial changes, and thickening and contraction, leading to facet joint pain generation *(30)*.

The diagnosis of facet joint pain frequently can be made on the basis of history and examination of the affected joint. Back pain caused by facet joint disease frequently presents or is aggravated by various motions or postures including those during stretching, bending (hyperextension and lateral flexion), rotary motion, or sitting in the erect position for a period of time. Pain may present in the lower back, thighs, buttocks, knee, and lower extremities, aggravated with straight-leg raising *(11)*. Focal tenderness when palpating over the afflicted joint may be found on directed physical examination. In patients whose pain is from the facet joint alone, the neurological exam-ination could be expected to be otherwise normal.

A patient presenting with a chief complaint of pain overlying a cervical facet joint must be suspected of having the underlying joint as the pain generator *(31)*. Neck pain, shoulder girdle pain, ear pain, and headaches have

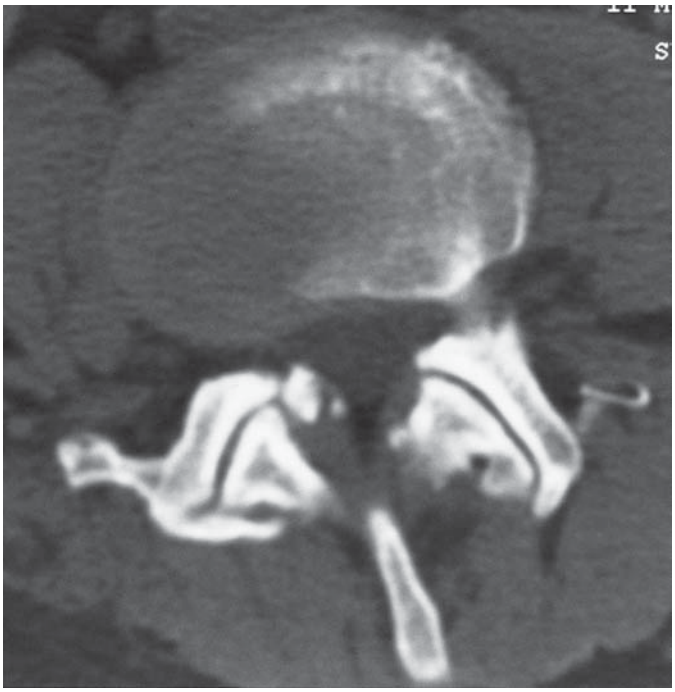


Fig. 3. Axial CT image using bone window algorithm demonstrating degenerative hypertrophic facet joint changes at the L4 level in a symptomatic patient.

all been described in affected patients *(32)*. Reproduction of pain can be realized with extension and rotation *(33)*.

INDICATIONS

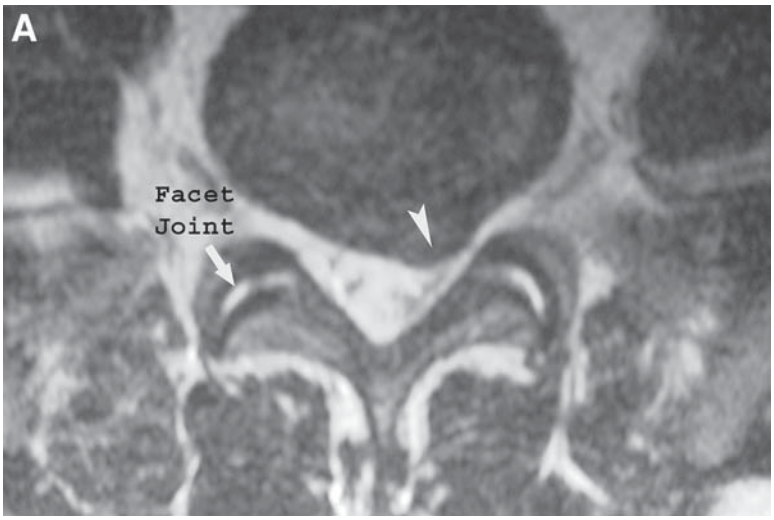
The indications for performing a facet joint injection are twofold, diagnostic and therapeutic. Intraarticular injection of a local anesthetic can provide diagnostic information regarding the source of the patient's pain. If the patient has symptomatic relief with injection then it can be postulated that the facet joint was the pain generator. It follows that if the patient does not have symptomatic relief, then the facet joint was not the pain source.

Concomitant injection of steroids can reduce inflammation in the joint, neural innervation, and paraspinal muscle attachment sites. This can potentially provide the patient with symptomatic relief of a variable duration.

Diagnostic facet blocks can also lead to ablative procedures such as cryoablation and radiofrequency, providing the patient with longer term denervation and pain relief.

CONTRAINDICATIONS

Absolute contraindications include major hypersensitivity (anesthetic solutions and steroids), local infection at the site of the proposed injection, systemic infection, coagulopathy, and contraindication to steroid therapy (active bleeding from gastritis or peptic ulcer disease, resistant diabetes mellitus, severe congestive heart failure, and severe hypertension). Relative contraindications include an allergy to iodinated contrast agents (procedure can be performed without contrast).



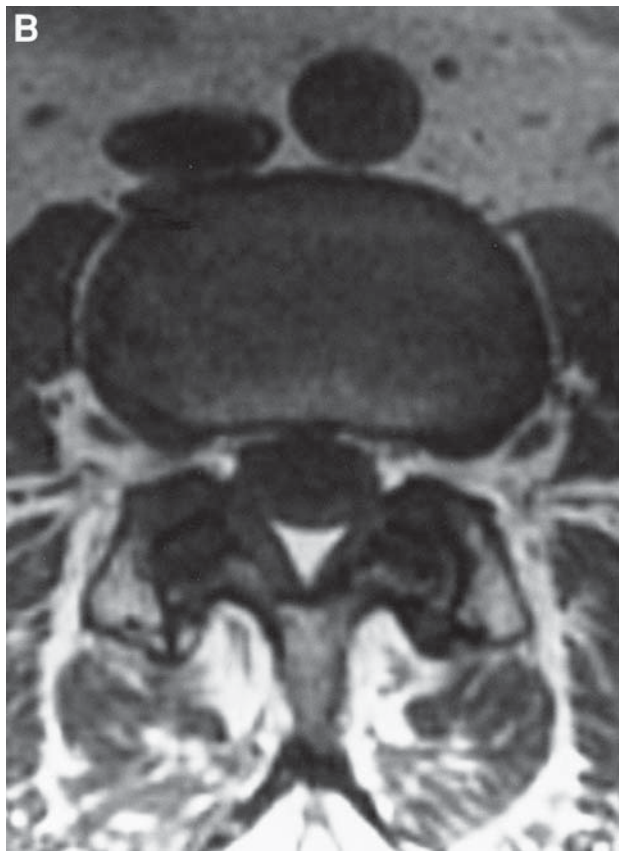


Fig. 4. **(A)** Axial T2-weighted MR image demonstrating normal appearing facet joints. Notice the high signal intensity from the synovial fluid in the joint. (Note the disc herniation [*arrowhead*]). **(B)** Axial T1-weighted MR image demonstrating degenerative hypertrophic facet joint changes at the L4 level in a symptomatic patient.

TECHNIQUE

It is important, among other items, to inquire as to the allergy history of the patient, prior to proceeding with any invasive injection of the facet joint. Specifically, providone iodine based skin preparation agents, iodine-based arthrography contrast agents, local anesthetic agents, steroids, and agents used for preserving various pharmaceuticals may all be present for utilization during portions of this procedure. Specific investigation as to whether there is a history of latex allergy should be made, as some arthrogram kits come complete with latex gloves or other latex-containing devices, such as syringes, included. Many liquid pharmaceuticals are secured in the bottle by rubber-containing stoppers, which must be removed and not transversed with the injection needle for such patients, for example. Alternatives exist for most of these agents, and utilization of substances to which the patient may be allergic is contraindicated, especially because they can lead to such life-threatening reactions as anaphylaxis in certain individuals.

Facet joint injection can be performed safely in the outpatient setting. No premedication is otherwise indicated in the absence of allergy to the materials being utilized. Few side effects are reported from the local injection of anesthetics or steroids *(34)*. Steroid injections can produce local reactions, lasting 24–48 h, and can frequently be relieved by applying an ice pack. Septic arthritis, a potential major complication, can be avoided with strict adherence to aseptic technique. As degenerative disease of the facet joints usually affects multiple levels, multilevel injections are frequently provided bilaterally.

Facet joint injection is performed under the radiologic guidance of fluoroscopy. The patient is placed in the prone position on the fluoroscopy table. For lumbar facet joint injections, a pillow can be placed under the patient's abdomen, so as to achieve a more flexed spine. To best view the facet joint in the tangential plane, the patient, or, where possible, the image intensifier is rotated obliquely until the facet joint of interest is centered in the field of view and the joint space visualized. To minimize irradiation to the physician's hands and other anatomy, a metallic localization probe can be used as a pointing device, and, under fluoroscopy, the desired location for needle placement can be found on the patient's skin, thereafter being marked with an indelible skin marking pen.

The skin under and around the marked site is prepared and draped in standard, sterile fashion, utilizing a providone iodine based skin prep when possible and an isopropyl alcohol based prep for patients with an iodine allergy. At least three sterile washes are made on and about the area to be injected and instrumented. Following air drying of the skin preparation agent, the sterile drapes are placed into position. Using a small (3- or 5-cc) syringe and a small 25-gauge injection needle, a skin wheal is made using 1% or 2% lidocaine, through which slightly deeper anesthesia may be given, depending on the body habitus of the patient. The 25-gauge needle is left in place in the skin, to confirm the desirability of the chosen site of injection.

The 25-gauge anesthetizing needle is replaced with a 20- or 22-gauge spinal needle. As the facet joints are curved, the joint can be divided visually into an anteromedial and a posterolateral half. Because the needle must transverse the posterolateral aspect of the joint, a shallow obliquity to the needle is best. The obliquity necessary for successfully intubating the facet joint varies by level, for example, being as little as 30° for an upper lumbar level joint, while as great as 60° for a lower lumbar level joint. The needle is advance under fluoroscopic guidance until the tip hits bone or cartilage, and is then repositioned until it slips into the center of the joint space (Figs. 5 and 6). The needle tip placement can be checked further by lateral (orthogonal) fluoroscopy. In cases in which the aforementioned technique is unsuccessful, or where the facet joint is difficult to appreciate fluoroscopically, or where severe osteoarthritis blocks the needle from entering the joint space, the needle can be directed toward the inferior recess of the facet joint, a synovial outpouching that projects inferior to the tip of the inferior articular facet *(35)*. The adequate position of the needle tip can be confirmed with an injection of a minimal amount (0.1 cc) of nonionic contrast (180 mg/dl of iohexol [Omnipaque]; Nycomed, Princeton, NJ), as the capacity of the synovial joint may be only 1–2 cc *(36)*. An attempt to aspirate the contrast following arthrogram should be made prior to any pharmacotherapy.

Pharmaceutical therapy of the facet joint routinely involves the utilization of both an anesthetic agent and a steroid agent. Both agents are generally drawn into a single syringe for simultaneous intraarticular injection. Just such a steroid–anesthetic mixture might include 0.5 cc of methylprednisolone acetate (Depo-Medrol) with 2 cc of 0.25% bupivacane hydrocloride (Marcaine) for each separate joint injected. With the joint space so small, injection is terminated when resistance to further injection is encountered, to avoid capsular rupture.

Various local anesthetic agents that have been utilized for joint space injection include 5–25 mg of Xylocaine (lidocaine), 10–50 mg of Carbocaine (mepivacaine), 2.5–12.5 mg of Sen-sorcane (bupivacaine), and 2.5–12.5 mg of Marcaine (bupivi-caine). Various long-acting steroid agents that have been utilized for joint space injection include 1.5–3 mg of Celestone suspension (betamethasone sodium phosphate and beta-methasone sodium acetate), 2–6 mg of an Aristospan suspension (triamcinolone

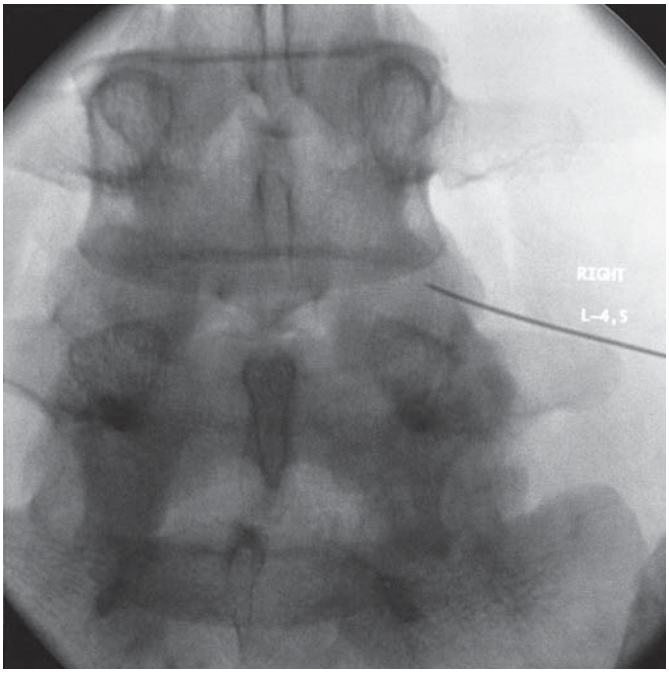


Fig. 5. A supine, posteroanterior fluoroscopic radiograph of the correct prearthrographic positioning of the 22-gauge spinal needle in the right L4–5 facet joint.

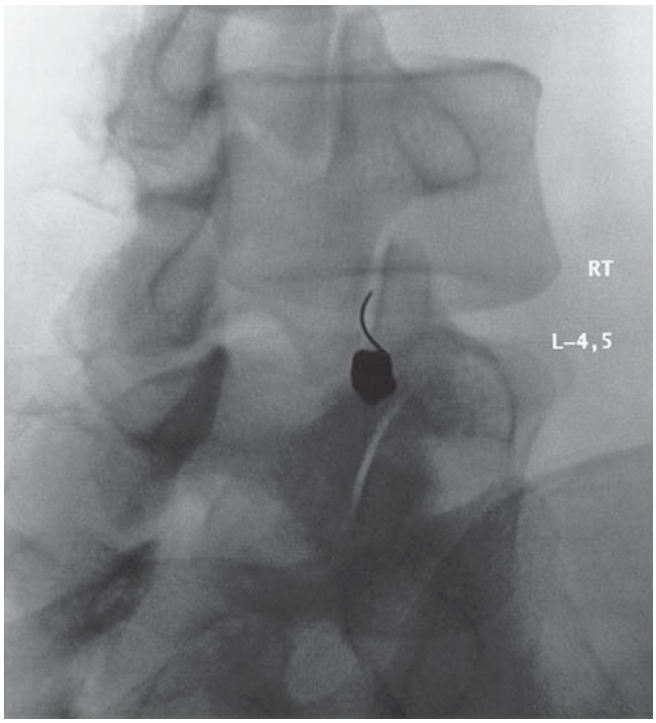


Fig. 6. An oblique, posteroanterior fluoroscopic radiograph of the correct prearthrographic positioning of the 22-gauge spinal needle in the right L4–5 facet joint, in the same patient as in Fig. 5.

hexacetonide), and 4–10 mg of Hydeltranol (prednisolone tebutate). Care must be taken to ensure combinations of agents are combatable to be admixed to avoid such potential incompatibilities leading to precipitation or flocculation *(19)*.

For cervical facet joint blocks, the skin puncture point is selected two to three segments below the target level, as the joint space slopes posteroinferiorly. The needle is then advanced craniad and ventrally toward the target joint. As the needle tip articulates with the inferior margin of the joint, it can be passed into the middle of the joint space, as confirmed on posteroanterior and lateral imaging. It is important to remember that the epidural space rests just medially to the anatomy under investigation, with spinal nerves and vertebral arteries also in close proximity.

If CT-guided injection is being utilized, the patient is placed on the CT table in a prone position. Contiguous axial views can be obtained through the facet joint. Under CT, the proposed site of skin puncture can be marked utilizing an opaque or metallic marker, such as a paper clip. Once a proposed site is chosen, the skin can be marked with an indelible marker and thereafter prepped and draped in a similar fashion as described in the preceding. A procedure and instruments similar to those described in the preceding for fluoroscopic guidance can be used with CT as the guidance modality.

COMPLICATIONS

Complications from lumbar facet blocks have fortunately usually been temporary and infrequent. The most common complication is an exacerbation of pain (2% incidence) lasting as long as 6 wk to 8 mo *(37)*. Spinal anesthesia has occurred after facet joint injection *(38)*. Several reports of chemical meningitis after lumbar facet block have also been published *(39,40)*. Both of these complications are thought to have occurred after inadvertent dural puncture. Other complications are much more infrequent and include paraspinal infections, facet capsule rupture, and vertebral artery puncture (cervical blocks).

RESULTS

Historically, immediate relief from facet joint induced pain is realized in up to 94% of treated cases *(18,41)*. Long-term relief is achieved in up to 54% of treated cases *(18,41)*.

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11 Sacroiliac Joint Injections

JEFFREY M. BOORSTEIN, MD, PhD AND J. KEVIN MCGRAW, MD

INTRODUCTION

Prior to the mid-1930s, the vast majority of medical literature concerning low back pain was dedicated to descriptions of the sacroiliac articulation *(1,2)*. More recent studies further show the joint to be a significant contributor to low back pain *(3)*. Diseases or disease states that frequently involve the joint include degenerative, infectious, inflammatory (i.e., ankylo-sing spondylitis, psoriatic arthritis, Reiter's syndrome, and enteropathic), traumatic, neoplastic, iatrogenic, metabolic, sacroiliac joint syndrome, and referred pain, with the most common source of low back pain emanating from the sacroiliac joint being sacroiliac dysfunction *(4)*. Spinal surgery, specifically lumbar fusion, can induce dysfunctional mechanical changes that lead to sacroiliac joint syndrome and pain *(5)*. Sacroiliac dysfunction is caused by an acquired degeneration and mechanical instability leading to a fixed subluxation or a hypermobility of the joint *(3–6)*.

ANATOMY

The sacroiliac articulation is complex and multiplanar, providing a stable attachment between the pelvis and the axial skeleton. The sacroiliac joints primarily serve to absorb and transmit forces between the more cephalad spinal column and the lower extremities. Previously classified as an amphiarthrodial joint (two hyaline cartilage surfaces joined by fibrocartilage), and a synarthrosis (in which the articular surfaces are joined by fibrous tissue), there is now general agreement that the sacroiliac joint meets the criteria for a synovial joint, specifically in its anterior and inferior portions *(7,8)*. It is formed between the lateral articulating surface of the sacrum and the medial articulating surface of the ilium (Figs. 1 and 2). A thin plate of cartilage covers the anterior articulation of each surface, with the plate being thicker and composed of hyaline cartilage on the sacral side, and thinner and composed of fibrocartilage on the iliac side *(7,9)*. The articular surfaces are normally closely aligned, united at their superior and posterior regions by fine interosseous fibrous tissue, and in some regions more convoluted with interdigitating patches of soft fibrocartilage. In the lower half of the sacroiliac joint, the syndesmosis lies posteriorly to the synovial portion, decreasing in size along its inferior most extent. The synovial portion may become obliterated by fibrous and fibrocartilaginous adhesions, undergoing arthrofibrosis throughout life *(10,11)*.

The anterior and posterior sacroiliac ligaments serve as the major connecting ligaments of the sacroiliac joints. The anterior sacroiliac ligament is made up of thin bands that connect the adjacent anterior surfaces of the ilium and sacrum. The anterior ligament is a thickening of the anterior joint capsule *(7)*. The joint capsule is absent posteriorly, with the interosseous sacrotuberous, sacrospinous, and iliolumbar ligaments forming the posterior border of the joint space adjoining the posterior surfaces of the ilium and sacrum. The posterior sacroiliac ligament is the chief structure bonding the sacroiliac joints together *(7)*.

The sacroiliac joint has extensive sensory innervation, with both anterior and posterior primary rami innervation *(6–8,12)*. The nerve supply to the sacroiliac joints varies among individuals, helping to account for the differing patterns of referred pain. Posteriorly, the innervation primarily arises from lateral branches of the posterior primary rami extending from L4 to S3. Anteriorly, the

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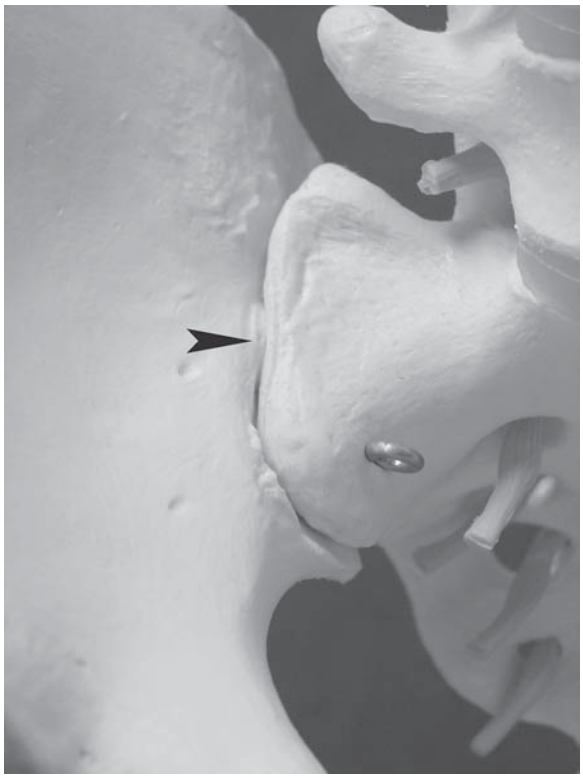

Fig. 1. Model of the sacroiliac joint formed by the articulation of the sacrum and ileum.

innervation may come from L2 through S2 *(7)*. Referred pain to the sacroiliac joint may come from facet joint syndrome, herniated nucleus pulposus, lateral recess stenosis, internal disruptions of the disc, hip diseases, and even piriformis muscle syndrome *(7)*.

CLINICAL FEATURES

Pain generated from the sacroiliac joint most frequently presents as pain or tenderness directly over the posterior aspect of the joint, just medial to the posterior superior iliac spines *(3,4)*. The muscles adjacent to the sacroiliac joint can be tender as well. Referred mechanical symptoms may include pain in the ipsilateral buttock, hip, groin, anterior thigh, and calf, with rare extension below the knee. Many of these symptoms are similar to those found in facet joint generated pain syndrome, which are discussed and delineated in another chapter. Patients may report that the pain is most severe on waking up in the morning, decreasing in intensity throughout the day.

Symptoms of sacroiliac dysfunction are frequently exacerbated by routine activities of daily living that may load the pelvis with asymmetric forces, such as climbing stairs, sitting, flexing, riding in a car, or riding a bicycle. Manual compression tests frequently reproduce the pain. A poorly mobile or fixated joint may be appreciated during distraction testing. Lumbosacral flexion and extension may elicit pain, with lateral motion rarely evoking pain *(7)*. The pain is frequently alleviated by standing or walking *(5)*. Up to one third of all low back pain results from a sacroiliac disorder *(13)*.

INDICATIONS

In patients suspected of having the sacroiliac joint as a pain generator, intraarticular injections of anesthetic solutions can provide diagnostic information if the sacroiliac joint is the source. Concomitant injection of glucocorticoids can reduce joint inflammation, providing reduction in pain associated with sacroiliac inflammation.

CONTRAINDICATIONS

Absolute contraindications include major hypersensitivity (anesthetic solutions and steroids), local infection at the site of proposed injection, systemic infection, coagulopathy, and contraindication to steroid therapy (active bleeding from gastritis or peptic ulcer disease, resistant diabetes mellitus, severe congestive heart failure, and severe hypertension). Relative contraindications include an allergy to iodinated contrast agents (procedure can be performed without contrast).

TECHNIQUE

Injection therapies are interventional techniques used to treat pain conditions that have failed to respond to other, more conservative therapies. It is important, among other items, to inquire as to the allergy history of the patient prior to proceeding with any invasive injection of the sacroiliac joint. Specifically, providone iodine based skin preparation agents, iodine-based arthrography contrast agents, local anesthetic agents, steroids, and agents used for preserving various pharmaceuticals may all be present for utilization during portions of this procedure. Specific inves-tigation as to whether there is a history of latex allergy should be made, as some arthrogram kits come complete with latex gloves or other latex-containing devices, such as syringes, included. Many liquid pharmaceuticals are secured in the bottle by rubber-containing stoppers, which must be removed and not transversed with the injection needle for such patients, for example. Alternatives exist for most of these agents and utilization of substances to which the patient may be allergic is contraindicated, especially as they can lead to such life-threatening reactions as anaphylaxis in certain individuals.

Sacroiliac joint injection can be safely performed in the outpatient setting in the fluoroscopy suite. No premedication is otherwise indicated in the absence of an allergy to the materials being utilized. Few side effects are reported

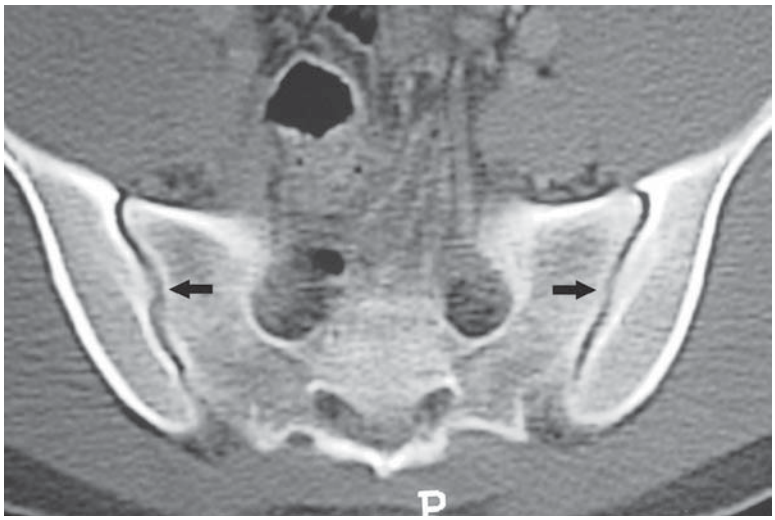

Fig. 2. Axial CT image of the sacroiliac joint (*arrows*).

from the local injection of anesthetics or steroids *(14)*. Sacroiliac joint injection can be performed under the radiologic guidance of fluoroscopy or computed axial tomography (CT). Fluoroscopy is the preferred modality as the procedure can be performed more quickly, with greater ease of physician movement and patient access, and can be more cost effective than utilizing the more bulky and technologist-intensive CT scanner.

The patient is placed in the prone position on the fluoroscopy table. To view the sacroiliac joint in the tangential plane, the patient may be positioned in an oblique position, or if the fluoroscopic equipment permits, the image intensifier can be rotated to the appropriate obliquity, as determined under fluoroscopic imaging. Recall that the sacroiliac joints are angled between 10 and 30° posteriorly relative to the coronal plane, and 10–20° medially relative to the sagittal plane *(9)*. In the prone position, the medial-most appearing portion of the joint is the most posterior joint plane, with the more lateral appearing portion being the anterior joint plane. Angling the fluoroscopy tube 20–25° in a cephalic direction will help to displace the posteroinferior portion of the sacroiliac joint in a caudal direction, allowing it to be clearly differentiated from the inaccessible anterior portion of the joint, which will be translated more cephalad on the image intensifier. To minimize irradiation to the physician's hands and other anatomy, a metallic localization probe can be used as a pointing device, and, under fluoro-scopy, the desired location for needle placement can be found on the patient's skin, thereafter being marked with an indelible skin marking pen.

The skin under and around the marked site is prepared and draped in standard, sterile fashion, utilizing a providone iodine based skin prep when possible, and an isopropyl alcohol based prep for patients with an iodine allergy. At least three sterile washes are made on and about the area to be injected and instrumented. Following air drying of the skin preparation agent, the sterile drapes are placed into position. Using a small (3- or 5-cc) syringe and a small 25-gauge injection needle, a skin wheal is made using 1% or 2% lidocaine, through which slightly deeper anesthesia may be given, depending on the body habitus of the patient. (Skin anesthesia is not always used, with some authors reporting that the direct transdermal puncture of the joint may be less painful than the puncture necessary for cuta-neous anesthesia) *(15)*. The 25-gauge needle is left in place in the skin, to confirm the desirability of the chosen site of injection. It is important that the site of intubation of the sacroiliac joint by the needle be the inferior aspect as this is the diar-throdial, synovial portion, which is under investigation or being treated by this technique. As defined in the preceding, the upper portion of the sacroiliac joint is fibrous. The preferred skin puncture site is therefore located approx 1 cm caudal to the inferior margin of the joint space, allowing the needle to approach the joint with a posteroanterior and mild caudocephalad trajectory *(15)*.The 25-gauge anesthetizing needle is replaced with a 22-gauge spinal needle (3 1/2- or 5-in, depending on patient body habitus). In obese patients a longer needle may be utilized; however, a 22-gauge needle remains the routine choice for needle size. The 22-gauge needle is placed through the anesthetized skin, from a slightly medial position to the desired joint space intubation site, allowing for the needle and its tip to be angled slightly laterally, following the normal angle and obliquity of the sacroiliac joint itself.

It is usual that the needle tip, when advanced, will articulate with the iliac bone, and when so, the tip can be immediately moved slightly more medial to be positioned within the joint space. The posterior longitudinal liga-

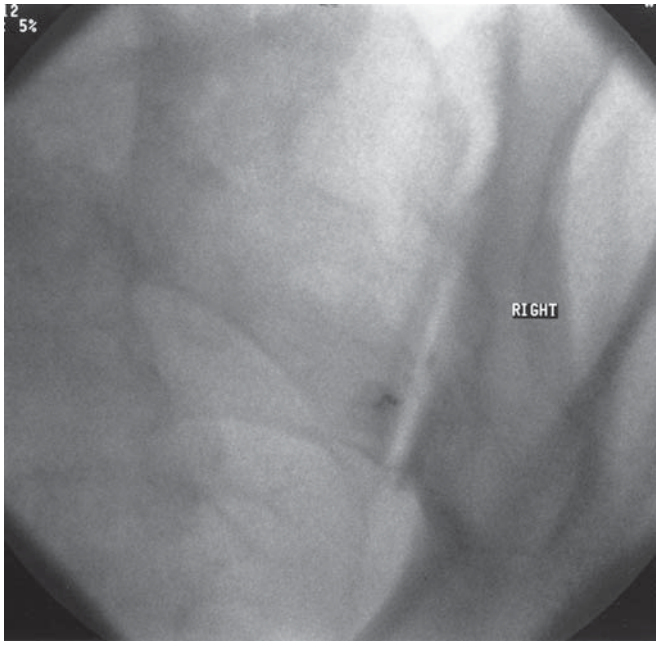

Fig. 3. Plain film image illustrating the correct prearthrographic needle positioning of the 22-gauge spinal needle in the poster-oinferior quarter of the sacroiliac joint.

ments are quite strong, and once transversed, an abrupt decrease in resistance to forward motion is appreciated (Fig. 3). At this time lateral imaging is performed to confirm that the needle tip has not transversed the anterior ligamentous structures and passed into the presacral region, an unusual but not impossible event. Further, 0.5 to 1.0 cc of nonionic contrast (180 mg/dL iohexol [Omnipaque]; Nycomed, Princeton, NJ) may be injected to document appropriate needle placement.

Pharmaceutical therapy of the sacroiliac joint routinely involves the utilization of both an anesthetic agent and a steroid agent. If septic arthritis is suspected, steroids should never be instilled. Analysis of joint effusion aspiration samples or sterile nonbacteriostatic saline lavage samples may be necessary to exclude an infected joint *(15)*. The anesthetic agent and steroid are generally drawn into a single syringe for simultaneous intraarticular injection. Just such a steroid–anesthetic mixture might include 40 mg of methylprednisolone acetate (0.5 mL of Depo-Medrol) with 2–3 cc of 0.5% bupivacane hydrocloride (Marcaine) for each separate joint injected.

Various local anesthetic agents that have been utilized for joint space injection include 5–25 mg of Xylocaine (lidocaine), 10–50 mg of Carbocaine (mepivacaine), 2.5–12.5 mg of Sensorcane (bupivacaine), and 2.5–12.5 mg of Marcaine (bupivicaine). Various long-acting steriod agents that have been utilized for joint space injection include 1.5–3 mg of Celestone suspension (betamethasone sodium phosphate and beta-methasone sodium acetate), 2–6 mg of an Aristospan suspension (triamcinolone hexacetonide), and 4–10 mg of Hydeltranol (prednisolone tebutate). Care must be made to ensure com-binations of agents are compatible to be admixed to avoid such potential incompatibilities leading to precipitation or flocculation *(16)*.

If CT-guided injection is being utilized, the patient is placed on the CT table in a prone position. Contiguous axial views can be obtained through the sacroiliac joint to visualize the mid- and lower joint spaces. The proposed site of skin puncture can be marked utilizing an opaque or metallic marker, such as a paper clip. Once a proposed site is chosen, the skin can be marked with an indelible marker and thereafter prepped and draped in a similar fashion as described in the preceding. A procedure and instruments similar to those described in the preceding for fluoroscopic guidance can be used with CT as the guidance modality. Prior reports suggest that although CT may provide additional clinical information in up to 10% of patients, it is not advocated for routine use *(17)*. Rather, it is reserved for morbidly obese patients or for those patients who have otherwise failed sacroiliac joint injection localization or intubation attempts performed under fluoroscopy.

As the sciatic nerve rests anterior to the piriformis muscle, aggressive injection of local anesthetic or improper position of the needle tip may cause a transient lower extremity weakness. Recent reports of magnetic resonance imaging (MRI) guidance for sacroiliac joint injection may help to minimize this potential complication *(18)*.

RESULTS

Fluoroscopically guided therapeutic sacroiliac joint injections are a clinically effective intervention in the successful treatment of patients with sacroiliac joint pain *(19)*. The efficacy has been demonstrated both prospectively and retrospectively *(20–22)*.

VISCOSUPPLEMENTATION

Degenerative disease of the sacroiliac joint includes pregressive erosion of the articular cartilage and synovial inflammation. Further, there is loss of the viscoelastic properties of the synovial fluid, making the cartilage more susceptible to further mechanical damage *(5,23,24)*. The loss of the viscoelasticity is felt to be the direct result of the loss of the protective effect of hyaluronan, a naturally occurring lubricating glycasaminoglycan found in synovial fluid *(5,25–28)*.

Viscosupplementation of the sacroiliac joint with hylan has been recently reported *(5)*, and can help achieve pro-

longed pain relief in patients with sacroiliac joint pain. Hylans are crosslinked hyaluronans, which produce an improvement in the rheological and viscoelastic properties while maintaining a longer retention time in the synovial space *(5,26)*. Hylan can decrease the progression of osteoarthritis in some joints *(5)*. The onset of significant relief occurs in less than 1 h, peaking within 4–5 d, and lasting up to 6–8 mo or longer. This treatment does not permanently resolve the pain. The hylan may serve to restore the rheological properties of the synovial fluid and the joint homeostasis, improving the fluid mechanics, allowing for improved joint motion, and decreasing the nociceptive responses of the inflammed joint (with its antibradykinin effects) *(5,7,25,27)*.

Injected viscoelastic solutions have a 1- to 2-d intraarticular half-life *(28)*, and therefore viscosupplementation injections must be repeated many times *(5)*. Following needle placement within the sacroiliac joint as described in the preceding, 1 cc (8 mg) of Hylan GF-20 (Sinvisc) is injected. The hylan injections are repeated three times at 2-wk intervals.

As the effects of viscosupplementation persist well beyond the half-life within the joint space, it is felt that the temporary restoration of and improvement of the rheological and viscoelastic properties of the synovial fluid allow for restoration of articular metabolic homeostasis *(5)*. This treatment may lead to a restoration of sacroiliac joint function.

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12 Discography

JOHN A. CARRINO, MD, MPH AND J. KEVIN MCGRAW, MD

INTRODUCTION

Discography is probably the most controversial image-guided procedure performed. It is controversial not because of the technical aspects or periprocedural complications, but rather because of the questionable downstream decision-making relevance and lack of a criterion standard. There is anatomic evidence and hence concept validity that the disc can be a source of pain because of the innervation that exists along the outer annulus from the ventral nerve roots that provide branches anteriorly (gray ramus communicans) and posteriorly (sinuvertebral nerve) *(1)*. However, there are many other structures in and around the spine that may be nociceptors or pain generators, and it is often difficult for the clinician to differenti-ate these potential sources of pain (or when multiple, which is the primary inciting source), especially if there are numerous imaging "abnormalities" (Fig. 1). The numerous pain sources have a variety of clinical expressions, which overlap with each other and with other disorders as well. Although the concept of discogenic pain represents a reasonable paradigm, poorly performed discography can assuage the importance of making this diagnosis and has contributed to its dubious reputation.

HISTORY OF DISCOGRAPHY

Lumbar discography developed as a complementary modality for studying the lumbar intervertebral discs at a time when oil-based myelography was associated with high false-negative rates, particularly at the lumbosacral junction. Radiographic contrast was first injected into a normal disc in 1941 by Lindgren in Scandinavia. In 1948, Knut Lindblom, a radiologist in Stockholm, Sweden, was the first to publish in vitro studies on discography by using a posterior transdural approach and coined the term discography *(2)*. Also in 1948, Karl Hirsch employed the procedure to identify painful discs in patients with radiculopathy. Hirsch's diagnostic parameter of the procedure was the pain response, which led to the concept of provocative discography *(3)*. Lindblom continued to modify the technique to utilize the injection of contrast to visualize the radial structures of the disc, and the diagnostic criteria were expanded to include the radiographic appearance of the disc as well as the patient's response to the injection *(2)*.

At the Cleveland Clinic, Wise and Weiford were the first in the United States, in the early 1950s, to visualize and study internal disc morphology *(4)*. Cloward and Busade continued the work and described the technique and indications for discography in their 1952 paper on the evaluation of normal and abnormal disks *(5)*. Ulf Fernstrom suggested mechanical and biomechanical causes for symptoms, based on cases of back and leg pain in which no nerve compression was detectable *(6)*.

The diagnostic merits and applications of discography have been challenged frequently and the modality remains highly controversial. In 1968, Holt questioned the validity of discography, reporting a 36% rate of positive findings in asymptomatic subjects *(7)*. His study, however, had flaws that included using prison inmates as his study subjects, using a very irritating contrast (sodium diatrizoate), and failing to include a positive pain response as a criterion for a positive result. Positive results in his study were based primarily on the radiographic appearance of the discogram *(7)*. Walsh and co-workers refuted Holt's findings in a well designed study demonstrating a

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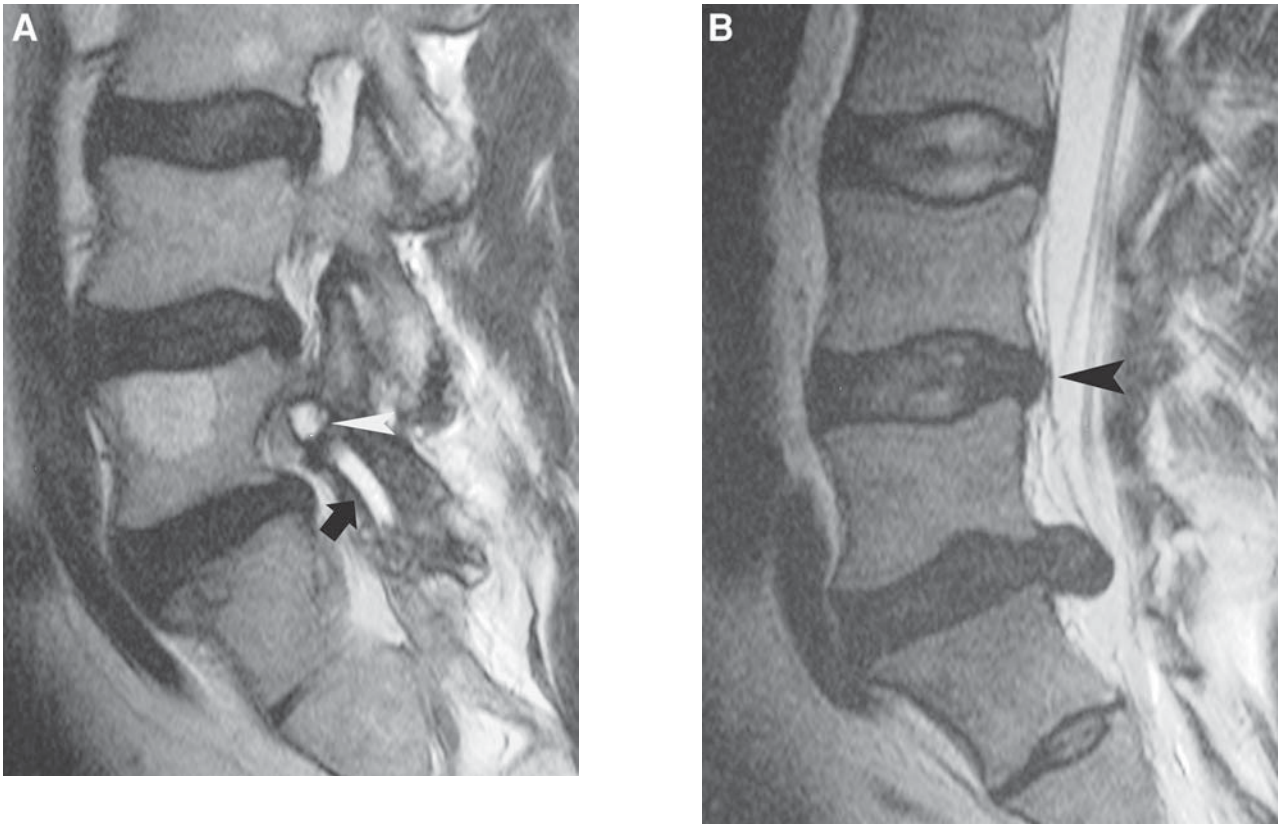


Fig. 1. **(A)** Sagittal T2 MRI showing fluid in the facet joint (*dark arrow*) and a synovial cyst (*white arrowhead*). **(B)** Sagittal T2 MRI showing a large disc herniation at L5–S1 and disc desiccation and a disc bulge at L4–5 (*arrowhead*). This represents some of many potential pain generators in the spine.

zero rate of false-positive results in 10 asymptomatic volunteers *(8)*. Walsh incorporated fluoroscopy and postdiscography computed tomography (CT) scanning that helped establish the standards of modern-day discography *(8)*. Largely as a result of the development of CT and magnetic resonance imaging (MRI), the primary purpose of discography today is for documentation of the disc as a pain source *(9,10)*.

PATHOPHYSIOLOGY OF THE PAINFUL INTERVERTEBRAL DISC

The intervertebral disc (IVD) is a composite structure consisting of three distinct components: the nucleus pulposus (NP), the annulus fibrosus (AF), and the cartilaginous endplates. Decreased tissue cellularity and altered matrix architecture characterize intervertebral disc degeneration. The disc derives its structural properties largely through its ability to attract and retain water. The AF is the main torque converter in the spine while the NP provides hydrostatic pressure. Delamination of the annulus is the key pathoetiologic feature that produces a herniated nucleus pulposus (HNP) (Fig. 2). Rotary strain sets the stage for herniation. Overt trauma has a variable and questionable role but may be the precipitating event superimposed on underlying degeneration. Collectively, these features can lead to abnormal spine biomechanics and pain. Degenerated discs are thought to cause pain in several ways, including mechanical instability (stretching of pain fibers), compressive impingement on adjacent nerves (radiculopathy) (Fig. 3), and biochemical irritation via the release of inflammation mediators such as phospholipase A_2, causing primary dural pain *(11)*.

LUMBAR SPINE

Internal disc disruption (IDD) is a term that was coined in the 1970s to describe pathologic changes of the internal structure of the disc. Internal disc disruption and degeneration involve a physiochemical change in the glycosaminoglycans of the NP, which act to bind water; over time this water-binding capacity diminishes. Disc degeneration is usually heralded by loss of hydration and thus decreased T2 signal on MRI. However, focal T2 bright areas reflecting annular tears indicate fragmentation of the outer collagenous AF. Hyperintense zone (HIZ) is the term that has been coined to denote this finding on T2-weighted MR images (Fig. 4). In the patient population undergoing MRI for lumbar back pain, this finding may be noted in

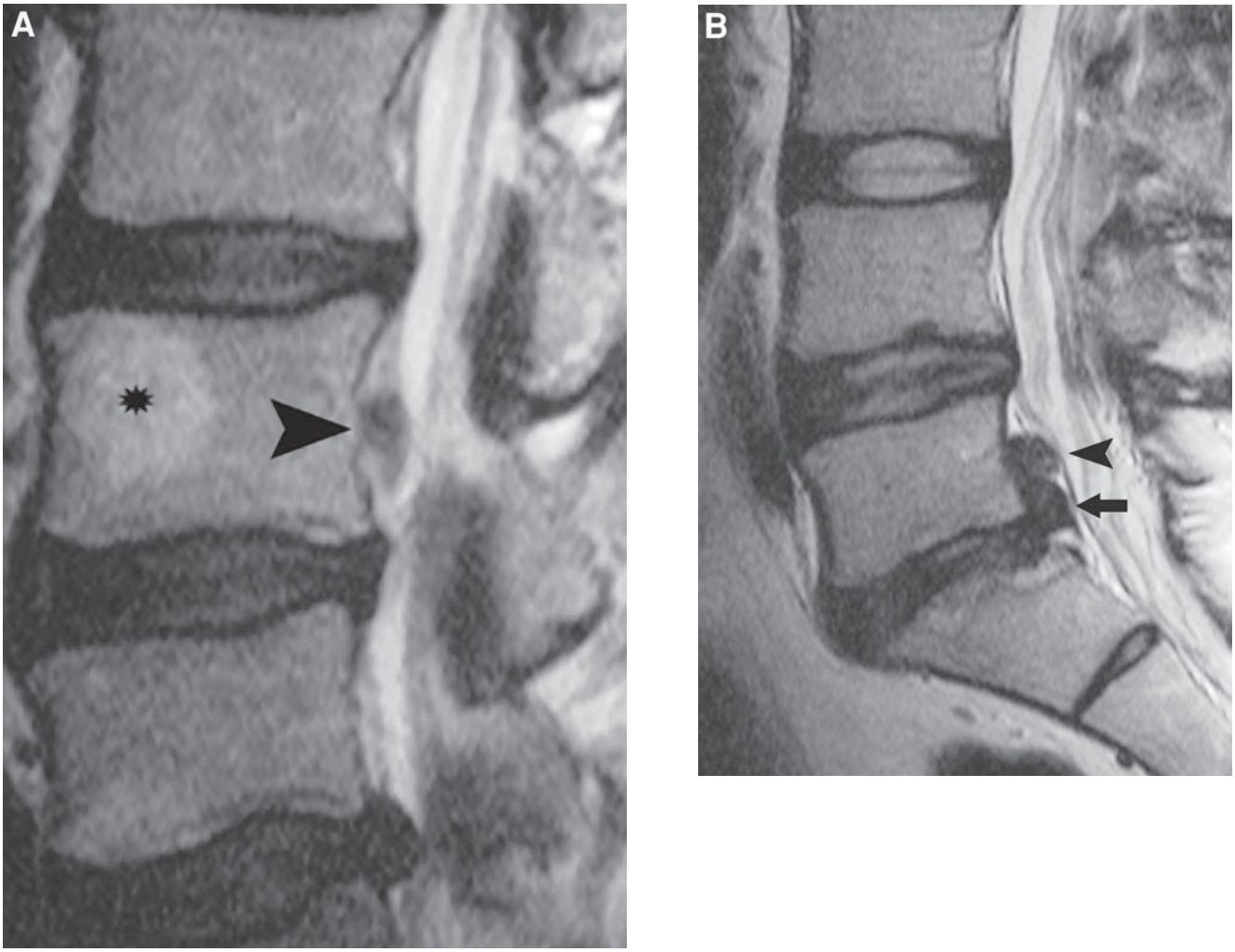


Fig. 2. **(A)** Sagittal MRI showing a disc herniation (sequestered disc). Incidental note is made of a vertebral body hemangioma (*star*). **(B)** Sagittal MRI showing a large disc herniation at L5–S1 with the disc material tracking posterior to the L5 vertebral body.

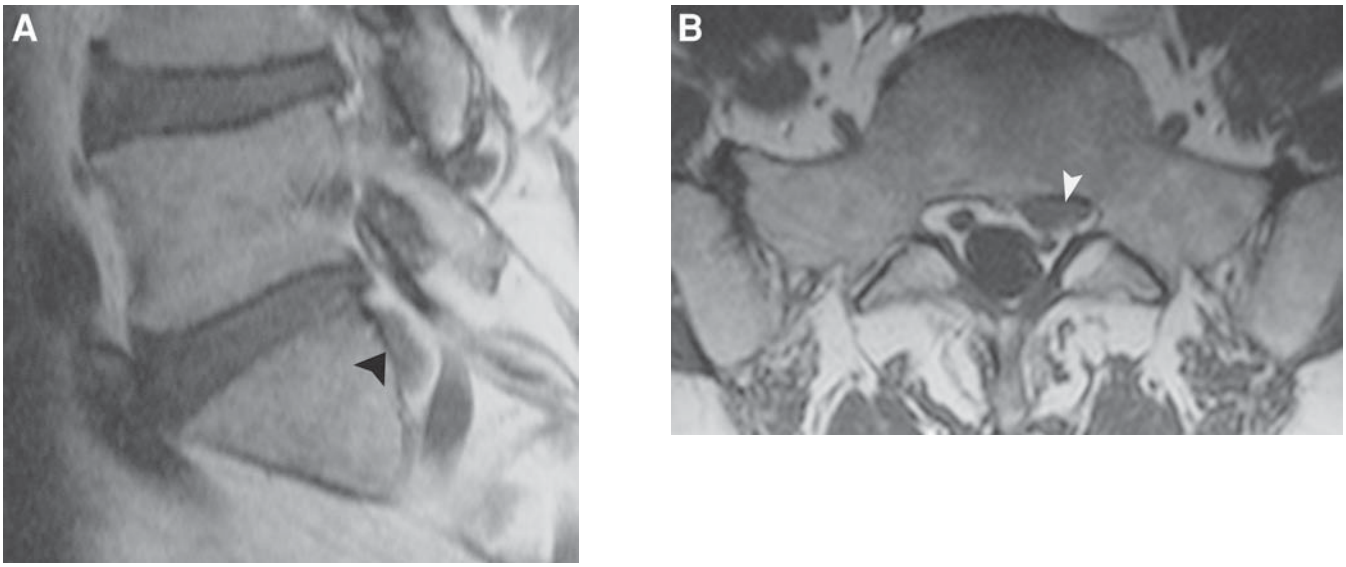


Fig. 3. **(A, B)** Sagittal and axial MRI showing a free disc fragment compressing the exiting nerve root (*white arrowhead*) in a patient with severe radiculopathy.

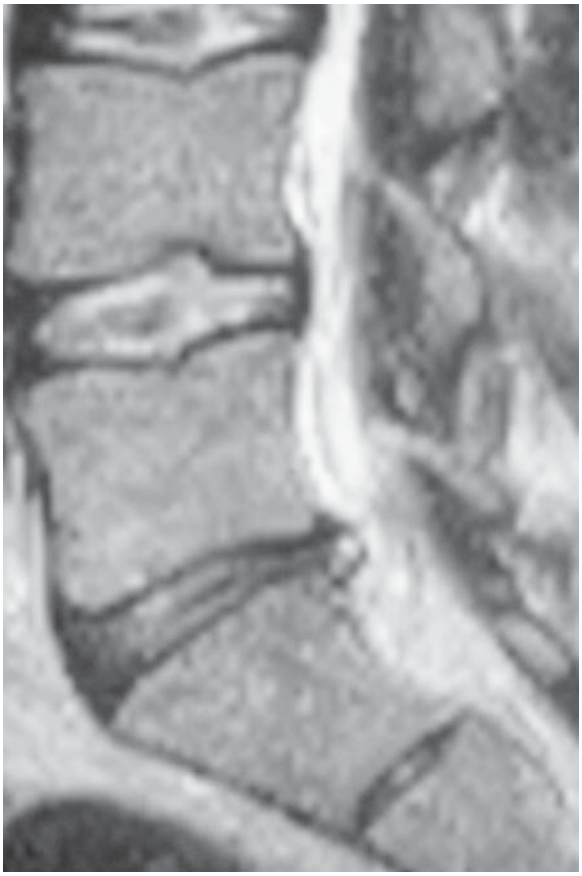


Fig. 4. Sagittal T2 MRI showing an area of bright signal in the posterior annulus fibrosis of the L5–S1 disc. This represents a high-intensity zone (HIZ).

approx 25% *(12,13)*. The presence of an HIZ correlates with an annular tear and an approx 85-87% chance that there will be concordant pain reproduction at discography *(12,14,15)*. An HIZ may enhance after contrast administration, reflecting the fibrovascular ingrowth into the region of the annular tear (Fig. 5). In addition, nerve tissue has also been seen by histology in this lesion and is the purported mechanism by which peripheral annular tears generate pain. The prognostic or therapeutic significance of this finding has not yet been elucidated and asymptomatic HIZs may also be encountered.

CERVICAL SPINE

The cervical spine is more biomechanically challenged than the rest of the spine. The ligaments and supporting soft tissues are important for mobility. Recent anatomical reevaluation of this area has determined that the AF is a crescentic anterior interosseous ligament rather than a completely circumferential "O-ring" that surrounds the NP, as in the lumbar spine *(16)*. It tapers laterally where the uncinate processes exist and is deficient in the posterolateral aspects. Posteriorly, there is a thin layer of vertically oriented fibers reinforced by the posterior longitudinal

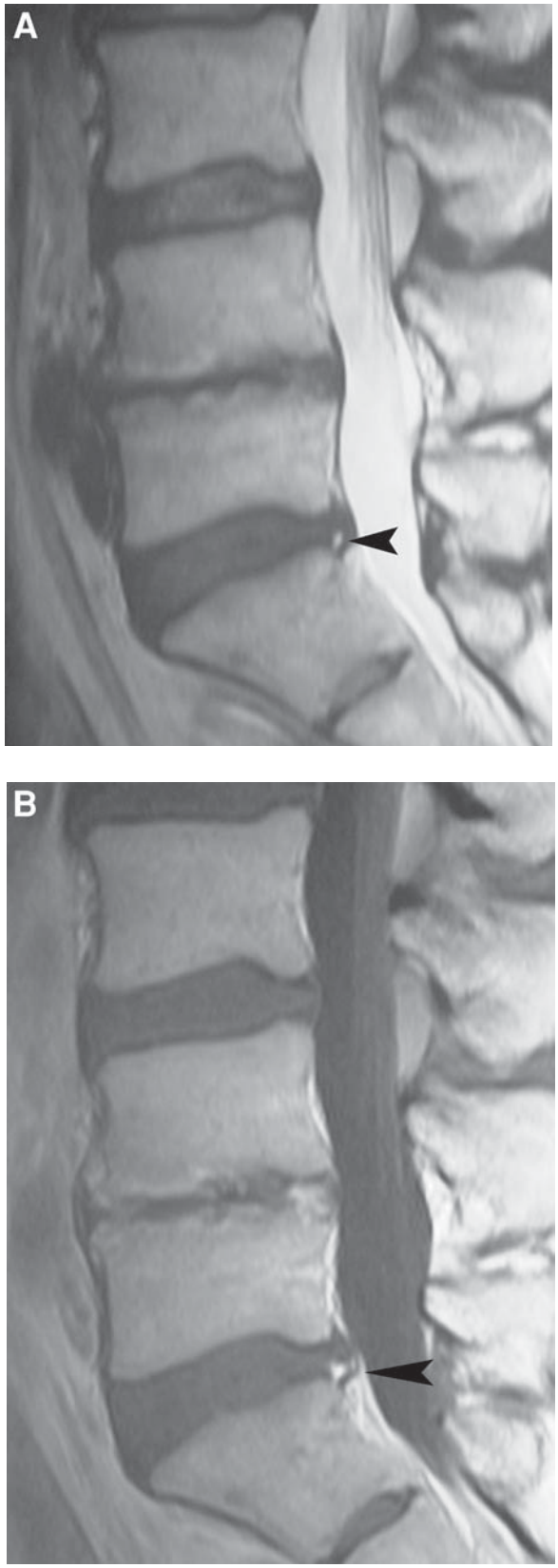


Fig. 5. Enhancing HIZ. **(A)** Sagittal T2 image shows a small focus of hyperintensity (*arrowhead*) within the posterior annulus fibrosis. **(B)** Intravenous contrast enhanced sagittal T1 image shows enhancement within the posterior annulus fibrosis (*arrowhead*) corresponding to the HIZ identified on the T2-weighted image. This phenomenon is thought to reflect the ingrowth of fibrovascular tissue to the area.

ligament (PLL). This anatomical structure is not present in the human fetus, child, or adolescent, and it is believed to represent a normal phenomenon of maturation. When bipeds turn their heads, a rotational component is involved; in quadrapeds, this is achieved mostly with lateral side bending. Therefore, uncovertebral joints are unique to vertebrate species that maintain an erect posture, and this biomechanical condition causes uncovertebral hypertrophy as a normal aging (presumably degenerative) phenomenon. In the cervical spine, intradural connections between adjacent nerves may account for the greater than expected overlap of dermatomal pain patterns in this region. Because of these considerations, chronic cervical spine pain of an axial nature is difficult to evaluate and treat.

THORACIC SPINE

The thoracic spine is stabilized by the ribs and has less range of motion than the other segments of the spinal column. Thoracic pain is relatively uncommon. However, it is important from a management perspective because dorsal back pain can be as disabling as cervical and lumbar pain *(17)*. While histological studies of the thoracic discs are currently being reevaluated *(18)*, it has been revealed that branches of the rami communicantes provide innervation circumferentially *(17)*. MRI reveals that a substantial number (11–12.5%) of asymptomatic degenerative or protruded discs also exist in the thoracic spine *(19)*. However, anatomical changes on imaging studies do not necessarily equate with pain generation. In one investigation, approximately one quarter of the discs injected provoked a pain response that did not match MRI findings or morphologic findings at discography *(20)*. One case series on thoracic discography concluded that useful information is obtained for treatment planning *(21)*. In this study, in addition to painful segments, control discs were also injected, which did not provoke pain.

PATHOPHYSIOLOGY OF DISCOGRAPHY

Discography probably provokes pain by three mechanisms: (1) stimulation of nerve endings, (2) biomechanical or neurochemical stimulation, and (3) deflection of vertebral body endplates.

It is believed that pain generated by discography occurs when annular fissures or nuclear herniations extend into the outer third of the annulus fibrosis *(22)*. Nerve endings from branches of the lumbar ventral rami, gray rami communicantes, and the sinuvertebral nerves innervate the outer third of the ventral, lateral, and dorsal annulus, respectively *(23)*. Histological and immunocytochemical studies have demonstrated the presence of a variety of nerve endings in the outer annulus, and neurotransmitters associated with pain perception (nociception) have been detected in the annulus and posterior longitudinal ligament *(23)*. The injection of contrast into the disc may increase intradiscal pressure, stretch the annulus, and stimulate nerve endings.

Histochemical studies have shown that nerve endings in the annulus contain peptides, such as calcitonin gene related peptide, vasoactive intestinal peptide, and substance P. These peptides have been shown to be associated with nociception *(24–26)*. The pain response provoked by concordant discography may be secondary to the stimulation of these nociceptive nerve endings by enzymes such as phospholipase A_2 and nuclear degradation products *(27)*. To simplify, the injection of contrast into the disc may result in some biochemical or neurochemical stimulation that causes pain.

The last proposed mechanism for pain provoked with discography is endplate deflection. Heggeness and Doherty have documented endplate deflection during intradiscal injection, which could explain a mechanical component for discogenic back pain *(28)*.

INDICATIONS FOR DISCOGRAPHY

Low back pain is one of the most common medical problems encountered by healthcare providers. Accordingly, the lumbar spine is the most commonly requested site for discography. For patients whose symptomatology is predominately axial and nonmyelopathic and/or nonradicular, imaging may be insufficient or equivocal for determining the nature, location, and extent of symptomatic pathology. Conversely, imaging reveals asymptomatic abnormalities in a substantial proportion of patients *(29)*.

A major controversial issue regarding discography is how effective spine arthrodesis is for alleviating primarily axial pain. Most of the recent literature supports the use of discography in select patients. In general, the role of surgery for axial pain is limited. At present, there is a paucity of prospective, randomized or controlled trials evaluating spinal fusion outcomes. However, one study supports that discogenic pain syndromes can be treated by arthrodesis, with a 46% satisfactory outcome *(30)*.

Demand for discography is increasing, as a diagnostic tool to determine levels of pain generation for patients who are being considered for surgical management (e.g., interbody arthrodesis) or other minimally invasive disc procedures (*see* Chapter 13). Degenerated discs may be relatively motionless, and the source of pain may be at the relatively normal appearing (or at least less degenerated appearing) levels above or below owing to abnormal biomechanics at these levels. Surgeons concerned with limiting the extent of fusion are interested in obtaining more

Table 1
Disc Classification Based on Pressure-Controlled Discography

	Intradiscal pressure at pain provocation	*Pain severity*	*Pain concordance*	*Interpretation*
• Normal	>90 psi	No pain		Negative
• Indeterminate	>50 psi <90 psi	≥6/10	Concordant	Further investigation warranted
• Mechanical	15–50 psi above opening pressure	≥6/10	Concordant	Positive (but other pain generators may be present)
• Chemical	Pain at <15 psi above opening pressure	≥6/10	Concordant	Positive
or				
	immediate onset of familiar pain occurring as < 1 cc of contrast is seen at the outer annulus	≥6/10	Concordant	Positive

psi, Pounds per square inch.
Adapted from Derby R, Howard MW, Grant JM, Lettice JJ, Van Peteghem PK, Ryan DP. The ability of pressure-controlled discography to predict surgical and nonsurgical outcomes. Spine 1999;24:364–371.

evidence beyond MRI abnormalities to document what disc levels are contributing to the painful syndrome.

To summarize, patients who may benefit from discography include *(31)*:

1. Patients with persistent back/neck and/or radicular pain when traditional diagnostic modalities have failed to identify the pain source precisely.
2. Patients in whom findings (bulging discs), identified on imaging studies, are equivocal (to determine if such abnormalities are the pain generator).
3. Patients who are to undergo fusion or other minimally invasive procedures (to determine which levels need treatment).
4. Patients who have previously undergone fusion of the spine (to help determine whether levels above or below are causing persistent symptoms).
5. Patients in whom imaging techniques cannot differentiate recurrent disc herniation from scar tissue.

CONTRAINDICATIONS TO DISCOGRAPHY

There are few contraindications to discography. Obviously, an uncorrectable coagulopathy, pregnancy, systemic or local infection, and severe contrast allergy would preclude discography. Discography may not be possible if an extensive, solid posterior bone fusion has been performed. A relative contraindication is the patient with severe spinal stenosis. There is the theoretical risk of exacerbating myelopathy from slight enlargement of the disc during the procedure.

INTERPRETATION OF THE DISCOGRAM

Interpretation of a discogram includes both a morphologic and a functional evaluation. The functional evaluation is more important because MRI is well suited for characterization of morphologic findings. The tenet of discography is that injection into the discs and subsequent increased intradiscal pressure will elicit a concordant pain response (one that mimics the patient's typical pain) if that disc is a pain generator. A scale of subjective pain severity from 0 (no pain) to 10 (maximal pain) can be determined during the procedure by asking the patient to relate what his or her level of pain is during each injection. The patient is also asked whether the pain mimics his or her typical pain (i.e., "concordant"). To evaluate the patient's pain response more objectively, multiple vertebral levels around the suspected pain generator are injected during the procedure; the patient is not told which level is being injected, or when the injection is starting. The authors coach the patient prior to the procedure regarding reporting of pain response and monitor for spontaneous pain elicited during the examination. It is important to establish a "reference level," or relatively pain-free level with injection. For discography to be considered positive, there should be at least one reference level, which is defined by the absence of pain or lack of concordant symptoms on injection. An unquestionably positive discogram consists of a single concordantly symptomatic disc with control discs above and below that level (if it is not the lumbosacral junction). Optimal benefit results when one or two levels demonstrate a highly concordant pain response, with a relatively pain-free adjacent reference level(s). If all levels are painful, a limited fusion may not result in patient satisfaction, and these results can suggest that continued medical management might be the best course, rather than surgery.

There is an interest in characterizing results based on pressure-controlled manometric discography (Table 1).

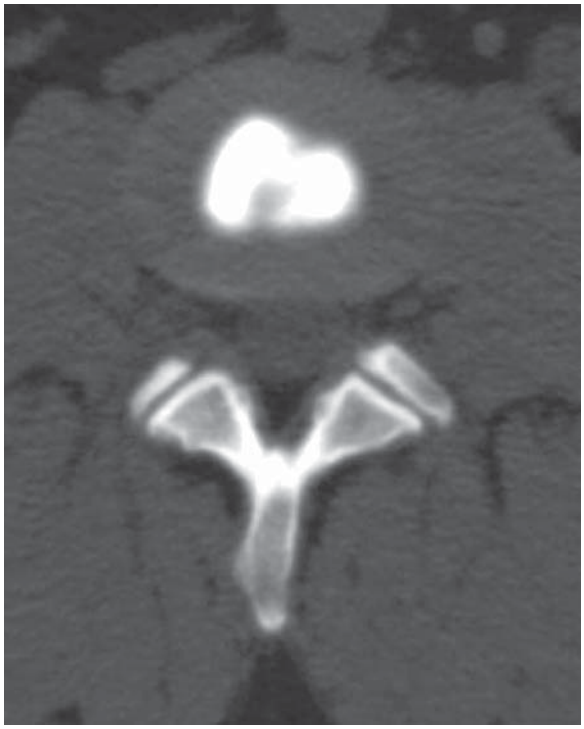


Fig. 6. Axial CT following a discogram showing contrast within the central confines of the nucleus pulposus. This is a normal appearing or grade 0 disc.

The information obtained includes opening pressure, pressure at onset of pain, and maximum pressure. The opening pressure is noted when contrast is first visualized in the disc space. The correlation of opening pressure and pressure at pain onset is important, potentially influencing surgical technique. The integrity of the disc can be evaluated by assessing the amount of pressure it can hold. An incompetent disc will fail to maintain pressure because of leakage of contrast. A typical nonpainful disc should be able to hold a pressure of at least 90 mmH_2O. Manometric discography may help stratify patients into categories that are more likely to improve from interbody fusions *(32)*. However, there are issues regarding whether intradiscal injection, which produces a tensile load, is comparable pathophysiologically to the compressive load that is exerted by virtue of our bipedal existence.

The Modified Dallas Discogram Scale *(33)* is the standard used for describing the radiographic and CT discographic appearance of annular disruptions of the lumbar, thoracic, and cervical discs. A normal disc is considered grade 0 and has the appearance of a cotton ball in younger patients and a hamburger bun in older patients *(10)* (Fig. 6). A radial tear confined to the inner third of the annulus is considered a grade 1. On fluoro-scopy it has the appearance of a small tail extending from the central nucleus but not reaching the disc margin. A grade 2 tear extends to the middle one third of the annulus, while a grade 3 tear extends to involve the outer annular fibers (Fig. 7). A grade 4 tear extends to the outer annulus and covers >30° of the disc circumference. Diffuse, severely degenerated discs often fall into this category. A grade 5 radial tear extends through all layers of the outer annulus and extends into the ventral epidural space *(33)* (Fig. 7).

Care must be taken to avoid an annular injection, as it can lead to a false-positive pain response. Annular injections can be avoided by placing the needle in the middle third of the disc in both the anteroposterior and lateral projections. An annular injection appears as a collection of contrast within the annulus along the periphery of the disc (Fig. 8).

PATIENT PREPARATION

Preprocedure instructions are similar to those for other spinal injections or vertebral biopsy-type procedures. These are related to the patient on an instruction sheet as follows. No solid food should be eaten 6 h prior to the procedure (sips of water for medications are allowed). No aspirin-containing products should be used for at least 1 wk prior to the procedure. Nonsteriodal antiinflammatory medications (e.g., acetaminophen or ibuprofen) or other pain control medication is accep-table as long as it does not contain any aspirin. However, all pain medication should be discontinued on the day of the procedure. If the patient is diabetic and taking insulin, the patient should consult his or her primary physician regarding the insulin dose to take the morning of the procedure. Patients may continue blood pressure medication unless contraindicated by their physicians. In general, it is recommended that patients review all medications with their primary physicians no later than 3 d prior to their procedure. The patient should bring any relevant outside imaging studies. The patient will need to rest in the recovery area for 60–90 min following the spinal injection. Patients must have a companion for discharge after the procedure. Postprocedure instructions for the patient include surveillance for signs and symptoms of disc infection. A telephone number is provided for the patient to contact the interventionalist or support staff if needed.

Discography is performed on an outpatient basis. Guidance for needle placement should be performed with a C-arm, floating image intensifier, or with biplane fluoroscopy. Patients must be informed ahead of time that the purpose of the procedure is to generate a pain response, which in some circumstances can be severe. Patients should be informed that complications include persistent pain, infection, bleeding, pneumothorax, and injury to exiting nerve roots *(9,10,34–41)*. To minimize the risk of disc infection, the procedure should be performed with a surgical-type prep and drape of the patient and surgical

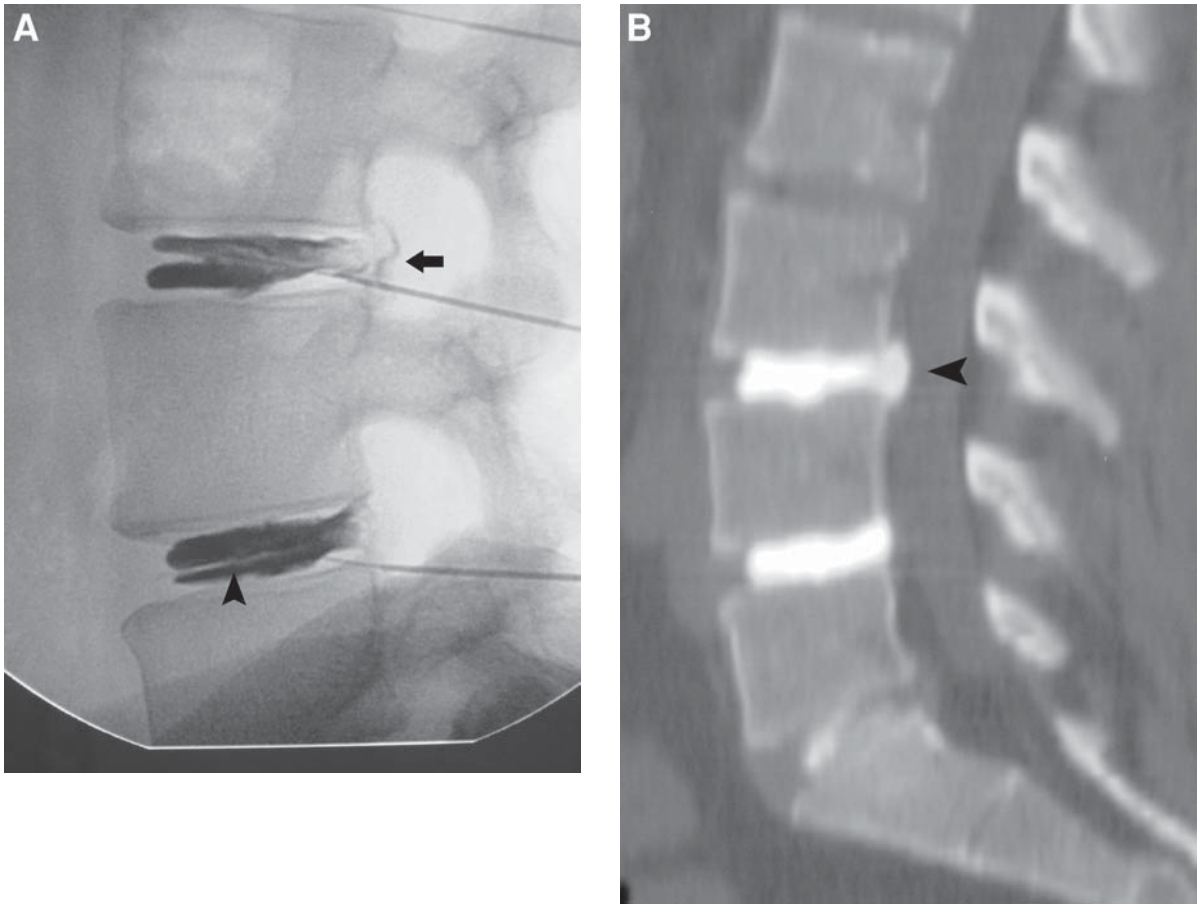


Fig. 7. **(A)** Lateral image from a diagnostic discogram showing contrast extending into the ventral epidural space at the L3–4 disc (*arrow*). The contrast extends through all layers of the posterior annulus. This represents a grade 5 radial tear. Also note the grade 3 tear at L4–5. The contrast extends from the disc center to the outermost margin of the annulus posteriorly. Note the nuclear cleft (*arrowhead*). The bilaminar or "hamburger bun" appearance can be seen in a mature disc and if seen in isolation is a normal finding. **(B)** Sagittal CT reconstruction. Again note the grade 5 tear (*arrowhead*) at L3–4 and the grade 3 tear at L4–5.

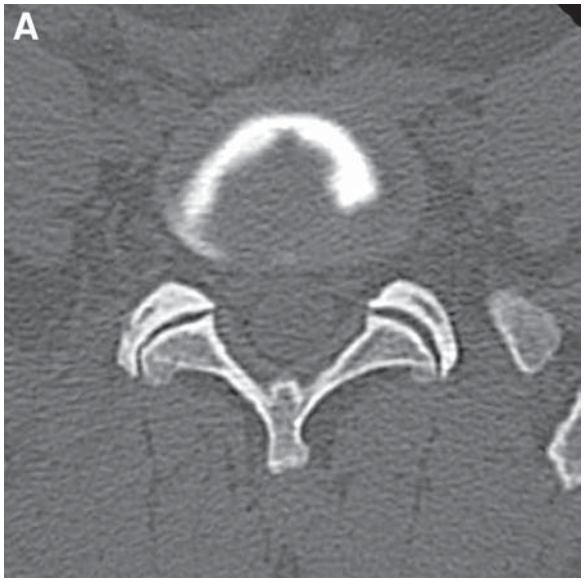
scrub, gown, mask, and gloves for the physician. Antibiotics should always be administered, whether intravenous or intradiscal. For cervical and thoracic discography, intravenous antibiotic prophylaxis is preferred (cephazolin or an equivalent cephalosporin). For lumbar discography, a cephalosporin antibiotic can be mixed with the contrast material injected. The authors reconstitute 1 g of cephazolin with 10 mL of nonionic contrast suitable for intrathecal administration.

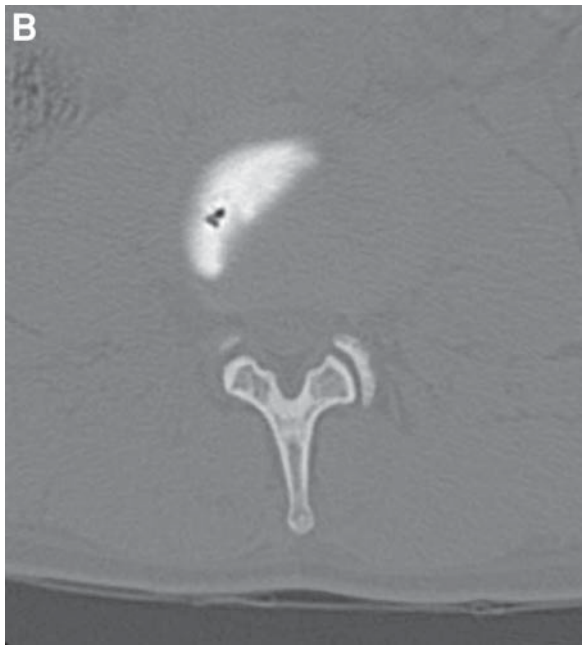
Intravenous anesthetic can potentially blunt a positive response and is not necessary for lumbar procedures, as placement of the needles can be performed relatively painlessly with proper technique. A short-acting agent can be used for cervical and thoracic procedures, but must "wear off" or be reversed before injection of the discs. Patients are monitored routinely during the procedure with pulse oximetry and a blood pressure cuff. Information assessed and recorded should include the volume of contrast injected, pain response with particular emphasis on its location and concordance to clinical symptomatology, and the pattern of contrast distribution. CT imaging can be performed following the procedure if additional information about the location of annular pathology is desired. The authors use CT imaging routinely for cervical and thoracic levels. We do not use it routinely for the lumbar spine but it is becoming more common as a complement to the fluoroscopic images or to delineate better and characterize IDD prior to minimally invasive disc procedures (Chapter 13).

DISCOGRAPHY TECHNIQUE

LUMBAR SPINE

Whereas the original description of lumbar discography used a transdural midline approach, currently most operators use a posterolateral extradural approach. The technique for lumbar injection is as follows (Fig. 9). Levels for injection are chosen based on imaging findings,





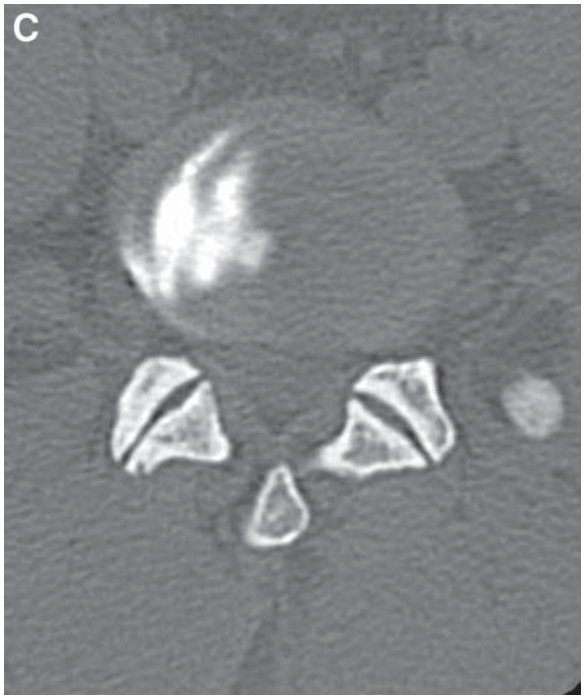


Fig. 8. **(A, B)** Annular injection demonstrated by contrast in the periphery of the disc. **(C)** A mixed injection with contrast in the periphery and central portion of the disc. Annular injections may lead to a false-positive pain response.

clinical examination, and surgical options, and should be discussed with the referring physician before the procedure is performed. Injection generally includes L3–4, L4–5, and L5–S1. The patient is positioned in a prone or prone–oblique position with the less painful side up. Each level is set up fluoroscopically so the disc is parallel to the beam and obliqued so that the superior articular process of the overlying facet joint is slightly posterior to the center of the endplate (30–50% zone). Lidocaine is administered under the skin. Next a 22- or 23-gauge 3.5-in. needle is advanced along the X-ray beam toward the disc, past the anterior margin of the superior articular process. Anesthetic is injected as the needle is withdrawn, thus fully anesthetizing the path to the disc. Care must be exercised with respect to the depth of the injection, so as not to inject the annulus or nerve root sheath.

A coaxial technique is used to place the discography needles into each disc. This reduces trauma to the annulus, and may reduce the risk of infection. The larger outer needle allows rapid positioning at the disc margin, with a small-gauge needle used to penetrate the annular fibers. At the L3–4 and L4–5 levels, a 20-gauge 3.5-in. outer needle can be used in conjunction with a 6- to 8-in. 25-gauge inner needle (Fig. 10). The L5–S1 disc may be located below the pelvic rim and can be difficult to access. Generally, the X-ray beam is oriented with more caudal angulation than the higher levels and is rotated slightly to open a small triangle of access over the iliac crest (Fig. 11). When this window is achieved, one needs to determine if the lumbosacral IVD can be punctured in the central portion with a direct approach or if the orientation is more parasagittal. If the course of the outer needle is parasagittal, a curved-needle technique is required to position the inner needle centrally. Prior to insertion of the inner needle, a bend (or curve) may be applied along the distal tip so that when it emerges from the guide needle, the inner needle deflects toward the center of the disc. Alternatively, precurved coaxial needle systems are available. Typically, a 22-gauge inner needle through an 18-gauge outer needle is used for most cases that require

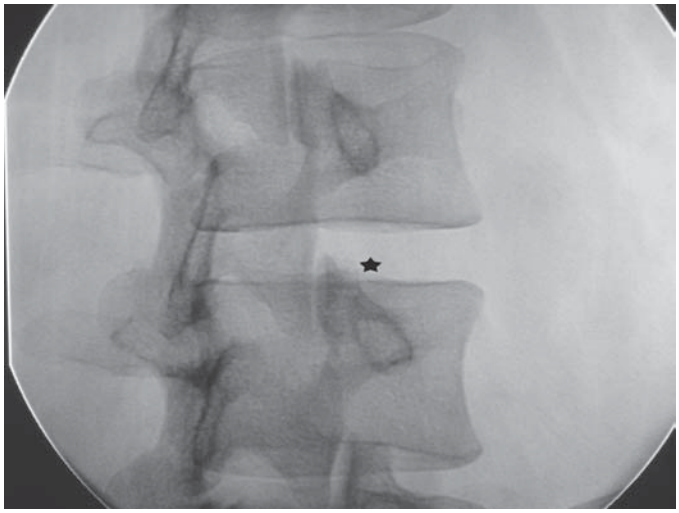


Fig. 9. Lumbar spine discography needle placement. Each level is set up fluoroscopically so that the disc is parallel to the beam and obliqued so that the superior articular process of the overlying facet joint is slightly posterior to the center of the endplate (30–50% zone) (*star*). The needle is then directly advanced along this path, being located slightly closer to the inferior endplate and superior articular process to avoid injury to the exiting nerve root.

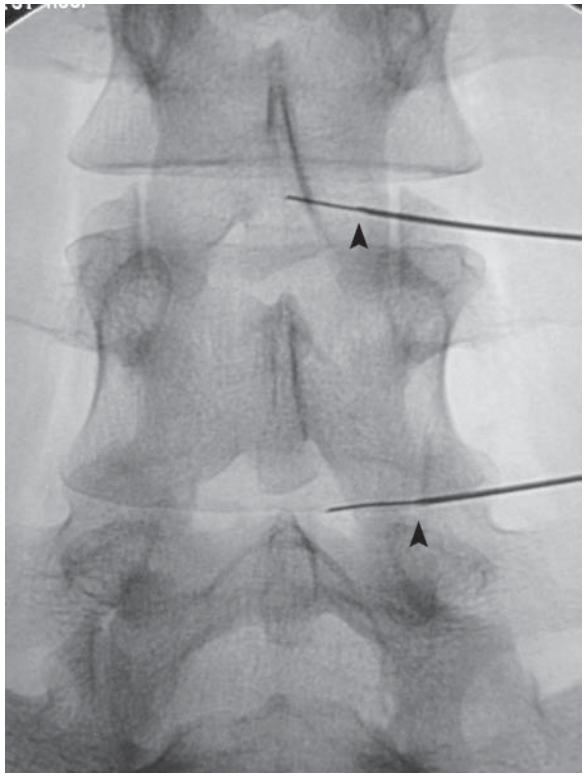


Fig. 10. Coaxial needle technique. The 20-gauge outer needle is advanced to the outer annulus (*arrowhead*). Through this the 25-gauge needle is advanced into the nucleus.

a curve. In addition, particularly at the lumbosacral junction, longer needles may be required.

Positioning of all needles during placement is checked frequently in the plane along the trajectory of the needle and is supplemented with the anteroposterior and lateral planes as the tip approximates the disc. The tip of the inner needle should be positioned as close as possible to the center of the disc, so that injection is into the nucleus pulposus instead of the innervated annular fibers, which can result in a false-positive pain response (Fig. 8). After all needles are placed, 1–2 mL of contrast (mixed with antibiotic) is injected at each level, with fluoroscopic monitoring and evaluation of any pain elicited. A morphologically normal disc demonstrates a central globule of contrast collection or "hamburger bun" configuration and degeneration is indicated by a horizontal, linear distribution of contrast (Fig. 7). An annular tear is diagnosed if contrast extends into the periphery of the disc in the expected region of the AF (Fig. 7). CT imaging may be used to complement projectional imaging techniques, and grading systems are available to characterize IDD as outlined in the preceding *(33)* (Fig. 12).

THORACIC SPINE

Thoracic spine discography can be performed in the prone semioblique 45° position (using a wedge) with the less painful side up. Alternatively, the patient may be placed prone and anteroposterior images obtained with the endplates in alignment. The C-arm is rotated to the side of injection until a lucent zone directly in line with the beam is seen projecting over the thoracic disc (Fig. 13). This usually requires approx 20° of rotation. The needle should enter the disc lateral to the interpedicular line and medial to the costovertebral joints to avoid potential complications, such as accidental puncture of the lung or thecal sac. Generally a single-needle technique is used in the thoracic spine. Usually 25-gauge needles will suffice for small individuals; however, 3.5–in., 23-gauge needles are often preferred because they are stiffer and can negotiate better around nerve roots and/or the osseous structures if necessary. The thoracic disc normally accepts a small volume of injectant (<1.0 mL). Fluoroscopic images may be difficult to interpret because of the superimposition of osseous structures, difficulty in obtaining a true lateral projection, and the presence of a small amount of injectant (Fig. 14). Therefore, post-discography CT imaging is often a useful adjunct to delineate IDDs and HNPs (Fig. 15).

CERVICAL SPINE

Cervical discography is performed using an anterior approach. Because the complication and false-positive rates appear to be higher than those for lumbar discography, cervical discography is performed less frequently than lumbar discography.

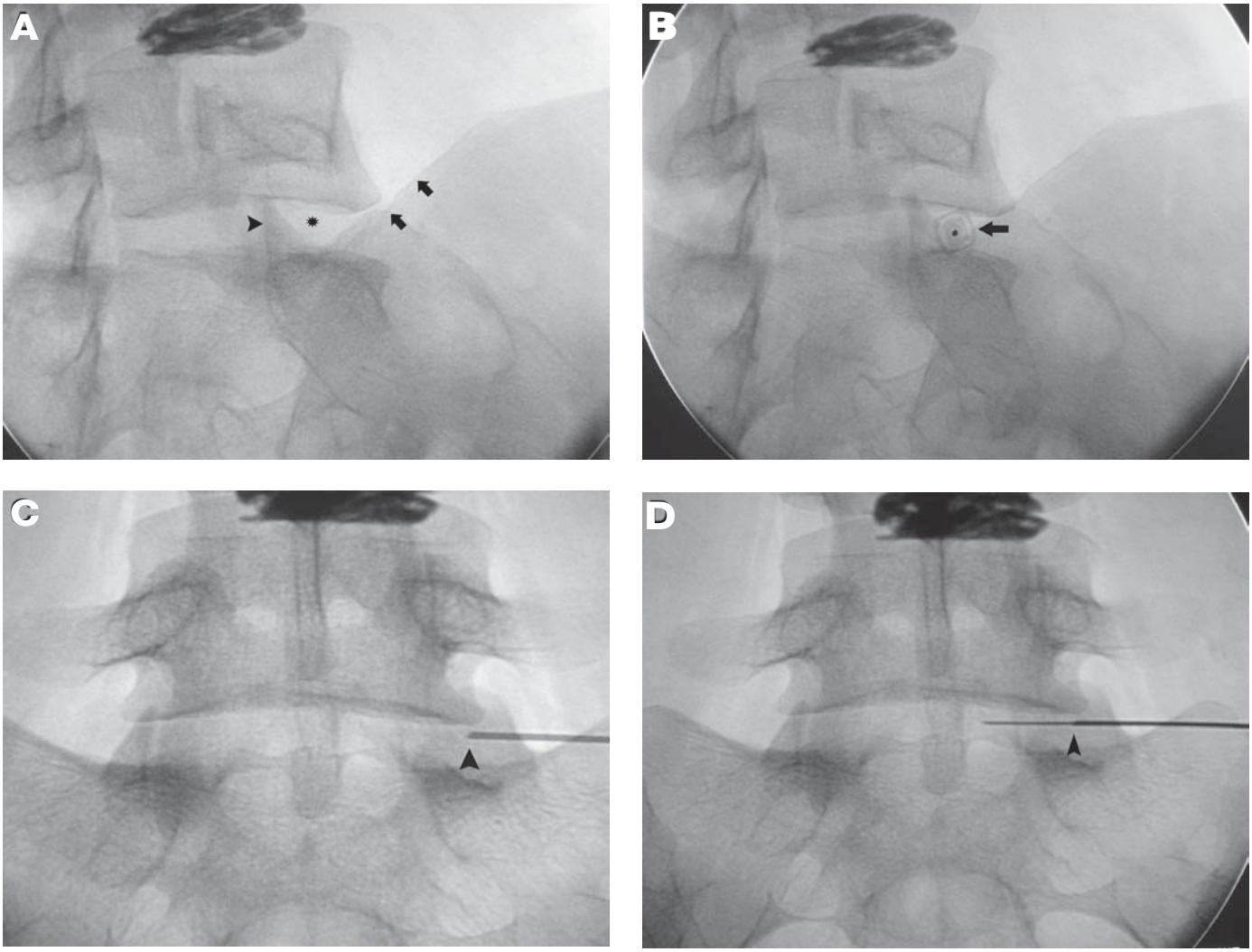


Fig. 11. Lumbosacral junction approach. **(A)** The fluoroscopic beam is oriented with caudal angulation and is rotated slightly to open a small triangle of access over the iliac crest (*arrows*). The target zone (*asterisk*) is the disc just anterior to the superior articular process (*arrowhead*) of the overlying facet joint. **(B)** The outer needle (*arrow*) is advanced down the X-ray beam until it comes in contact with the outer annulus. **(C)** The image intensifier is then rotated into the frontal projection. The outer needle is located at the outer annulus (*arrowhead*). The inner needle is now inserted into the nucleus **(D)** Occasionally, a curve will be needed with the inner needle to facilitate needle entry into the nucleus.

The patient is placed in the supine position with a small rolled towel between the scapulae to extend the neck and a small pillow under the neck itself for comfort. Disc puncture is usually accomplished using anteroposterior imaging for frontal visualization (Fig. 16). The skin of the anterior and anterolateral neck from the level of the mandible to the supraclavicular region is prepped. The esophagus lies to the left of the spine at the level of C7 in most individuals. Therefore a right-sided approach is normally used, especially for right-handed operators. Firm but gentle pressure is applied to the space between the trachea and medial border of the sternocleidomastoid muscle, displacing the laryngotracheal structures to the left. The right carotid artery is maintained underneath the fingers (Fig. 16). With this maneuver, the anterior surface of the spine can be palpated in almost every individual. Some operators will actually utilize ultrasound to direct needle placement away from the carotid sheath. Whichever method is chosen, the needle entry point should be adjacent to the medial border of the sternocleidomastoid muscle but not through the muscle belly. Using this landmark, the skin puncture site will be more lateral for the cephalad disc levels and more medial as one progresses caudally. Initially, the needle is directed to the vertebral body just below the endplate to ascertain the depth. Subsequently, minimal retraction and cephalad migration will direct the needle onto the anterolateral surface of the disc annulus and with small incremental movements can be advanced into the center of the disc (Fig. 17). The adult cervical disc normally accepts a volume of <0.5 mL.

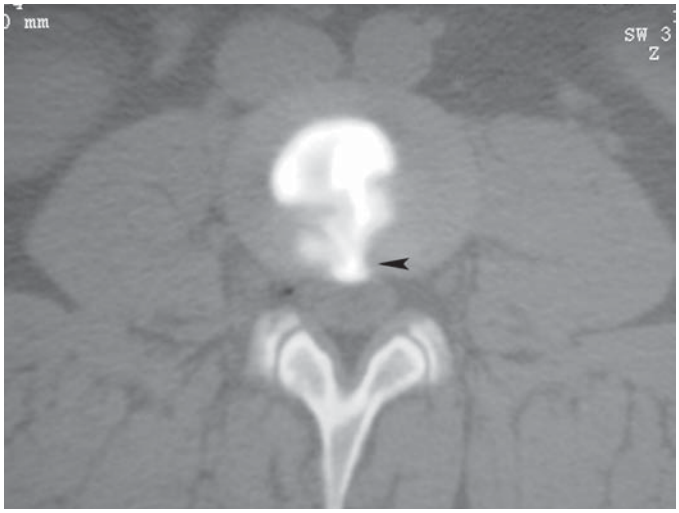


Fig. 12. Axial CT showing a grade 5 annular tear (*arrowhead*).

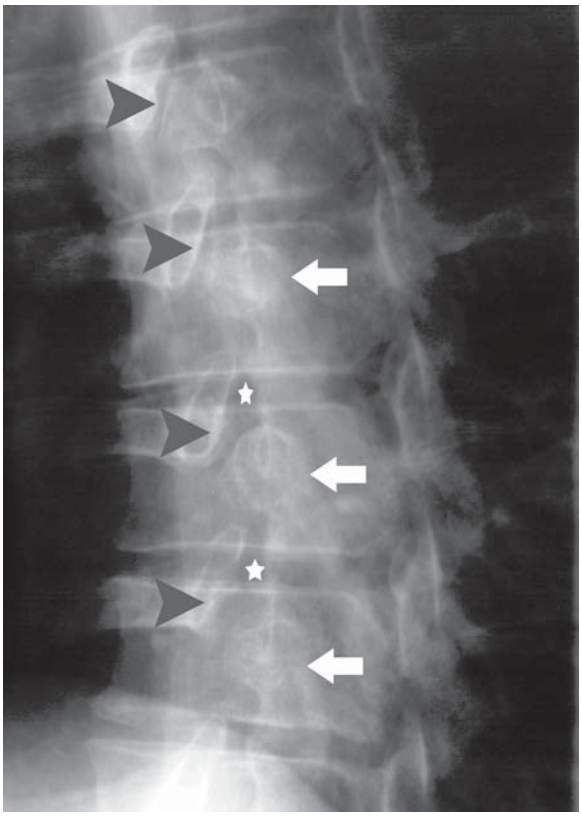


Fig. 13. Thoracic spine discography needle placement. Oblique fluoroscopic image obtained by approx 20° rotation from an anteroposterior projection to the side of injection. The target zone to identify (*white star*) is a lucent area directly down the beam seen projecting into the thoracic disc. The needle should enter the disc lateral to the interpedicular line (*arrows*) and medial to the costovertebral joints (*arrowheads*) to avoid potential complications such as accidental puncture of the lung or thecal sac. Adapted with permission from Carrino JA and Morrison WB. Discography: current concepts and techniques. Appl Radiol. 2002; 31: 32–40.

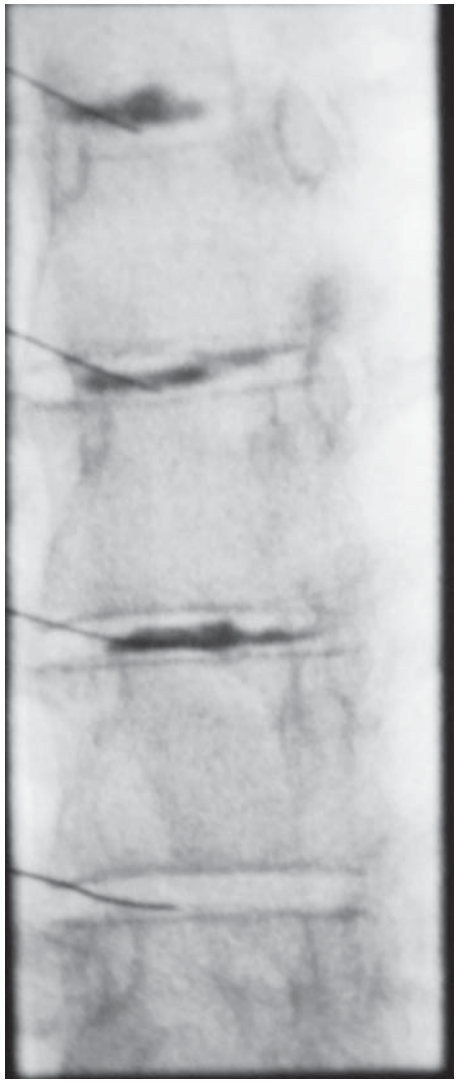


Fig. 14. Thoracic spine discogram. Anteroposterior fluoroscopic image shows contrast opacifying the intervertebral discs. Distinguishing normal from abnormal morphology is often difficult in this region. Adapted with permission from Carrino JA and Morrison WB. Discography: current concepts and techniques. Appl Radiol. 2002; 31: 32–40.

Usually a 25-gauge single needle approach will suffice. Skin and periosteal anesthesia is often unnecessary and may confuse the interpretation. As mentioned, the lateral and posterolateral portions of the cervical disc annulus are relatively attenuated. This results in clefts (joints of Lushka) that communicate with the nucleus, which are unique to the cervical spine. Opacification of these regions in patients older than 20 yr of age should not be confounded for degenerative disc disease based on this morphologic finding alone (Fig. 18).

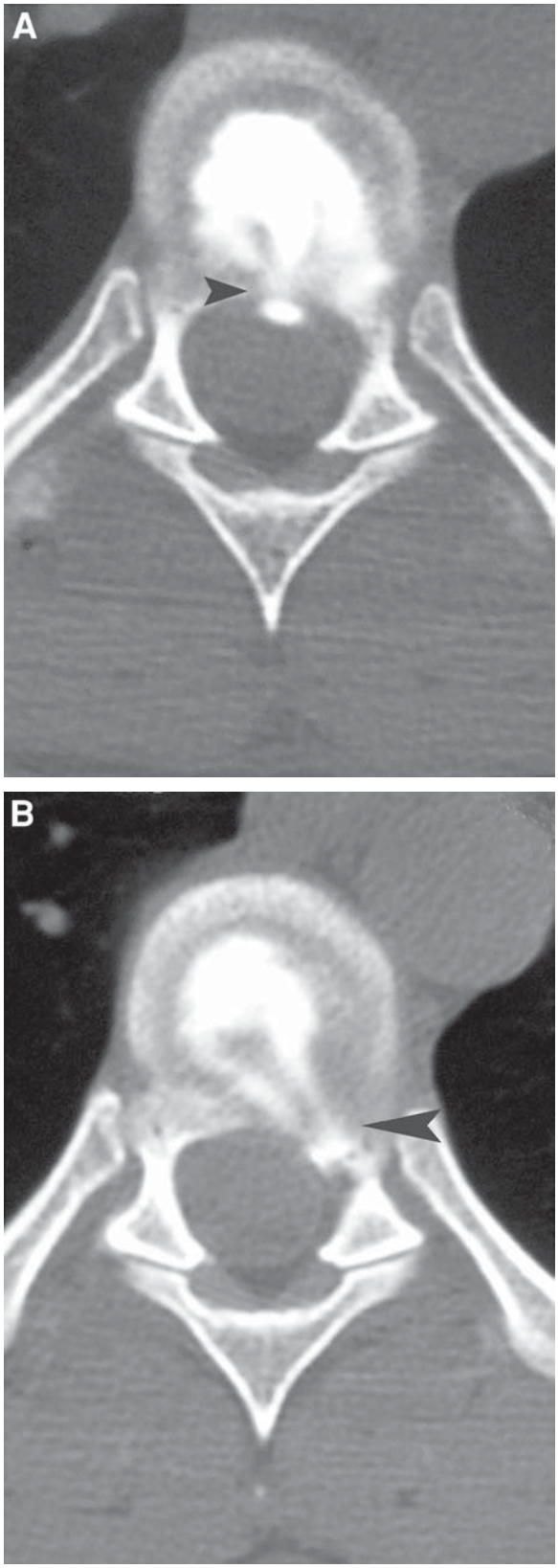


Fig. 15. Thoracic spine discogram morphology. **(A)** Axial CT image shows contrast opacifying a peripheral annular tear and extending posteriorly into a focal central protrusion (*arrowhead*). This should be distinguished from contrast extravasating along the needle tract (*arrowhead* in **B**). Adapted with permission from Carrino JA and Morrison WB. Discography: current concepts and techniques. Appl Radiol. 2002; 31: 32–40.

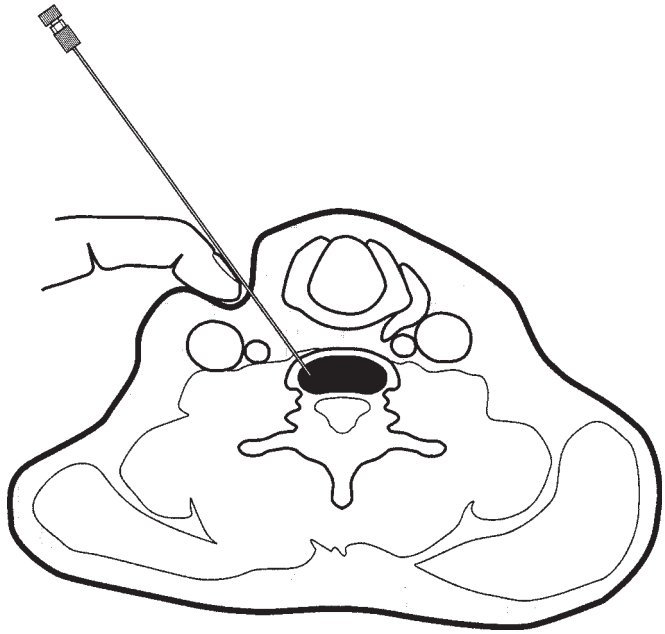


Fig. 16. Cervical spine discography approach. The idealized path taken by the needle is between the sternocleidomastoid muscle and the airway. During the procedure, the operator covers and displaces the carotid sheath laterally with one hand and hence protects it from inadvertent puncture.

COMPLICATIONS

Complications following discography are rare and include bacterial discitis, cerebrospinal fluid leak, retroperitoneal bleeding, and chronic pain *(34–41)*.

The most prevalent complication, discitis, fortunately is an uncommon event *(37,38)*. It is, however, debilitating for the patient and can pose a diagnostic dilemma for the physician. Signs and symptoms are not always clear and the diagnosis is often delayed secondary to inconclusive laboratory and imaging studies early in the course of the illness. An elevated erythrocyte sedimentation rate and narrowing of the disc space have been noted after several days of pain, but these are often normal at the initial presentation. Discitis occurs in 1–4% of patients undergoing discography; however, the frequency can be minimized by prophylactic antibiotic administration. Preliminary data show that uncomplicated discography does not produce MRI abnormalities immediately or within the 2- to 6-wk period following intradiscal injection *(42,43)*. Therefore, MRI is suitable for evaluation of potential postdiscography complications.

Carragee et al. evaluated the incidence of chronic back pain 1 yr after diagnostic discography in a cohort of patients with no prior history of back symptoms. Of the patients with normal psychometric testing, none reported persistent back pain following discography. However,

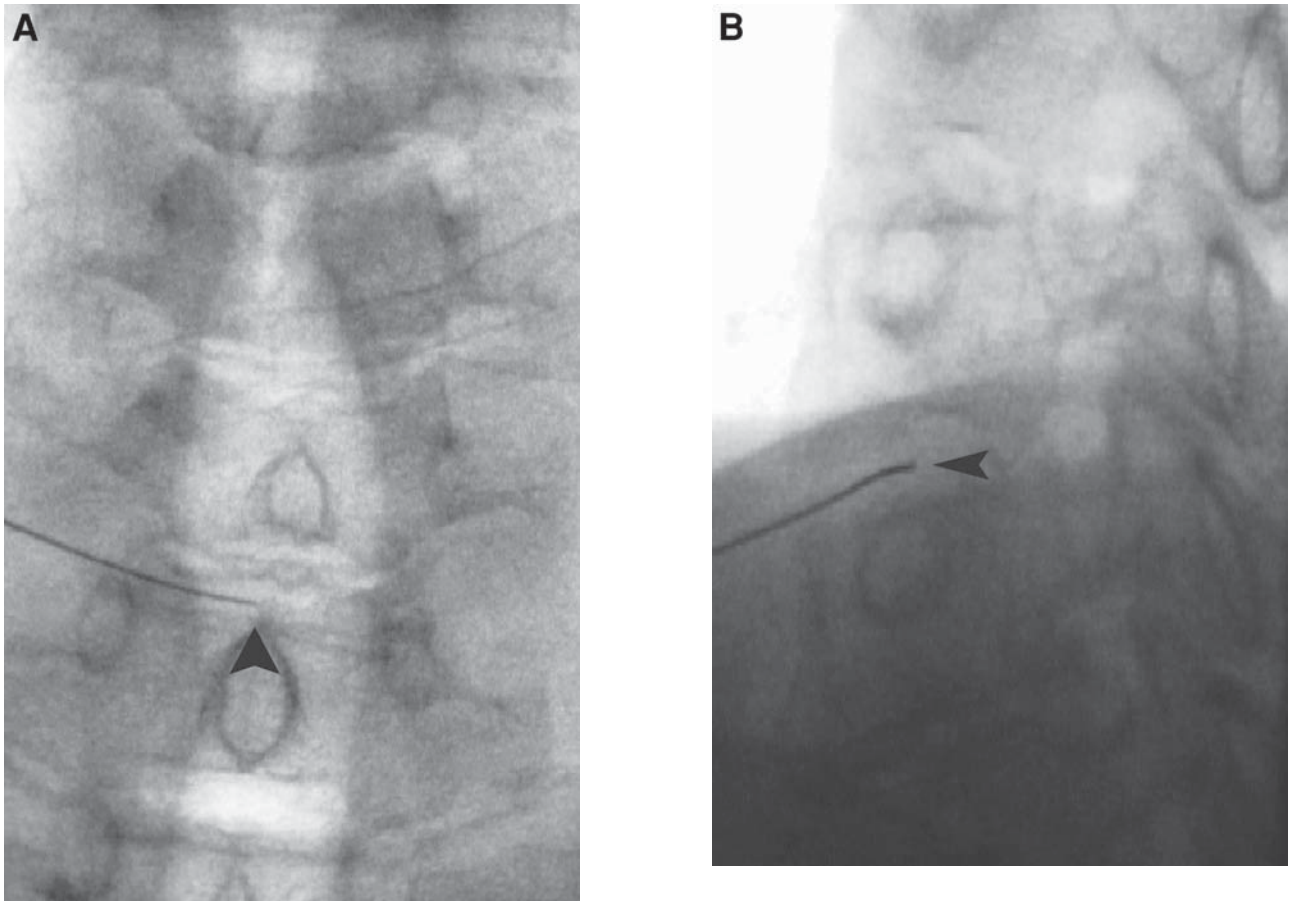


Fig. 17. Cervical spine discography needle placement. **(A)** Anteroposterior and **(B)** oblique fluoroscopic images show a needle placed from an anterolateral approach with the tips projecting near the center of the disc (*arrowhead*). Adapted with permission from Carrino JA and Morrison WB. Discography: current concepts and techniques. Appl Radiol. 2002; 31: 32–40.

patients with abnormal psychomotor testing reported a 40% incidence of new low back pain while patients with somatization disorder demonstrated a 66% incidence of new low back pain *(41)*.

RESULTS

As previously mentioned, discography is one of the most controversial procedures performed. Many studies have been performed supporting the use of diagnostic discography, while several studies refute discography.

SUPPORTING EVIDENCE

In 1990, Antti-Poika et al. conducted a prospective study of 279 injected discs in 100 patients. Exact reproduction of pain on injection was more common in fissured or ruptured discs. The results indicated that discography had a sensitivity of 81% and specificity of 64% for pain. Additional information yielded by follow-up CT scan was minimal *(44)*.

Also in 1990, Bernard prospectively studied 250 patients with low back pain who underwent lumbar discography followed by CT scan. In 93% of the patients, the combined discogram/CT provided significant information regarding equivocal or multiple level abnormalities and type of herniation, defining surgical options, and evaluating previously operated spines. In 94% of the patients, discography/CT correctly predicted disc herniation as protruded, extruded, sequestrated, or internally disrupted *(45)*.

In 1991, Simmons et al. performed a study in which 164 patients with low back pain underwent discography and MRI. Discography and MRI results correlated in 80% of the cases. Of abnormal disks, 76% reproduced symptoms on discography *(46)*.

In 1996, Schellhas et al. conducted a retrospective study of patients until records of 100 HIZ discs in 63 patients were found. Eighty-seven of the 100 discs tested were found to be concordantly painful. All 87 showed annular tears to the outer third of the annulus fibrosus. Of the 67 non-HIZ discs studied, 64 were nonconcordant. Schellhas concluded that in patients with symptomatic lower back pain, the HIZ is a reliable marker of painful outer annular disruption *(13)*.

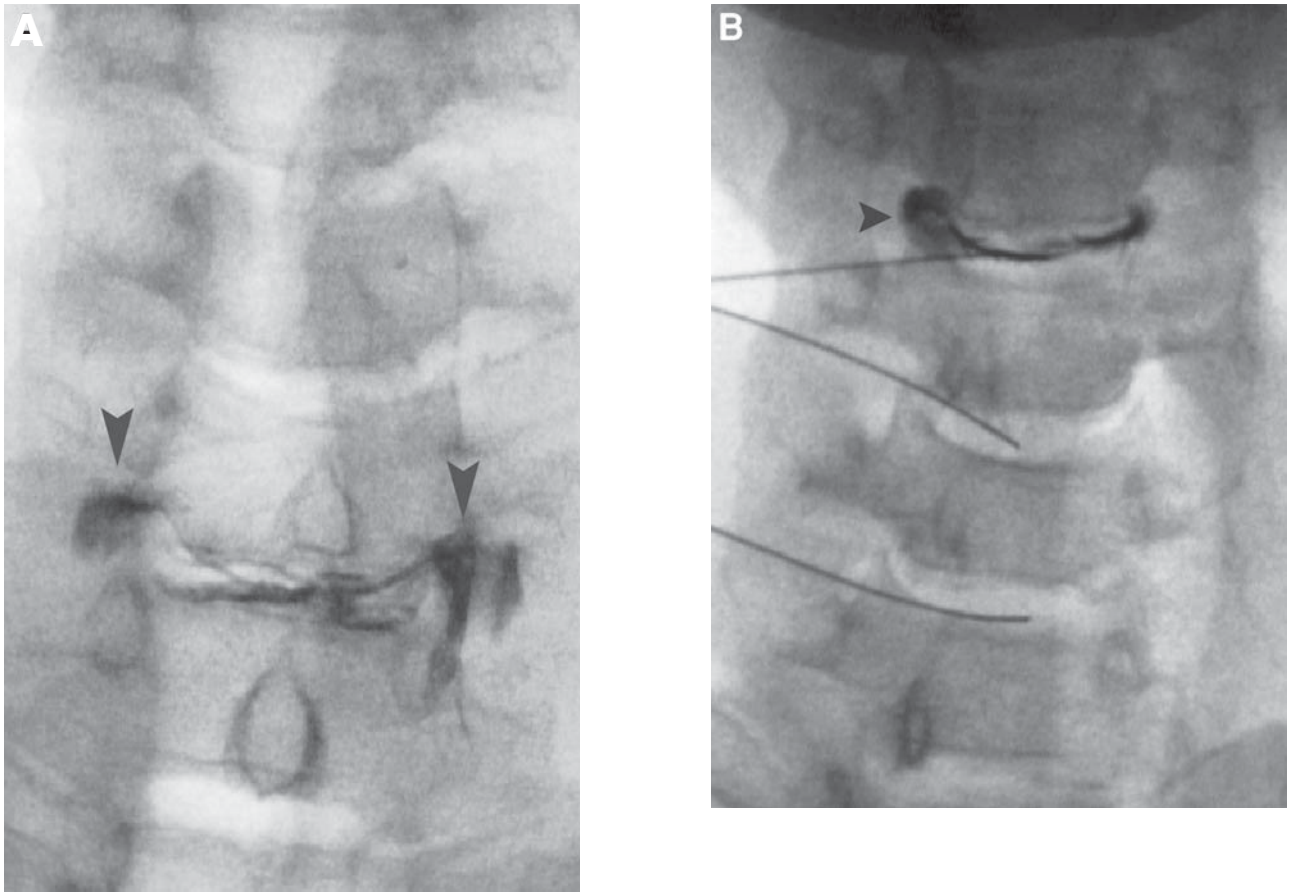


Fig. 18. Cervical spine discogram morphology. **(A)** Anteroposterior fluoroscopic image shows contrast opacifying the nucleus pulposus with extension posterolaterally into the uncovertebral articulations (*arrowsheads*). Opacification of these regions in patients >20 yr old should not be confounded for degenerative disc disease based on this morphologic finding alone. **(B)** Second example of a three-level discogram, with contrast opacifying the uncovertebral articulation (*arrowhead*).

In 1998, Saifuddin et al. retrospectively reviewed 99 lumbar discogram reports in which 260 discs were injected and 179 were abnormal. They found that pain experienced in the buttock, hip, groin, or lower limb can arise from the posterior annulus without direct involvement of the nerve root *(47)*.

Lastly, in 2000, Lam et al. conducted a prospective blinded study in which they found a significant correlation between abnormal disc morphology and the HIZ on MRI. In morphologically abnormal discs, a significant correlation between HIZ and reproduction of exact or similar pain is typical. Sensitivity, specificity, and positive predictive value for pain reproduction were 81%, 79%, and 87%, respectively *(14)*.

CONTRADICTORY EVIDENCE

Caragee et al. conducted a prospective study of 8 patients (24 discs) with no history of lower back pain who had undergone posterior iliac bone graft. They found that 50% experienced concordant pain of the usual gluteal area. Thus, the ability of a patient to separate concordant pain on discography may be less meaningful than often assumed *(48)*.

As previously mentioned, Carragee et al. evaluated the incidence of chronic back pain 1 yr after diagnostic discography in a cohort of patients with no prior history of back symptoms. Of the patients with normal psychometric testing, none reported persistent back pain following discography. However, patients with abnormal psychomotor testing reported a 40% incidence of new low back pain while patients with somatization disorder demonstrated a 66% incidence of new low back pain *(41)*.

Finally, Carragee also prospectively studied patients with and without lower back pain after laminotomy and discectomy. From a cohort of 240 patients who had undergone single-level discectomy, 20 asymptomatic patients with normal psychometric test results were recruited for three-level discography. A control group consisted of 27 symptomatic patients who had undergone single-level discectomy. The asymptomatic patients had a 40% rate of positive injection, while the symptomatic group had a rate of 63% *(49)*.

Carragee is not the only investigator to provide contradictory evidence for discography. Grubb and Kelly conducted a retrospective study of 173 cervical discograms over 12 yr. Of the 807 disks injected, 50% yielded concordant pain response. More than half of the discograms yielded three or more painful discs, which were more than the investigators expected *(50)*.

Rhyne et al. evaluated 25 patients with chronic low back pain (>6 mo duration) unresponsive to conservative therapy. All 25 patients had a single-level concordant discogram but refused surgery. Sixty percent of the patients were receiving workers' compensation while 32% were being treated for a psychiatric disorder. At an average follow-up of almost 5 yr, 68% had improvement in their symptoms, 8% were unchanged, and 24% had worsened. The patients who improved had a shorter duration of symptoms (3.5 yr vs 11 yr) and were older (45 yr vs 33 yr). Of the patients who worsened, two thirds were diagnosed with a current psychological disorder *(51)*.

WHAT DOES IT ALL MEAN?

Discography is positive in a high percentage of radiographically abnormal discs and in a small number of radiographically normal discs. It is unreliable in patients with secondary gain and psychological conditions.

CONCLUSION

Although discography remains controversial, the literature supports the use of discography in selected patients. A position statement regarding lumbar discography from the North American Spine Society (NASS) was published in 1995 *(31)*. Discography is useful in patients with persistent pain in whom noninvasive imaging and other tests have not provided sufficient diagnostic information. In preoperative patients who are to undergo fusion, discography can be used to determine if discs within the proposed fusion segment are symptomatic and if the adjacent discs are normal. In postoperative patients who continue to experience significant pain it can be used to assist in differentiating between postoperative scar and recurrent disc herniation or to evaluate segments adjacent to the arthrodesis. Also, less invasive forms of intradiscal therapy are evolving (e.g., percutaneous disc decompression using coblation and intradiscal electrothermal anuloplasty), which may make discography more relevant. One important consideration is that biomechanical and biological factors constrain the path of disc repair. Thus, biomaterials that either provide scaffolding or promote healing are theoretically favorable, and to be deployed successfully, they will need a suitable percutaneous delivery system. Therefore, discography techniques will likely be important for the next generation of minimally invasive intradiscal therapies

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13 Treatment of Discogenic Back Pain

JEFF S. SILBER, MD, J. KEVIN MCGRAW, MD, AND JOHN A. LIPPERT, MD

INTRODUCTION

Chronic lower back pain is a common cause of disability, with an estimated 5% of the American population suffering from chronic lumbar area pain. Fortunately, most patients with low back pain respond to conservative therapy. However, epidemiological studies have shown that more than 60% of patients will suffer from recurrent symptoms *(1)*. Of those myriad of patients with low back pain, the prevalence of clinically significant discogenic pain approaches 40% *(1)*. In the United States, between 3 and 6 million patients suffer from chronic discogenic low back pain. Treatment options for discogenic pain include conservative measures such as analgesics, antiinflammatory agents, steroid injections, and physical therapy. As not all chronic low back pain is discogenic, evaluation of patients for facet disorders, sacroiliac joint abnormalities, psychosocial problems, systemic disease, neoplasm, and infection is warranted. Chronic discogenic pain remains a challenging clinical entity to manage, particularly because patients present with a variety of chronic pain syndromes and many treatment options remain controversial.

After Mixter and Barr established the relationship between intervertebral disc disruption and back pain *(2)*, investigators attempted to find minimally invasive ways to treat this pervasive problem. These procedures included chemonucleolysis *(3)*, automated percutaneous lumbar discectomy (APLD) *(4)*, and percutaneous laser discectomy *(5)*. Now, newer, minimally invasive techniques such as intradiscal electrothermal therapy (IDET) (Oratec Interventions) and Nucleoplasty (ArthroCare Spine) may play an important role as an intermediate treatment for patients suffering from discogenic pain when conservative therapies have failed. More aggressive approaches used for the patient with persistent symptoms refractory to conservative management include surgery with discectomy and spinal fusion, but these operative techniques are associated with a distinct morbidity (Fig. 1). In fact, the scientific data supporting surgical spinal fusion to treat patients suffering from low back pain in the absence of fracture, neoplasm, or spondylolisthesis are lacking *(6)*. To date, there is no evidence to suggest that spinal fusion can improve sitting tolerance, one of the more common disabling symptoms of patients with chronic discogenic low back pain.

THE PATHOPHYSIOLOGY OF LUMBAR DISC DISRUPTION

Understanding the pathophysiology of discogenic pain is critical for understanding the treatment options. Discogenic pain represents a complex interaction of multiple pathologies. The intervertebral disc is an innervated structure capable of producing severe pain *(7)*. In addition, pain fibers (nociceptors) are present in the outer posterolateral portion of the disc. Nociceptor afferent pain transmissions are relayed through the dorsal root ganglion *(8)*. Ingrowth of granulation tissue and small unmyelinated fibers has been shown to occur in the degenerated disc *(9)*. The degenerating disc loses water with a reduction in the nuclear hydrostatic pressure, leading to buckling of the annular lamellae and increased mobility. As the process continues, the annular wall shear stresses produce radial or concentric fissures of the annulus fibrosis, causing altered disc mechanics *(10)*. The discogenic pain develops with any combination of annular fissures,

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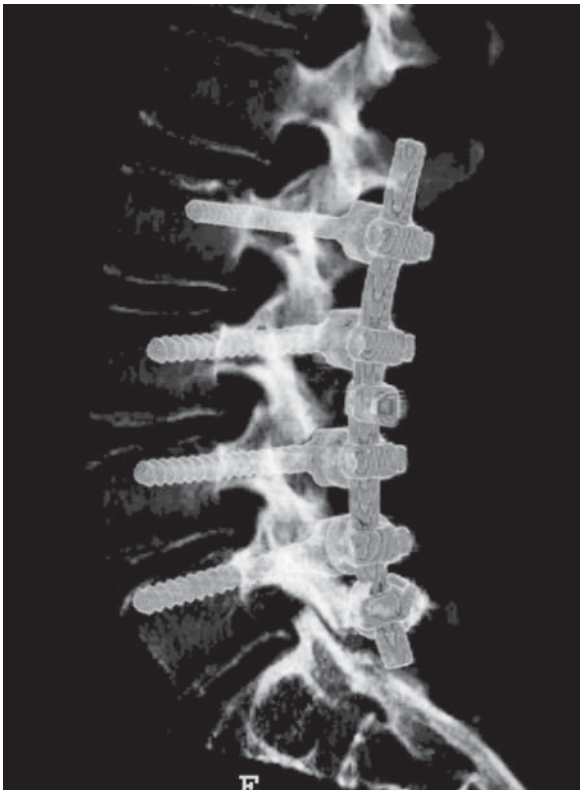


Fig. 1. Computed tomography three-dimensional reconstruction of lumbar spine following posterior spinal fusion. (Courtesy of Philips Medical Systems, Bothell, WA.)

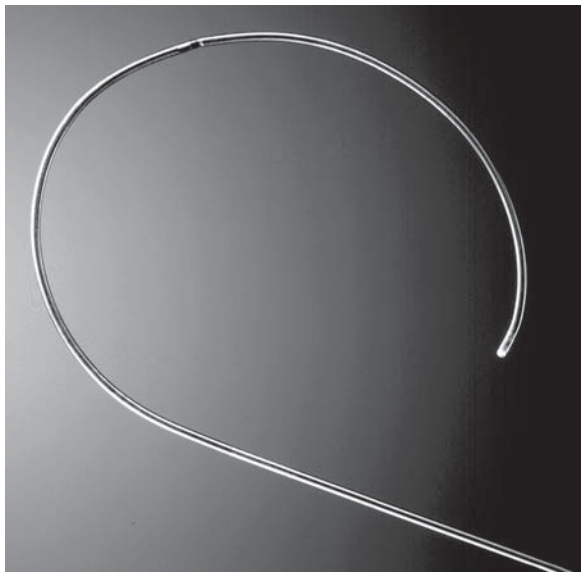


Fig. 2. Intradiscal electrothermal therapy catheter (Courtesy of Smith and Nephew, Menlo Park, CA.)

delamination, or micro-fractures of collagen fibrils leading to mechanical distortion of the annular lamellae and sensitization of nociceptors with release of substance P. In fact, provocative discography triggers substance P release *(11)*. As a result of stimulation of the dorsal root ganglion or direct chemical irritation of the nerve roots, the patient may experience referred pain to the buttocks and legs *(39)*. Patients may present with one of three general types of disc pathologies. The first is the classic "leg pain" disc caused by disc herniation with nuclear migration through an annular tear and sciatica due to true dural tension. The internally disrupted disc with annular pathology, which produces back pain and variable amounts of buttock and leg pain but no true radiculopathy, causes the "back pain" disc. The "mixed" pattern of painful disc disease presents with features of both pathologies caused by small, contained disc herniations and central herniations.

There is a continuum of disc degeneration that starts with loss of nuclear hydrostatic pressure. This may lead to an annular tear. An annular tear can result in a contained disc rupture or a noncontained disc rupture. A contained rupture is contained by the posterior longitudinal ligament. Conversely, a noncontained rupture extends beyond the posterior longitudinal ligament. There are two types of a contained rupture, a disc protrusion and a subannular–ligamentous disc extrusion. Likewise, there are two types of noncontained rupture, a transannular disc extrusion and a sequestered disc. Contained ruptures (contained by the posterior longitudinal ligament) may be treated with minimally invasive techniques whereas non-contained ruptures usually require surgical intervention.

MECHANISM OF ACTION

INTRADISCAL ELECTROTHERMAL THERAPY

The mechanism of action of IDET is primarily based on two factors, nerve fiber damage and collagen contraction. Heat energy has been used for many clinical applications, including tumor ablation and thermal coagulation as well as physical therapy for many years. Recently radiofrequency energy has been used for lax shoulder capsules to shrink collagen within the capsule.

The effect of heat on neural tissue is an important factor in the effectiveness of IDET. The disc has been shown to be an innervated structure. Bogduk illustrated the sources of lumbar disc innervation *(7)* and Coppes et al. demonstrated nociceptive receptors in the outer annular wall *(12)*. Fremont showed nerve fibers to be as central as the inner third of the annulus in location, with occasional fibers extending into the nucleus pulposus *(13)*. Thermal destruction of nerve tissue is widely used in the brain as well as elsewhere. Brodkey et al. established irreversible blocks, which occur at 45°C in the brain *(14)*. With IDET, heat produced by a thermal resistive coil is conducted to the annular wall (Fig. 2). The catheter reaches 90°C but the outer annular wall usually attains a temperature

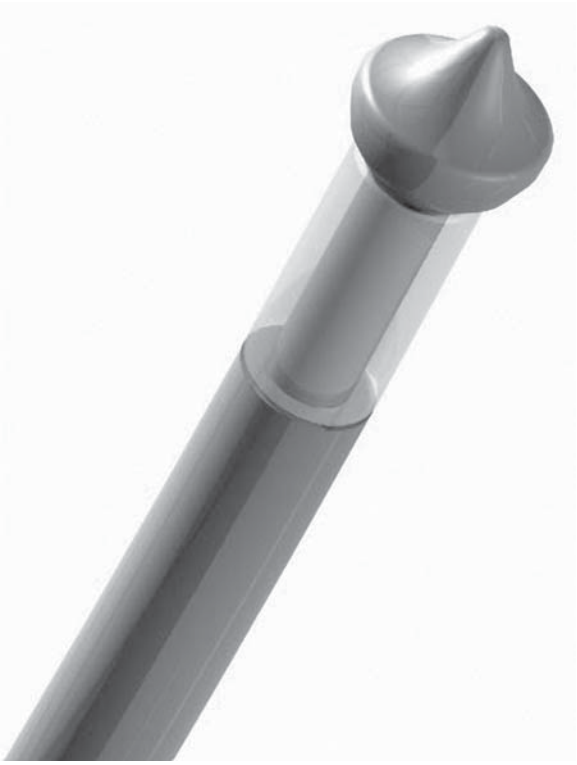


Fig. 3. Diagram of Perc-D Spine Wand used for nucleoplasty. (Courtesy of Arthrocare Spine, Sunnyvale, CA.)

between 46 and 48°C. This is felt to be sufficient for the destruc-tion of pain fibers or nociceptors.

The effect of heat on collagen is also felt to be a contributing factor. The intervertebral disc is composed of type 1 and type 2 collagen fibers, which are similar in molecular structure. Their strength is due to a triple helix molecule, crosslinked with hydrogen bonds. Collagen shrinks when heated because of disruption of the heat-sensitive hydrogen bonds *(15,16)*. The optimal temperature for collagen contraction is reported to be 65°C *(17)*. In addition to the temperature, the degree of contraction is related to the duration of heat applied, with more contraction with longer periods of heat exposure *(17)*. IDET can shrink the fibers of the disc annulus and nucleus, and thus can relieve the pressure of a disrupted disc by decreasing the volume of the nucleus pulposus *(18)*. In addition, the contraction and concomitant tightening of the annular fibers with stabilization of fissures may also enhance the structural integrity of the degenerated or damaged disc. As the intervertebral disc is relatively avascular, the heat is held in the disc tissue with little temperature fluctuations during treatment. The spinal cord and nerve roots are protected from thermal injury by the adjacent vascular circulation, which rapidly dissipates the heat conducted beyond the disc.

The combination of nociceptor heat damage and collagen contraction together result in the effective treatment observed with IDET. It is likely that the degree of therapeutic contribution varies depending on the patient and the underlining diseased disc. In other words, the relative value of the collagen shrinkage and nerve destruction is likely different in each patient.

NUCLEOPLASTY

Nucleoplasty represents a nuclear-reducing procedure very much like chemonucleolysis, APLD, and laser discectomy. It has been shown with APLD and percutaneous laser discectomy that decompressing the disc centrally also decompresses a contained herniation at the disc periphery *(19–22)*. In addition, studies with pressure transducers inserted into the nucleus showed a sharp drop in nuclear pressure after ablation of nuclear material. It is felt that the rapid drop in intradiscal pressure may be a factor in the relief of symptoms in many patients undergoing laser discectomy *(23)*. Nucleoplasty accomplishes disc decompression by a multifunctional bipolar radiofrequency probe that uses Coblation technology to ablate tissue, while alternating with thermal energy for coagulation *(24)* (Fig. 3). As the Perc-D spine wand (ArthroCare, Sunnyvale, CA) is advanced into the nucleus, tissue ablation (Coblation) occurs. Coblation generates approx 125 V of energy at the tip of the wand with a resultant tip temperature of 50–70°C. As the spine wand is pulled back into the introducer needle coagulation occurs. The coagulation mode is 65 V of energy and a tip temperature of 70°C. Tissue ablation occurs by molecular dissociation while coagulation occurs by resistive heating. During ablation, an ionized plasma field is created at the wand tip with the plasma field reaching depths of approximately 120 µm. The ionized plasma field breaks molecular bonds. The nuclear tissue is then broken down into the elementary molecules and low molecular weight gases such as oxygen, nitrogen, hydrogen, and carbon dioxide. These low molecular weight gases are then expelled from the disc via the introducer needle. Coagulation occurs as a zone of resistive heating is created with the depth of the zone varying by the speed of wand movement. If the wand is pulled back into the introducer needle at 0.5 cm/s, approx 1 mm radius of coagulation will occur *(24)*. It has been shown that when six channels are created, approx 1 cc of nuclear tissue is removed *(24)*.

INDICATIONS

IDET

The process of patient selection involves identification and exclusion of patients who would be unlikely to ben-

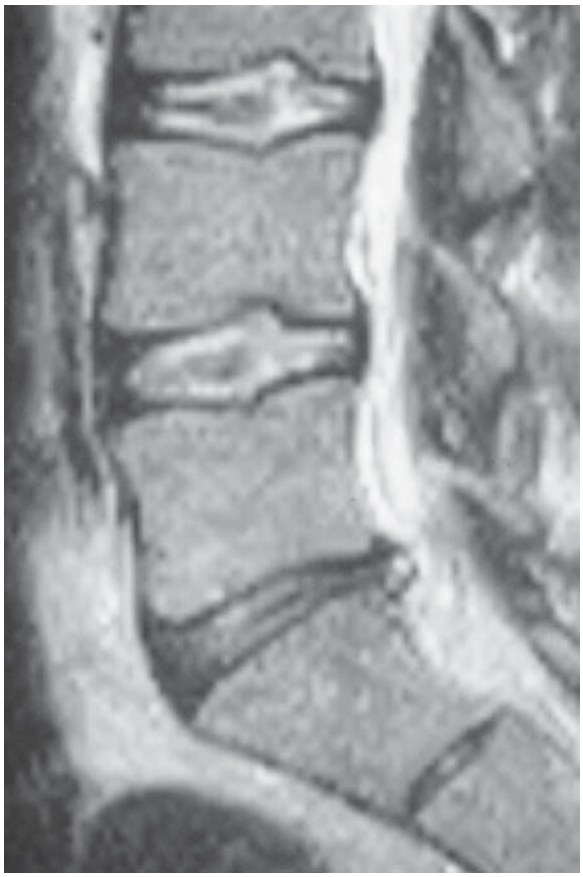


Fig. 4. Sagittal T2-weighted MRI of the lumbar spine showing disc desiccation (dark signal on T2-weighted image) and a bulge at L5–S1. Also note a high-intensity zone (HIZ) posteriorly. A HIZ has a strong correlation with an annular tear.

efit from the IDET procedure. Patients with mild to moderate degenerative disc disease, absent radicular symptoms, and a positive disco-gram are the best candidates for IDET. Patients with discogenic pain following previous discectomy may also be good candidates. Patients with severe radicular symptoms due to a frankly herniated disc are not candidates for the procedure. Careful patient evaluation allows for appropriate exclusion of patients with multifactorial back complaints who would be unlikely to benefit from IDET. The inclusion criteria for IDET include function-limiting low back pain of at least 3–6 mo duration, lack of satisfactory improvement with a comprehensive nonoperative care program, a normal neurological examination, negative straight leg raise maneuver, magnetic resonance imaging (MRI) without neural compressive lesion, and concordant pain on a provocative discogram.

The findings of disc desiccation and the presence of a high-intensity zone have been shown to have a high correlation with an annular tear in most patients *(25,26)* (Fig. 4). The high-intensity zone is, however, present in only 20–30% of patients with annular tears; therefore, discography is an essential diagnostic criterion (Fig. 5). Patients may have a painful annular tear without concomitant MRI findings. Disc bulging is always associated with annular degeneration and fissures; however, the presence of disc bulging does not necessarily produce clinically significant discogenic pain *(27)* (Fig. 6). Discography is performed at all abnormal and possibly symptomatic disc levels demonstrated on MRI as well as at a normal MRI disc control level. Multiple regression analyses have established that radial fissures are not a feature of degeneration and that degenerative changes do not correlate with pain, but that radial fissures correlate strongly with the reproduction of pain when the disc is stressed during discography *(28)*. If concordant pain, that is, pain representing the patient's typical symptoms, is reproduced at discography, the patient is a candidate for the IDET procedure. If the pain at discography is not concordant, the IDET procedure is not offered. The patient is usually then further counseled on what to expect from the IDET procedure and the postprocedural course. The IDET procedure may then be performed, at least 1 wk following discography. The physiologic rationale for the delay is that the liquid contrast within the disc could potentially cool the IDET catheter and prevent the even distribution of thermal energy into the posterior annular wall. Patients who usually respond most favorably are young, nonsmokers, highly motivated individuals, and those who have an annular tear.

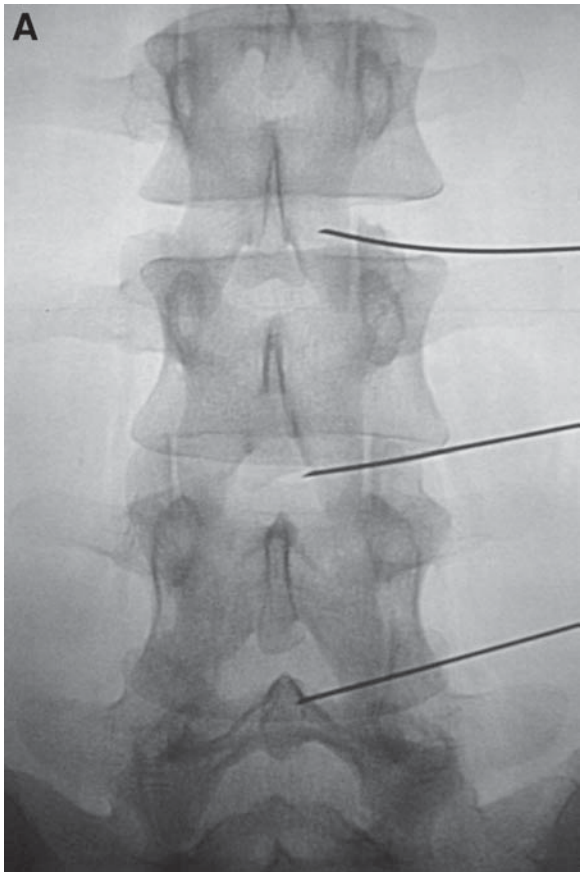
NUCLEOPLASTY

Inclusion criteria for nucleoplasty usually include a patient who has radicular pain out of proportion to back pain, although nucleoplasty has been used exclusively on axial back pain. Patients should also have MRI evidence of a contained disk herniation and symptoms that correlate with the MRI findings. Patients should have failed conservative therapy for at least 6 wk. Most advocate performing provocative discography to determine candidacy at a concordant level, particularly in the axial back pain group. It is also useful to perform a diagnostic nerve root block at the suspected level of pathology in patients with radicular pain. If the patient has symptomatic relief, then nucleoplasty may be beneficial.

CONTRAINDICATIONS

IDET

Contraindications to the IDET procedure include large disc herniations (Fig. 7), nerve root irritation secondary to mass effect, central stenosis, instability, and disc height loss beyond 50% (Fig. 8).



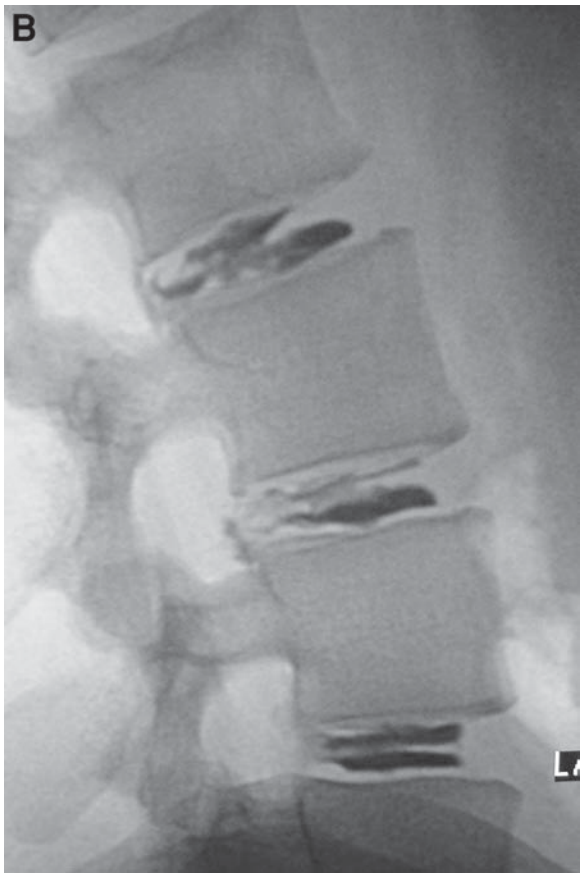


Fig. 5. **(A)** Frontal image of discography needles in position before contrast injection. **(B)** Lateral image of a three-level discogram.

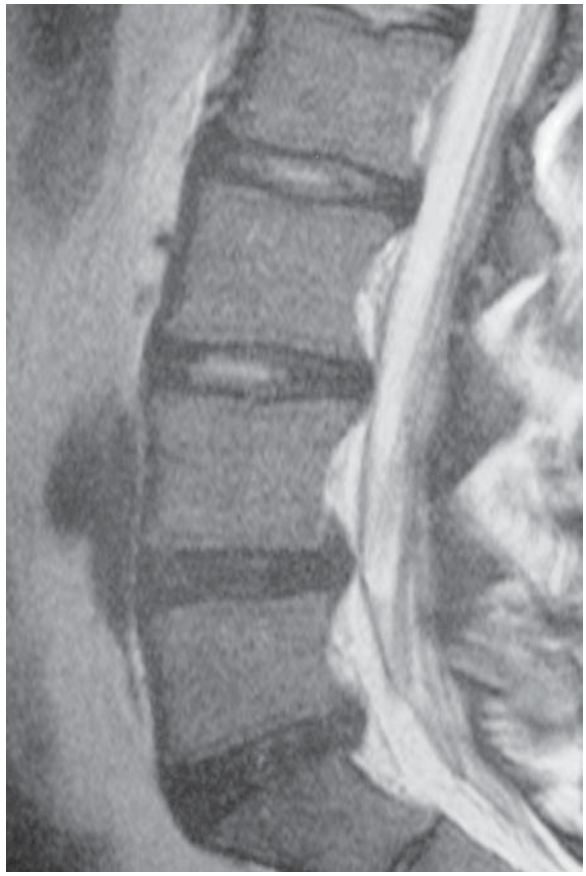


Fig. 6. Sagittal T2-weighted MRI of the lumbar spine showing disc bulges and desiccation (dark signal on T2-weighted image) at L4–5 and L5–S1.

NUCLEOPLASTY

Exclusion criteria are essentially the same as for IDET and include loss of disc space height by more than 50–75%, complete annular disruption, extruded disc fragments, disc herniation >33% of sagittal diameter of the spinal canal, spinal fractures, tumor, and moderate to severe spinal canal stenosis.

TECHNIQUE

PATIENT PREPARATION

Nucleoplasty and IDET are performed as outpatient procedures. After informed consent is obtained, the patient is placed in the prone position. Intravenous conscious sedation is then administered, attempting to allow the patient to be relaxed, but he or she must be able to give important feedback during the procedure. The skin is prepped and draped for a potential bilateral approach. If L5–S1 is the disc to be treated, placing a pillow under the patient's abdomen may help by reducing the lumbar lordosis. Also, a side bend may facilitate disc access by lowering the iliac crest.

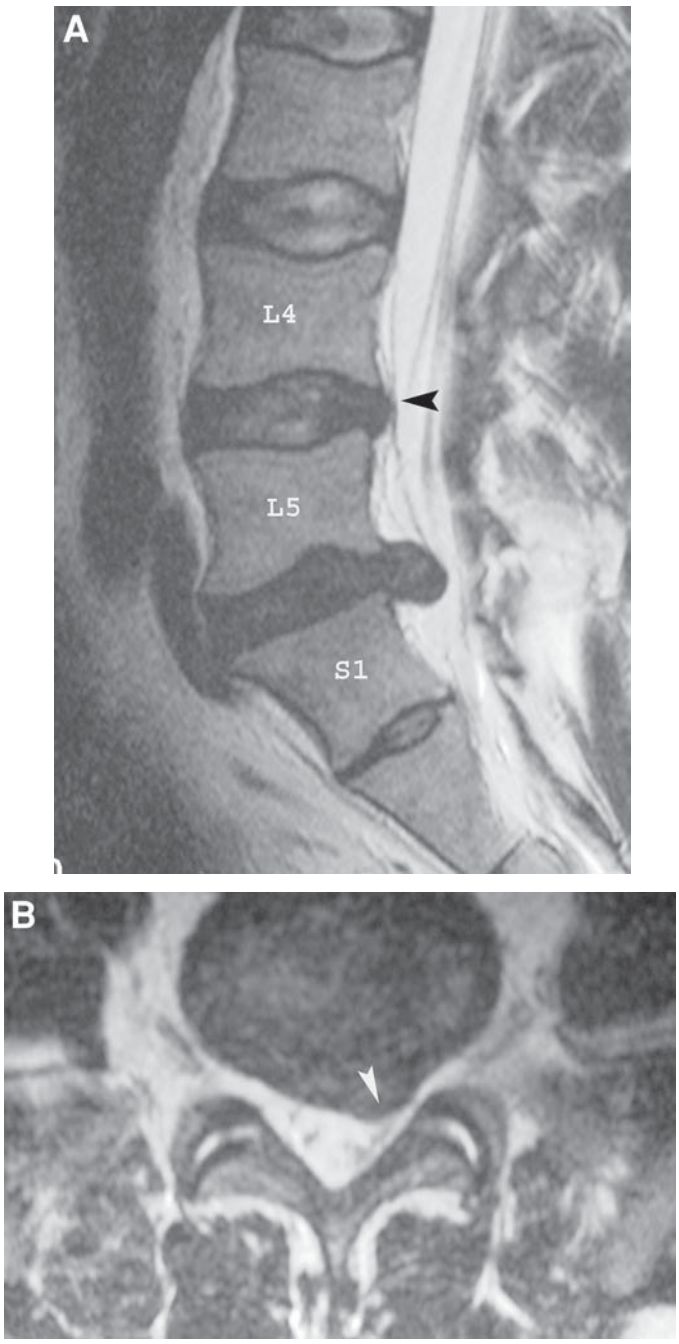


Fig. 7. **(A)** Sagittal T2-weighted MRI of the lumbar spine showing a large disc herniation at L5–S1. This would not be amenable to percutaneous techniques. Also notice the disc bulge at L4–5 (*arrowhead*). This could be treated with IDET or nucleoplasty if indicated. **(B)** Axial T2-weighted MRI at L5–S1. The *arrowhead* demonstrates the large disc herniation.

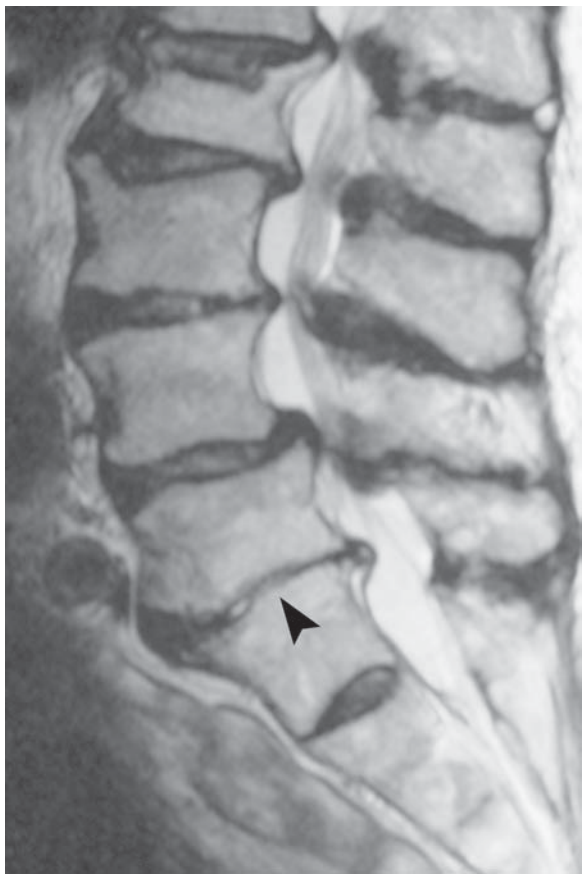


Fig. 8. Sagittal T2-weighted MRI of the lumbar spine showing multilevel degenerative disc disease with severe disc space narrowing at L5–S1.

NEEDLE PLACEMENT

The disc to be treated is localized under fluoroscopy. The image intensifier (II) is angled either cranially or caudally to open the disc space. The II is then rotated into an oblique position until the superior articular process (SAP) bisects the disc space. A metal marker can be used to determine the skin entry site. The skin is infiltrated with a local anesthetic using a 25-gauge needle. A 22-gauge spinal needle can be used to anesthetize the deeper structures. Using a "down the barrel" approach, the 17-gauge introducer needle is advanced until it contacts the outer annulus. The needle is advanced in a path anterior to the articular facet and above the pedicle to avoid nerve roots (Fig. 9). The lumbar nerve roots typically exit below the pedicle and course obliquely inferiorly and laterally (Fig. 10). Occasionally, the introducer needle can be curved to facilitate L5–S1 access.

IDET

Once the needle is in the disc, position is checked in the frontal and lateral projection. The optimal needle position is within the center of the disc (Fig. 11). The stylet is then removed and the Spine Cath, a steerable and flexible probe with a distal thermal resistive coil portion, is advanced using frontal and lateral fluoroscopy for guidance (Fig. 12). The catheter will pass through the nucleus and curl along the interface of the nucleus and annulus with little resistance. If resistance is met or the path of the catheter is outside of the expected confines of the disc, the catheter

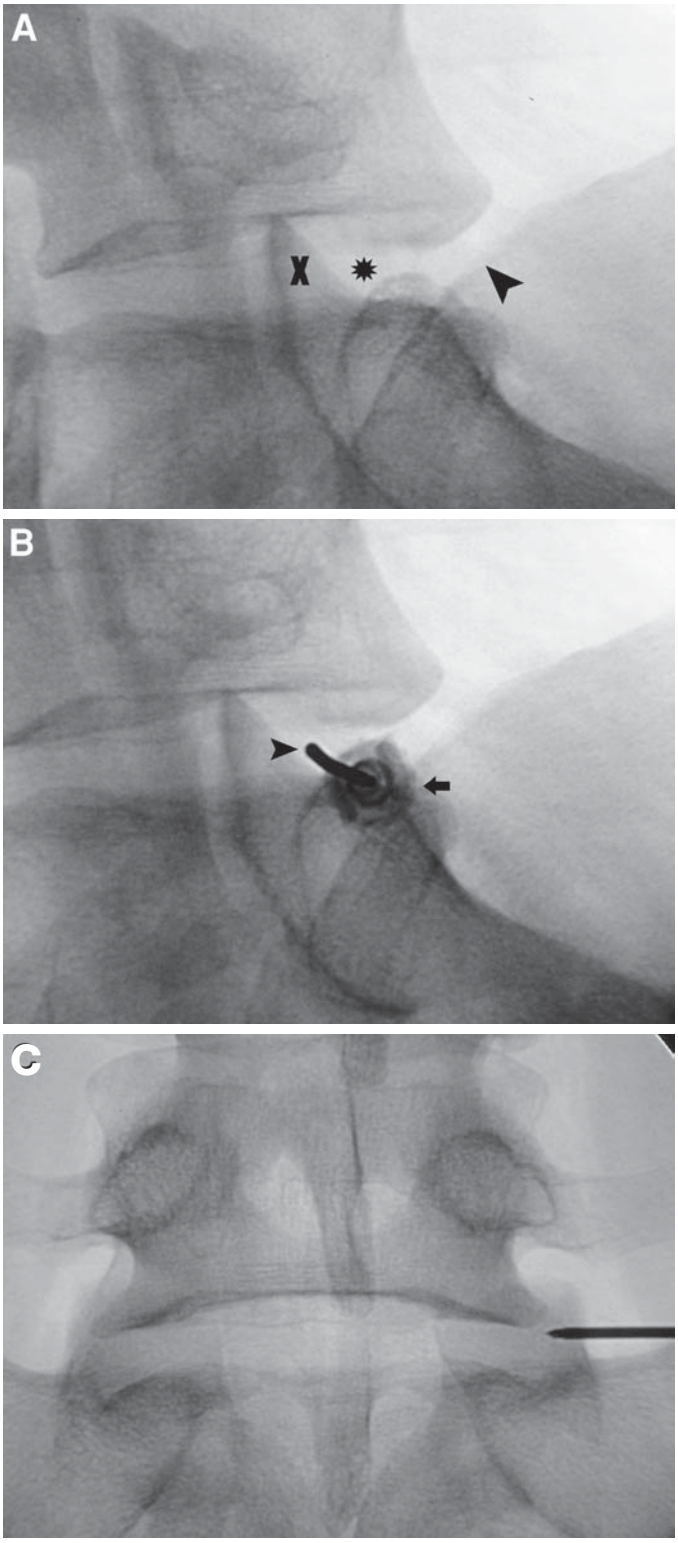


Fig. 9. **(A)** Oblique image with cranial angulation to open the L5–S1 disc space for needle entry. The needle should enter the disc just anterior to the superior articular process of S1 (X). The intended needle entry site is indicated by the *star*. The *arrowhead* indicates the iliac crest. **(B)** Using a "down the barrel" approach, the needle is advanced until resistance is felt. This usually indicates the outer annulus. (The *arrowhead* is at the needle tip; the *arrow* demonstrates the needle hub.) **(C)** Once resistance is felt, the image intensifier is rotated to the frontal projection and the needle is advanced into the disc. For IDET, the needle is advanced into the center of the disc. For nucleoplasty, the needle is advanced to the nuclear–annular interface.

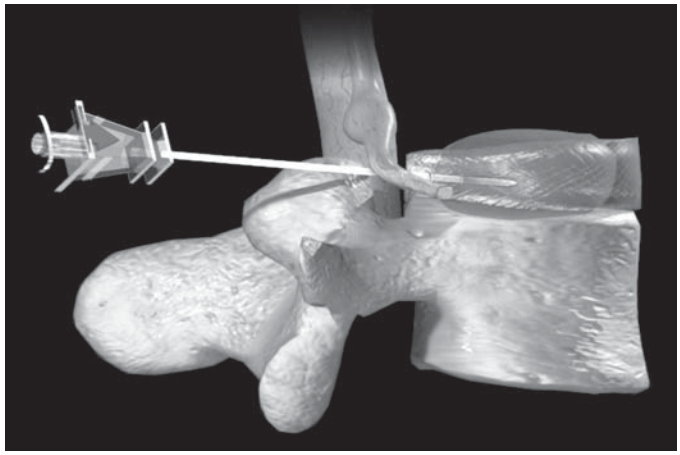


Fig. 10. Diagram showing correct needle placement under the exiting nerve root. (Courtesy of Smith and Nephew, Menlo Park, CA.)

is partly withdrawn and redirected by turning the hub. Ideal placement is along the entire posterior annulus from the 3 o'clock to the 9 o'clock position (Fig. 13). In approximately one third of the cases, only half of the posterior annulus can be covered by this approach with the catheter being caught in annular fissures posteriorly. This can sometimes be avoided by reviewing the morphology of annular fissures at the post-discogram CT scan. If this cannot be avoided, the procedure is completed by placing a contralateral needle and spine catheter. Before applying heat, one must confirm that the catheter is contained within the disc space and that the heat delivery portion of the catheter, which is indicated by radiopaque markers, is beyond the needle tip. Once optimal catheter position is achieved, the generator is attached to the catheter by sterile cables (Fig. 14). The heating protocol, which includes slowly increasing the temperature of the catheter from 65 to 90°C, is then begun. The protocol typically lasts 16 min and requires frequent patient feedback. Patients usually feel no discomfort until the temperature reaches 75°C within the catheter, at which point reproduction of their usual symptoms may occur, similar to discography. If radicular symptoms are present with pain extending below the knee, the unit is turned off and the catheter is repositioned. Once the protocol is completed, the catheter is withdrawn with a steady pull, with care to avoid shearing the catheter on the introducer needle. An antibiotic can be administered into the disc via the 17-gauge needle. Some operators will choose to administer intravenous antibiotics. The needle is then removed and manual compression is applied. The patient is transferred to a recovery area and observed in the supine position for 1 h.

NUCLEOPLASTY

With Nucleoplasty, the 17-gauge needle is positioned at the posterior nuclear–annular interface. Through this

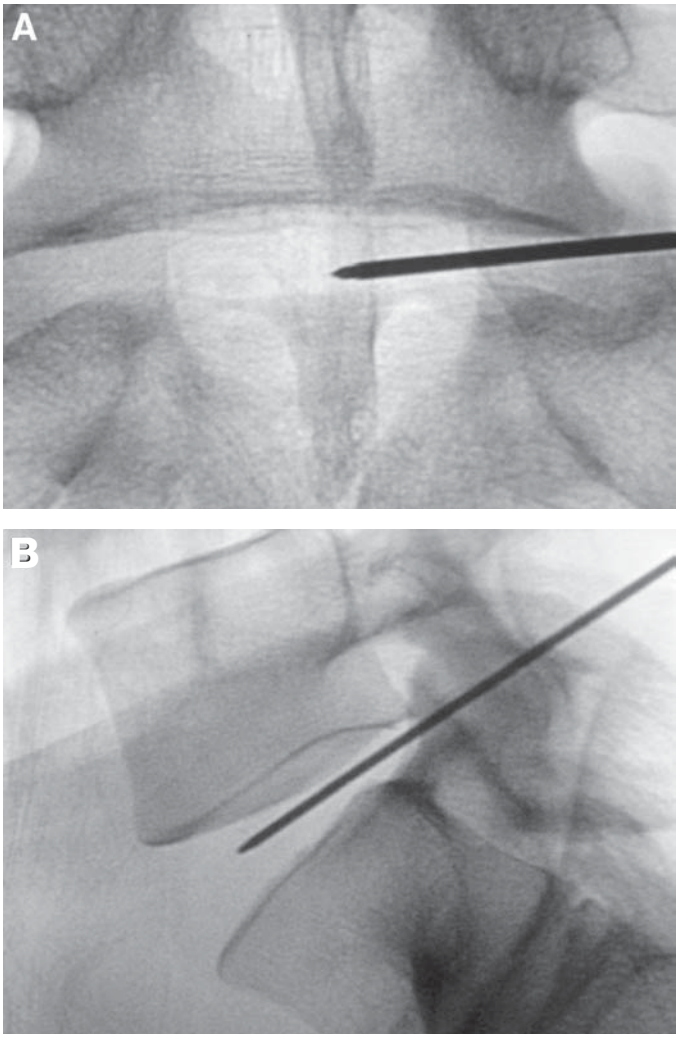


Fig. 11. **(A, B)** Frontal and lateral image showing correct needle position in the disc prior to IDET catheter insertion.

17-gauge needle the Perc-D Spine Wand is introduced. The Wand is advanced to the anterior nuclear–annular interface (Fig. 15). The position must be confirmed with fluoroscopy. The Wand is attached to the generator and advanced under the Coblation mode, and withdrawn under the coagulation mode (Fig. 16). Six channels are created within the disc with rotation of the Spine Wand to the 12 o'clock, 2 o'clock, 4 o'clock, 6 o'clock, 8 o'clock, and 10 o'clock positions. Because of the C-shaped curve at the tip of the Wand, these six channels decompress a cone-shaped area of the nucleus and result in the removal of 1 cc of disc material (Fig. 17). Some practitioners advocate a bilateral disc puncture, or placing the introducer needle within a different portion of the nucleus. This allows removal of approx 2 cc of tissue. After the channels are created, the Spine Wand is removed, followed by removal of the introducer needle. Manual compression is applied to the puncture site, followed by placement of a sterile bandage. Some practitioners will administer intradiscal or intravenous antibiotics.

POSTPROCEDURE PROTOCOL

IDET

After the procedure, patients are maintained in a supine position for 1 h, and then slowly mobilized prior to discharge. They may continue oral analgesics as needed but some practitioners advocate avoidance of antiinflammatory medications for 6 wk. Patients are asked to rest in a comfortable position for the first several days. The patient is typically prescribed a lumbar corset prior to the procedure, so that it will be available at the time of discharge. The lumbar corset is to be worn for the first 6–8 wk. They are instructed to limit their duration of sitting to 30-min time periods for at least the first 6 wk. Their discharge instructions also include no lifting of greater than 5–10 pounds, and no bending or twisting motions for 4–6 wk. A walking program is prescribed, which starts with walking 20 min daily at the end of the first week, with a gradual increase in the time spent walking as tolerated. They are followed up by telephone in 48 h and are seen in an office setting at 2, 6, and 12 wk postprocedurally. Most patients do experience an exacerbation of their pain after the procedure, which gradually subsides over the first 1–7 d. Patients generally return to their preprocedural pain level between the 7th and 14th days after IDET. Patients usually first note improvement in their leg pain symptoms, often within 4 wk. The back pain symptoms commonly require 6–12 wk for significant improvement. Patients can return to a sedentary work environment in 2 wk, but are mandated to limit their time in a sitting position to 30 min at any one time. Light lifting duties may be performed in 6 wk following the IDET procedure. Heavy lifting and physical labor, however, require 4–6 mo to resume safely.

NUCLEOPLASTY

After Nucleoplasty, patients are encouraged to walk, stand, or sit. Patients are instructed to avoid lifting, bending, and stooping. They may return to sedentary or light work 2–4 d after the procedure. Physical therapy is initiated 2–3 wk after the procedure to emphasize lumbar stretching, back strengthening, and proper body mechanics. Usually, by 6 wk postprocedure, patients may return to regular duties. Unlike the situation for IDET, a lumbar brace is usually not recommended for Nucleoplasty.

COMPLICATIONS

IDET

Unfortunately, not all of the published IDET studies have reported complication rates, perhaps because tran-

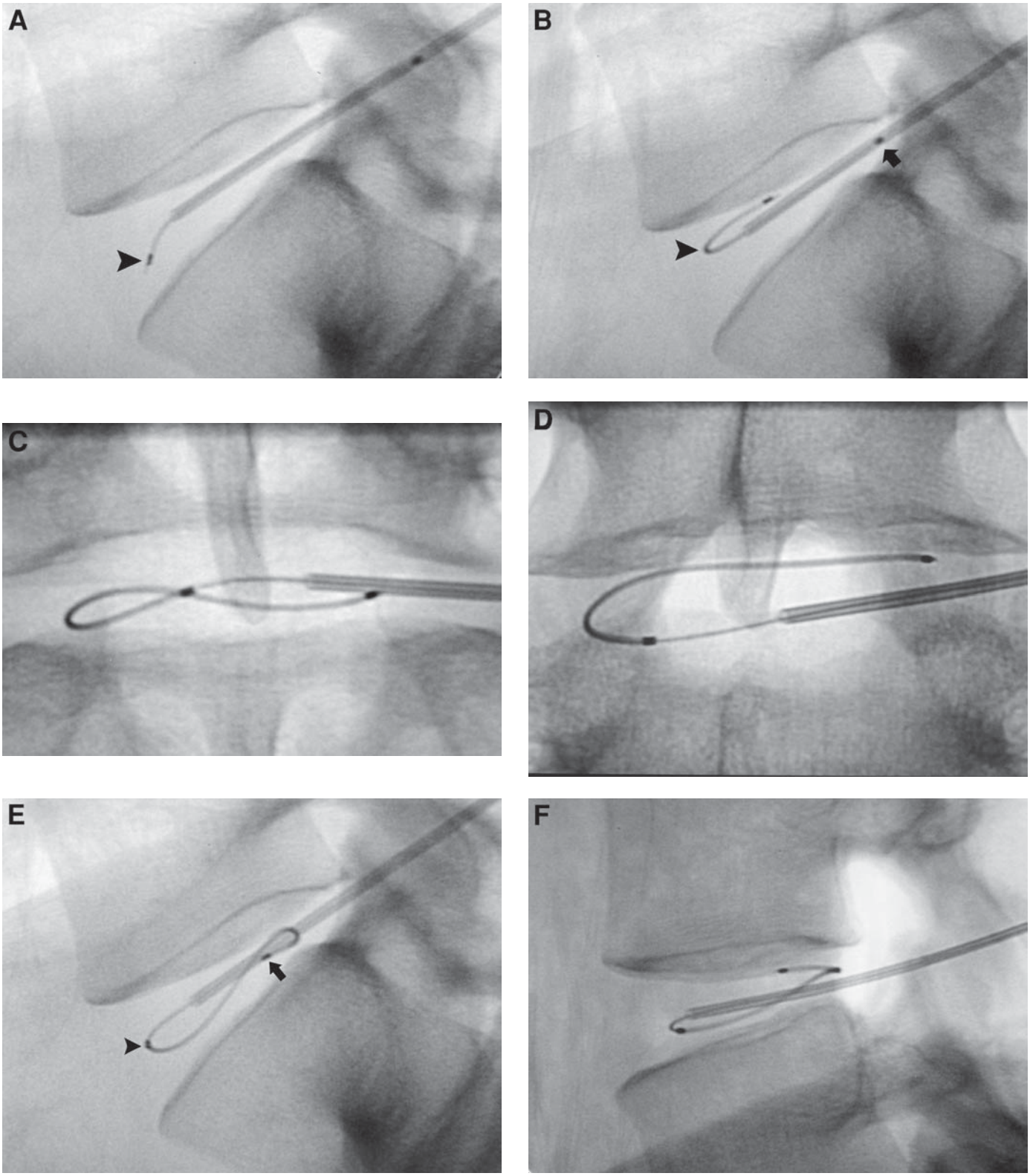


Fig. 12. **(A)** Starting in the lateral projection, the IDET catheter is advanced through the introducer needle; as it reaches the anterior nuclear–annular interface it usually makes a turn (*arrowhead*). **(B)** The catheter is advanced further until it makes a turn posteriorly. The image intensifier (II) is then rotated into the frontal projection. (The *arrow* on distal radiopaque marker still in the introducer needle.) **(C)** In the frontal projection, the IDET catheter is advanced across the disc. Notice how the proximal marker is superimposed on the introducer needle. Care must be taken to ensure that the catheter is not touching the needle. **(D)** By slightly rotating the II either cranially or caudally one can see that the catheter and needle tip are not touching. **(E)** The final catheter position must be verified in the lateral projection to ensure that the catheter is not in the spinal canal. It also appears that the catheter and needle are touching. (*Arrow*, proximal marker; *arrowhead*, distal marker. The heating element lies between the markers.) **(F)** By slightly rotating the II the catheter tip and introducer needle are separated. Now it is safe to proceed with the heating protocol.

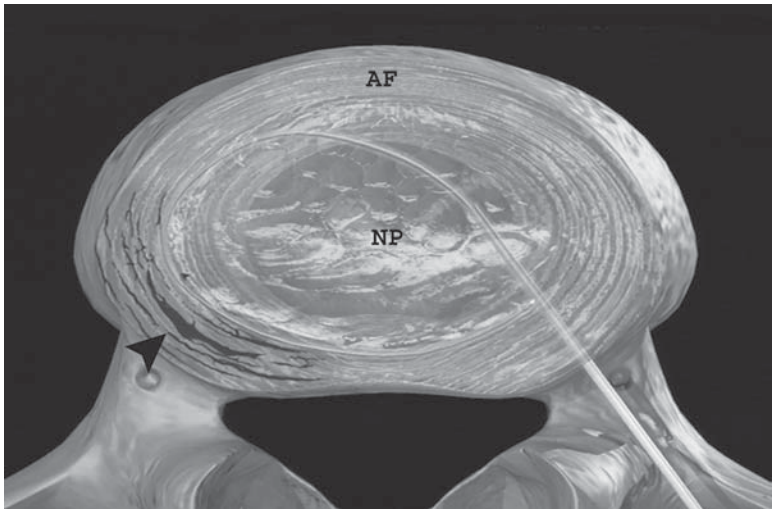


Fig. 13. Diagram showing the correct needle position and catheter within the disc. (The *arrowhead* illustrates an annular tear. AF, Annulus fibrosis; NP, nucleus pulposus.) (Courtesy of Smith and Nephew, Menlo Park, CA.)

sient lower extremity pain is an accepted side effect for a short period of time following the procedure and is not a complication. Saal et al. reported no adverse events or complications in their study of 62 patients followed over 24 mo *(29)*. McGraw et al. reported one minor complication of radicular pain that improved after 6 wk in their study of 30 patients with 41 treatment levels *(30,31)*. In the prospective study reported by Saal et al., they reported no complications in 58 patients followed over a 2-yr duration following treatment with IDET *(32)*. There has been one report of a major complication of cauda equina syndrome, which likely resulted from poor catheter positioning beyond the expected posterior location of the annulus as well as the application of persistent thermal energy despite the patient's complaints of severe lower extremity pain and pelvic pain *(33)*. There has also been one case report of vertebral osteonecrosis following IDET *(34)*. This developed in a 28-yr-old man treated for axial back pain radiating to the buttocks. L4–5 and L5–S1 were treated uneventfully with IDET. The patient returned 5 mo with worsening symptoms. An MRI showed edema in the L5 and S1 vertebral bodies with disc space collapse. Osteomyelitis was considered and the patient underwent a biopsy of L5 and the L5–S1 disc space. The biopsy revealed necrotic bone and disc material with cultures remaining negative *(34)*.

Approximately 25,000 IDET procedures have been performed in the United States at this point, and there have been no reports of discitis. Obviously, given the similarity of this procedure to discography, discitis remains a potential complication. One plausible explanation for the absent discitis rate might be the coaxial nature of the catheter system, such that the catheter within the disc applying the heat to the posterior annulus does not contact the skin, which would be the primary source for infection.

NUCLEOPLASTY

To date, approx 10,000 patients with both axial and radicular pain have been treated. Currently no complications have been reported. As with any percutaneous disc procedure, discitis is a concern.

RESULTS

IDET

There have been several studies reporting the clinical outcomes of IDET in the literature since 1998. The most publicized study was reported by Saal et al., a group of physiatrists from Stanford *(29)*. These investigators reported on a consecutive series of 1116 patients presenting with chronic low back pain of 3 mo duration or longer. Of the study group, 1025 (92%) improved significantly with conservative treatment measures and were discharged to self-care. Surgical fusion was offered to the 91 patients who did not respond to conservative measures. Sixty-two of these 91 patients underwent IDET as an alternative therapy and 29 remained in a control group to assess the impact of natural history on symptom resolution. Data were collected on 58 of the 62 patients treated with IDET at 6, 12, and 24 mo. At 6 mo, there was a significant improvement in the patient's pain with a decrease in the visual analog scale (VAS) of 3.71 ± 1.95. At 12 and 24 mo, the mean decrease in VAS was 3.52 ± 2.30 and 3.41 ± 1.96, respectively *(29)*. Based on these data, the authors concluded a statistically significant reduction in pain was

Fig. 14. Intradiscal electrothermal therapy generator. (Courtesy of Smith and Nephew, Menlo Park, CA.)

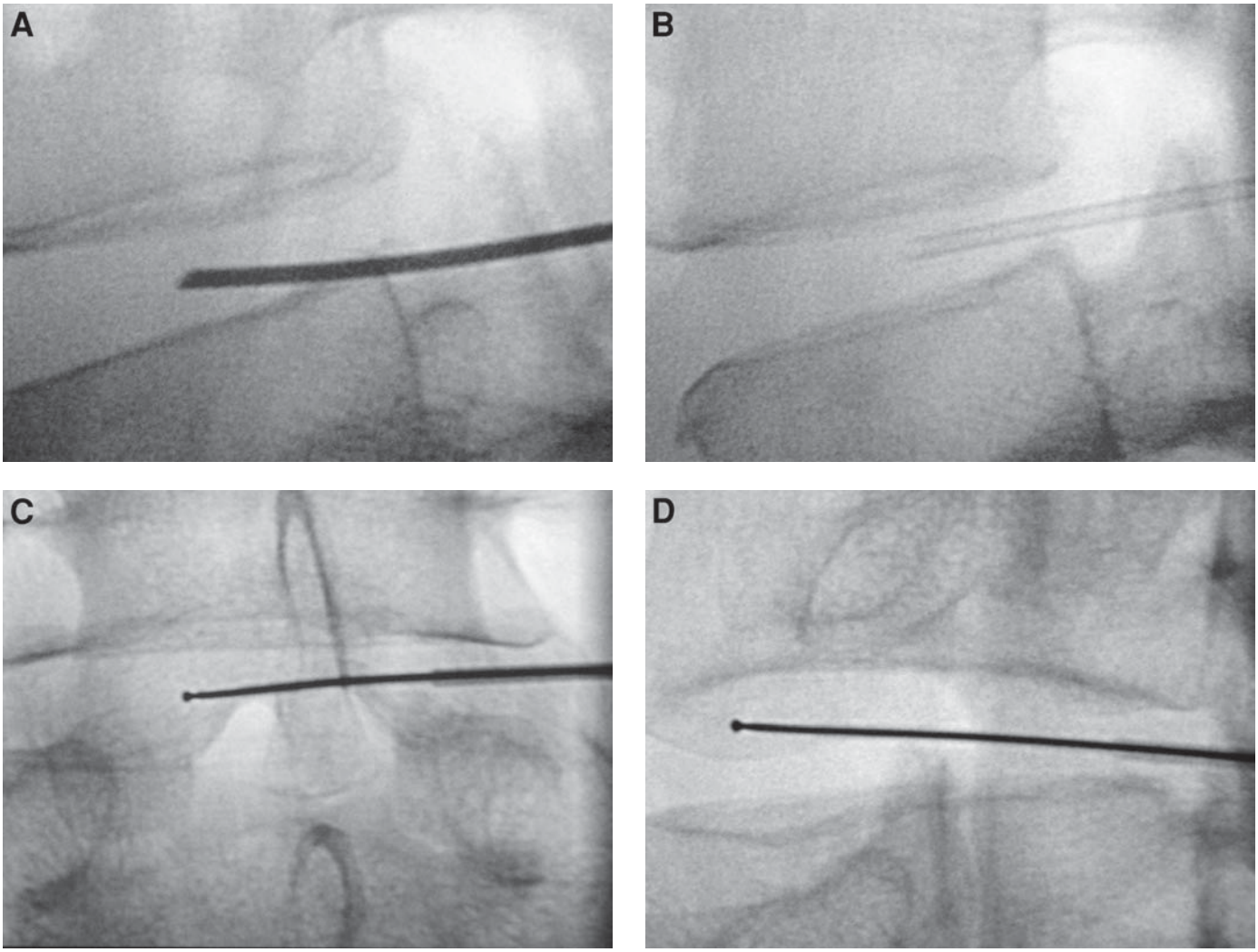


Fig. 15. **(A)** Lateral image of nucleoplasty introducer needle within the disc. **(B)** The inner stylet is removed and the Spine Wand is introduced. **(C)** The Spine Wand is advanced until resistance is felt. This usually indicates the nuclear–annular interface. **(D)** The II is rotated until the X-ray beam is perpendicular to the needle to ensure that the Spine Wand does not go beyond the confines of the disc.

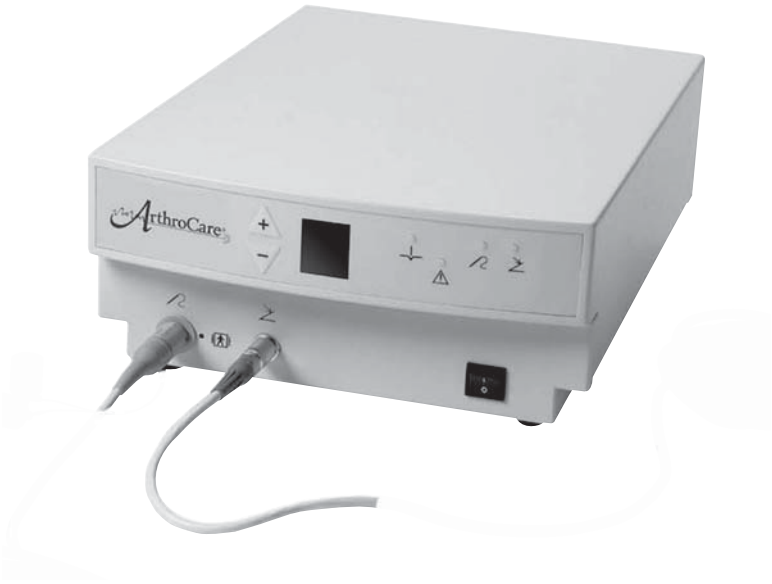


Fig. 16. Nucleoplasty generator. (Courtesy of Arthrocare Spine, Sunnyvale, CA.)

obtained in patients with chronic discogenic low back pain treated by IDET. McGraw et al. treated 41 disc spaces in 30 patients with a follow-up ranging from 2 to 10 mo *(30,31)*. Twenty-one (72%) of patients reported a significant improvement in their back pain with a VAS score decreasing by four or more points. Nine (28%) of the 30 patients had either no improvement or a decrease of fewer than four points in their VAS score. Karasek and Bogduk compared 35 patients treated with IDET to a control group of 17 patients treated with physical rehabilitation only *(35)*. At the 3 mo follow-up, only one control patient had any significant pain relief while 23 patients in the IDET group experienced significant pain relief. In the IDET group, pain relief was sustained at 6 and 12 mo, which was associated with decreased disability, decreased drug use, and a return to work rate of 53% *(35)*.

More recently, Saal et al. reported on a prospective outcome study with a 2-yr minimum follow-up–*(32)*. In their study, they followed longitudinally 58 patients with chronic discogenic disease who had failed conservative therapy for at least 6 mo and then underwent treatment with IDET. Their study group demonstrated a statistically significant improvement in their VAS scores, sitting tolerance, bodily pain, and physical function SF-36 scores, with a significant overall improvement in their quality of life at 2 yr following treatment with IDET. The study population not only demonstrated a statistically significant improvement at 6 mo, but also demonstrated an additional statistically significant improvement in outcomes, increasing over the follow-up duration from 6 to 24 mo *(32)*. A seven-point change in the SF-36 scales has been documented to represent clinically significant improvement *(36)*. In the Saal et al. cohort, 81% of patients experienced a 7-point increase in the SF-36 physical function scale, 72% demonstrated at least a 14-point improvement, 53% demonstrated at least a 21-point improvement, and 45% demonstrated at least a 28-point improvement *(32)*. This study confirmed prospectively that patients appropriately selected for IDET for the management of their low back pain not only experienced a short-term relief in their discogenic pain but also experienced a long-term and durable decrease in their low back pain. Two-year follow-up data have recently been presented by Thompson et al. *(37)*. In this group, 100 patients were studied at 2 yr and >80% had decreased pain that persisted at 24 mo.

There is one randomized, double-blind, placebo-controlled trial evaluating the efficacy of IDET. Pauza et al. reported on 55 subjects (32 IDET and 23 placebo) who were followed for 6 mo *(38)*. As part of the procedure protocol, a 17-gauge introducer needle was advanced under fluoroscopy to the outer annulus. Randomization assignments were then disclosed to the operating physician. In subjects assigned to the IDET treatment group, a catheter was introduced into the disc and advanced to cover the posterior and bilateral posterolateral portion of the disc to be treated. In the placebo group, the needle remained at the outer annulus. Identical postprocedural protocols were followed by both groups. A statistically significant greater improvement in pain, based on the VAS and bodily pain (BP) scale, was demonstrated by the IDET treatment group compared to control. The VAS improved 2.4 points in the treatment group compared to 1.2 points in the control group. The BP score improved 17.3 points

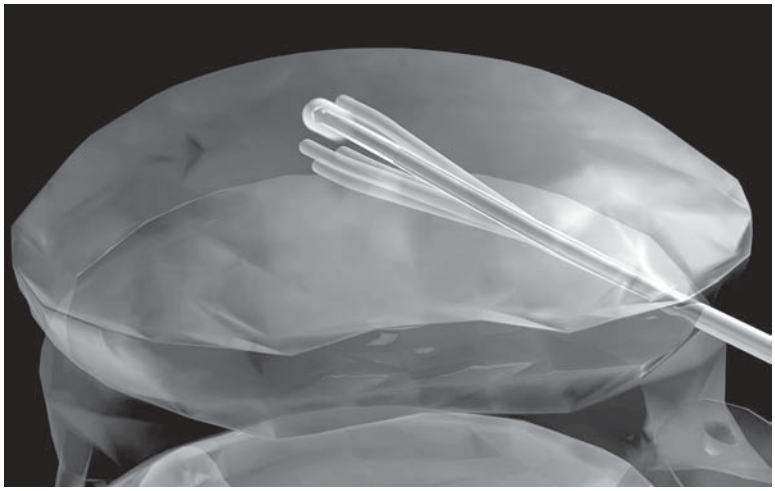


Fig. 17. Diagram of Spine Wand in the nucleus illustrating the six channels that are created with rotation of the Wand. The Wand tip has a gentle S-shaped curve on the end. (Courtesy of Arthrocare Spine, Sunnyvale, CA.)

in the treatment group compared to 8.6 in the placebo group *(38)*.

NUCLEOPLASTY

Because the first nucleoplasty procedure was performed in 2000, long-term results are limited. There are currently two studies in the medical literature. Sharps et al. published preliminary results on 49 patients who underwent nucleoplasty *(40)*. Follow-up was obtained in 49 patients for 1 mo, 41 patients for 3 mo, 24 patients for 6 mo, and 13 patients for 12 mo. The preprocedure VAS score was 7.9. At 1, 3, 6, and 12 mo, the mean VAS was 3.6, 3.1, 3.2, and 4.3, respectively. No complications were reported *(40)*. Singh et al. reported on 67 patients (70% female, 30% male, mean age 44 yr) who underwent nucleoplasty *(41)*. Primary back pain was reported by 70% of the patients, 10.5% reported primary leg pain, 10.5% reported equal levels of back and leg pain, and 9% reported groin and buttock pain. Of the 67 patients, 66, 62, 61, and 41 were available for follow-up at 1, 3, 6, and 12 mo respectively. Overall, 85%, 84%, 79%, and 80% of the patients indicated improvement in their numeric pain scores at 1, 3, 6, and 12 mo. The average preprocedure pain level for all patients was 6.8 while average pain scores at follow-up were 3.56, 3.85, 4.23, and 4.1 at 1, 3, 6, and 12 mo, respectively. No complications were reported *(41)*.

CONCLUSION

Percutaneous procedures used to treat degenerative disc disease will continue to proliferate as back pain is such a prevalent problem. IDET and nucleoplasty are two promising new procedures that may help patients suffering from chronic discogenic back pain.

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14 Spinal Biopsy Techniques

THOMAS M. DAVIS, MD

INTRODUCTION

Percutaneous needle biopsy has undergone considerable evolution in the past 70 yr. As a minimally invasive procedure, percutaneous needle biopsy has gained acceptance as a safe and effective procedure for the diagnosis of vertebral and disc pathology. Martin and Ellis *(1)*, Coley et al. *(2)*, and Robertson and Ball *(3)* demonstrated the feasibility and effectiveness of fine-needle aspiration (FNA) biopsy of bone in the 1930s. Valls et al. in 1968 used a mechanical device for large-bore biopsy of lumbar vertebrae *(4)*. In the late 1960s and 1970s, several review articles were published discussing the variable success rates of the procedure *(5,6)*. Needle biopsy systems demonstrated increasing sophistication with the development of the trephine core biopsy needle. Ackerman and Craig developed trephine needles capable of providing large bone cores for histologic diagnosis *(7–9)*. With advancements in fluoroscopy, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine, precise delineation of a lesion size, morphology, and location could be obtained *(10–26)*. More aggressive biopsy techniques using tandem needle or coaxial biopsy techniques in areas of greater risk such as the thoracic and cervical spine could be performed *(27–36)*. With advances in cytologic and histologic techniques, newer bone biopsy needle systems were developed to allow multiple needle types and biopsies through a single access site. Today, percutaneous vertebral biopsy is an integral procedure in the diagnosis and treatment of spinal pathology.

INDICATIONS

Back pain is the predominant complaint of patients presenting for percutaneous vertebral interventions. The interventional radiologist is typically consulted after an initial workup by a referring service. A review of the literature indicates almost all types of vertebral lesions have been diagnosed by needle biopsy *(37,38)*. Vertebral biopsy for metastatic disease represents the most common indication for biopsy. Other indications include:

- Destructive vertebral lesion in a patient with or without known primary tumors.
- A patient with clinically and radiologically suspected osteomyelitis or discitis.
- A vertebral body compression fracture of uncertain etiology.
- A patient with previously treated vertebral lesion to evaluate for tumor viability.
- Unexplained vertebral abnormalities seen on radiologic studies.

CONTRAINDICATIONS

Absolute contraindications for percutaneous vertebral biopsy include uncorrectable coagulation disorders. Relative contraindications include hypervascular lesions at risk of bleeding into confined spaces such as the epidural or precervical space. The interventional radiologist's experience, imaging capabilities, and backup support may limit the site and biopsy technique used for a vertebral lesion. With newer technologies and interventional training, there are few if any lesions that cannot be successfully and safely biopsied.

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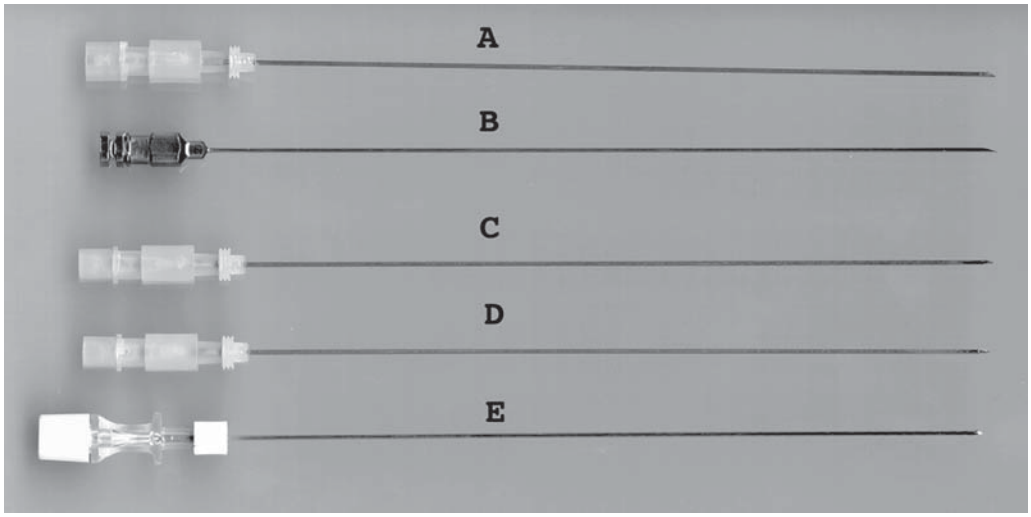

Fig. 1. Fine cutting aspiration (FNA) needles: (A) Spinal needle. (B) Chiba needle. Aspirating-cutting needles: (C) Crown; (D) Greene; (E) Franseen.

PATIENT EVALUATION

Percutaneous needle biopsy is generally performed as an outpatient procedure. More complex cervical biopsies may require general anesthesia and a 23–h observation stay in the hospital *(33,39)*. The interventional radiologist needs to be familiar with the patient's clinical presentation, past medical history, previous diagnostic procedures, and expectations of both the patient and the referring physician concerning the risks and benefits of the biopsy. The pathologist should be consulted prior to the procedure to ensure appropriate handling of the biopsy specimen including any additional cytologic or histologic techniques such as flow cytometry or immunohistochemical staining necessary for an accurate diagnosis. Pre- and post-biopsy treatment strategies need to be discussed with radi-ation and medical oncologists, surgeons, and internists to ensure appropriate timing and therapeutic interventions *(40)*. Surgical consultation for high-risk biopsy of vascular tumors or cervical spine lesions may be indicated. Preprocedural coagulation studies including international normalized ratio (INR), partial thromboplastin time (PTT), and platelet counts are recommended *(41,42)*. Aspirin, nonsteroidal antiinflammatory medications, coumadin, and new antiplatelet (i.e., clopidogrel bisulfate) medications need to be discontinued several days prior to the procedure. Platelet infusion can be used to rapidly reverse clopidogrel while vitamin K and fresh frozen plasma can be used to reverse coumadin if a biopsy is emergent. If anticoagulation therapy cannot be discontinued, the patient can be placed on subcutaneous low molecular weight heparin on an outpatient basis or intravenous heparin on an inpatient basis until the patient's INR normalizes. At the time of biopsy, the heparin can be reversed with intravenous protamine and the biopsy performed. Following the procedure, the heparin can be restarted along with the coumadin therapy. Patients with platelet counts <50,000 should be given platelet transfusions immediately prior to the biopsy. If the etiology of abnormal coagulation studies is not immediately obvious, a hematology consult may be necessary.

With conscious sedation, a medical history with review of the patient's medications, allergies, previous medical problems, and surgeries is necessary. With intravenous conscious sedation, patients need to be fasting (NPO) or on clear liquids for at least 6 h prior to the procedure.

TECHNICAL CONSIDERATIONS

BONE BIOPSY NEEDLES

FNA Needles FNA needles represent a class of thin-walled fine-caliber beveled needles with a removable inner stylet *(43,44)* (Figs. 1 and 2). They are typically used on soft-tissue lesions to obtain material for cytology and microbiology. The beveled tips provide a cutting surface and negative pressure is applied to the needle to aspirate tissue *(45,46)*. Typically, 20- to 22-gauge needles are used with variable bevel angles (spinal—30°; Chiba—25°; Meditech, Boston Scienti-fic, Natick, MA; Turner—45°, Cook, Bloomington, IN). The needle is advanced into the lesion and the stylet is removed. A syringe is attached to the needle hub and gently retracted to apply negative pressure as the needle is moved back and forth. The needle is removed and the material is expressed on slides and into 10% neutral buffered formalin. Slides can be air dried or fixed in alcohol. Air-dried specimens can be stained with Diff-Quik (Baxter Healthcare, McGraw

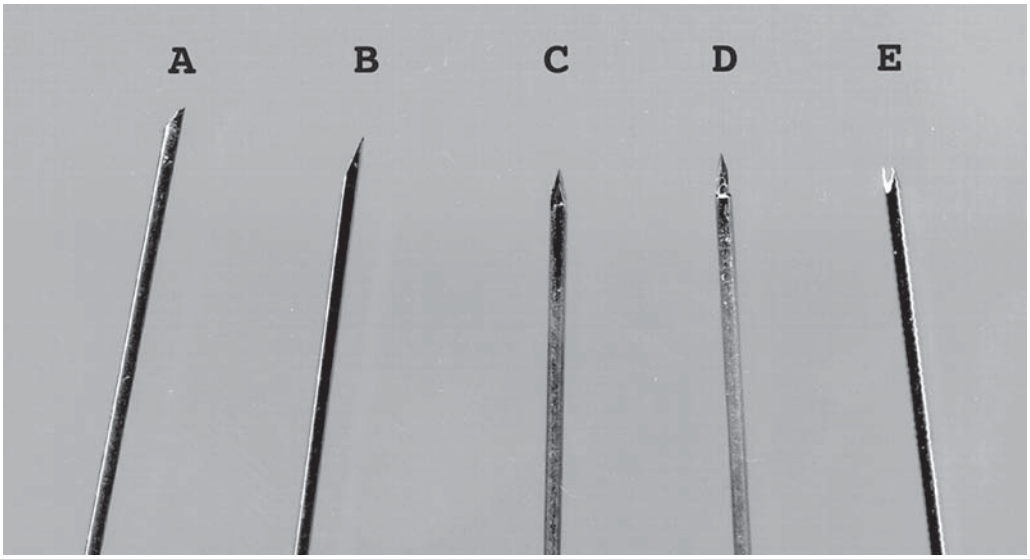

Fig. 2. Fine cutting aspiration: (A) Spinal needle, (B) Chiba needle. Aspirating-cutting needles: (C) Crown; (D) Greene; (E) Franseen.

Park, IL) for prompt cytologic diagnosis. Hematoxylin and eosin (H&E) and Papanicolauou staining can be used on the alcohol-fixed slides. Material placed within the 10% neutral buffered formalin is processed as a cellblock and used for immunohistochemical and flow cytometric studies.

Modified FNA needles or aspiration cutting needles have been designed to increase cytologic and potentially histologic yield *(47)* (Figs. 1 and 2). They differ from FNA needles in having different tip configurations that allow greater tissue cutting. As with aspiration needles, syringes are used to apply negative pressure while the biopsy is performed.

The Greene (Cook, Bloomington, IN), E-2-Em (E-2-EM, Westbury, NY), Crown (Meditech, Boston Scientific, Natick, MA), and Franseen (Medi-tech) are aspiration cutting needles available with small calibers (20- to 22-gauge) (Figs. 1 and 2). For the purposes of this chapter, FNA and aspiration cutting needles are interchangeable and are described as FNA needles.

FNA needles are advantageous because their smaller caliber minimizes complications and provides adequate cytologic material for the diagnosis of many lesions. Cytology has been proven to be effective in diagnosing metastatic vertebral lesions in patients with known primaries. Other lesions such as primary bone tumors, certain benign tumors, lymphomas, and metabolic bone disease may require additional material for a histologic diagnosis *(48–54)*. Recent studies have shown the combined use of cytology and histology improves diagnostic yields in many lesions. Numerous articles have described coaxial biopsy techniques using bone coring needles in combination with FNA and cutting needles on vertebral lesions to provide additional cytologic and histologic material *(51)*. These techniques are discussed later in the chapter.

Automated, Spring-Driven Slotted Cutting Needles Slotted cutting needles are patterned after the traditional TruCut needle (Travenol; Deerfield, IL) and provide large soft tissue cores for cytologic, histologic, and microbiologic diagnosis *(55–57)* (Fig. 3). A variety of automated cutting needles are available (ASAP, Meditech, Boston Scientific, Natick, NY; MaxCore, CR Bard, Covington, GA). These spring-driven devices consist of an outer cutting cannula advanced over an inner slotted stylet for tissue collection. If the bone surrounding the lesion remains intact, FNA and cutting needles are ineffective. Several techniques have been described to traverse cortical bone to provide access to intramedullary soft tissue lesions for FNA and cutting needle biopsy *(28,30,31)*. These typically involve a coaxial technique using a trephine combination or 18-gauge trocar needles to cut through the bone. A recent article describes the use of an 18-gauge trocar needle to traverse bone and provide access for cutting needle biopsies *(31)*. The trocar needle consists of a diamond-tipped trocar and a thin-walled outer cannula (disposable two-part trocar needle, Cook, PO Box 227, Spencer, IN 47460) that is advanced through bone with a rotary motion. The trocar is removed and a 20-gauge automated cutting needle is passed through the canula to obtain a biopsy. The use of trephine and combination needles in coaxial biopsies is discussed in the following sections.

Trephine Needle Systems Trephine needle systems are used to obtain cores of bone for histologic and micro-

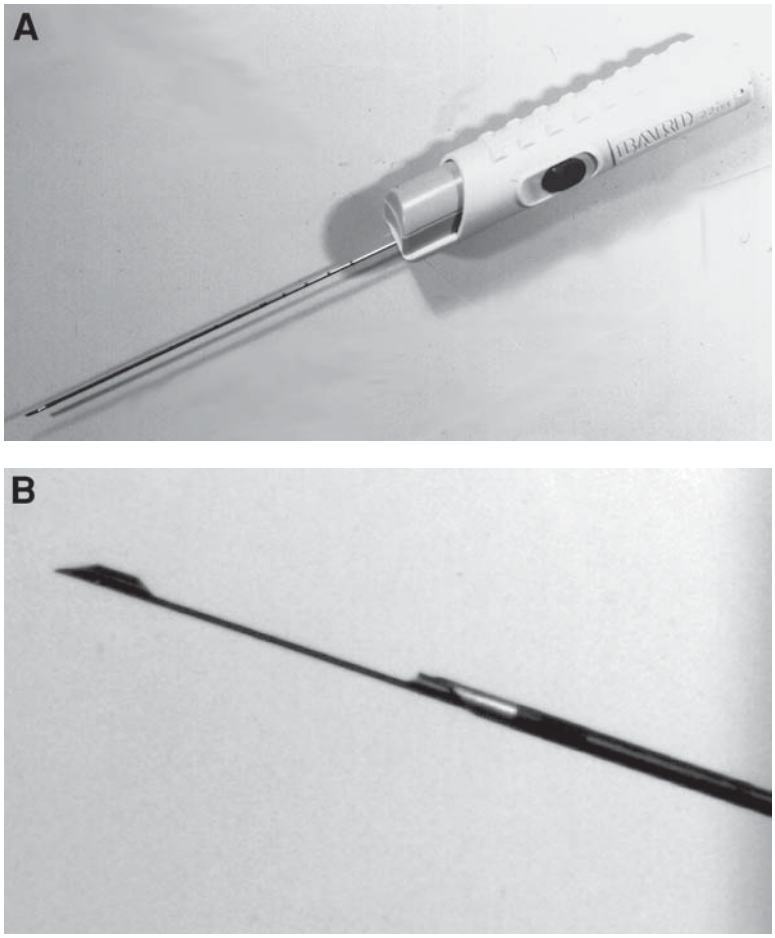

Fig. 3. **(A, B)** Automated spring-driven cutting needles. (ASAP, Meditech, Boston Scientific, Natick, NY.)

biologic diagnosis *(7–9,58–60)*. A variety of trephine needles are available and vary predominantly in their coring diameter. Large-core biopsies can be obtained using the Craig (10-gauge, Becton Dickinson, Rutherford, NJ) and the Ackerman (12-gauge, Cook, Bloomington, IN) trephine needles (Fig. 4). Trephine needle systems consist of a large outer cannula with a fitted obturator, which is advanced to the bone surface. Once the obturator is removed, the trephine needle containing cutting teeth is advanced through the cannula to the bone. Using a clockwise–counterclockwise motion, the needle is advanced through the bone and a bone core is obtained. The trephine needle is withdrawn and a blunt obturator is used to remove the specimen *(40)*.

Trephine needle systems can be used as a coaxial system for subsequent FNA and cutting needle biopsies. Once the trephine needle has traversed the cortex during a core biopsy, FNA and cutting needles can be advanced through the outer cannula into the medullary cavity through the bone biopsy defect. Serial FNA and cutting biopsies can be performed.

Newer trephine systems use a coaxial technique for initial needle placement in high-risk areas such as the upper thoracic and cervical spine *(28,29,59)*. The Elson (Cook, Bloomington, IN) and Geremia (Cook, Bloomington, IN) coaxial systems use a 22-gauge needle with a removable stylet and hub to act as a coaxial guiding needle (Fig. 5). The Geremia needle is a smaller caliber (16-gauge) needle than the Elson (12-gauge) and is preferred by many interventional radiologists in the thoracic and cervical spine. After local anesthesia, the 22-gauge needle is advanced to the desired site on the bony surface (Fig. 6A). The stylet is removed and the periosteum is anesthetized through the needle with local anesthesia. Subsequently, the hub is removed and a coaxial introduction cannula is advanced over the needle to the site (Fig. 6B, C). (The Geremia system replaces the stylet with a hubless stiffing stylet prior to the coaxial cannula placement.) After removal of the 22-gauge guiding needle and inner cannula, the trephine needle is advanced through the outer cannula to the lesion (Fig. 6D, E). The coaxial placement allows the trephine needle to follow the predeter-

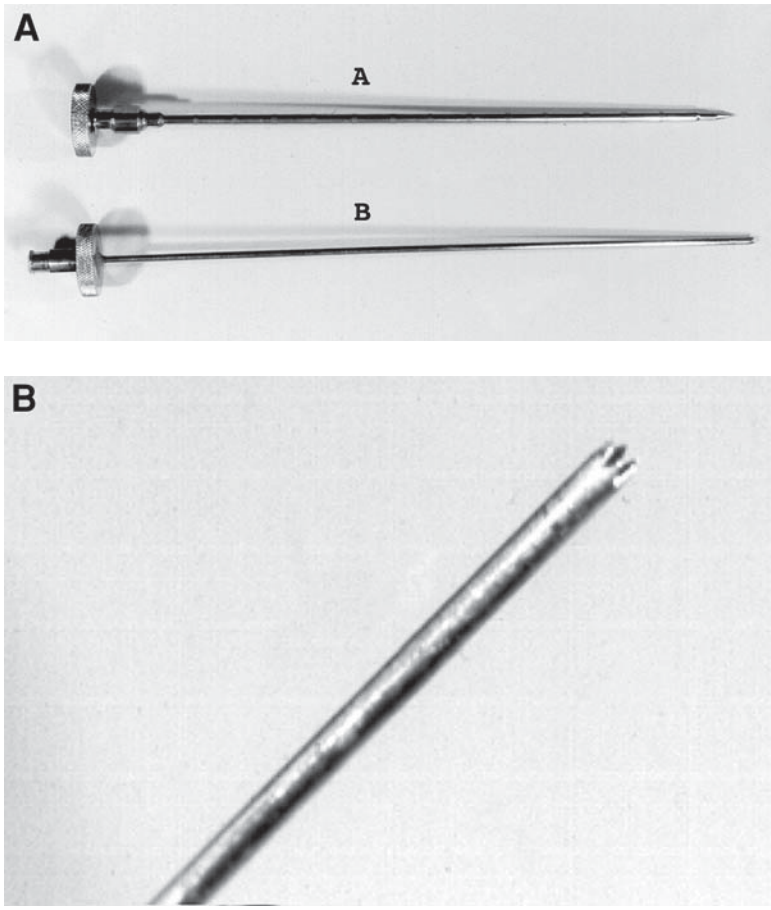

Fig. 4 **(A)** Trephine needle systems. (Ackerman needle, Cook, Bloomington, IN.) (A) Large outer cannula with a fitted obturator. (B) Trephine needle containing cutting teeth that is advanced through the cannula. **(B)** Close-up of Trephine needle.

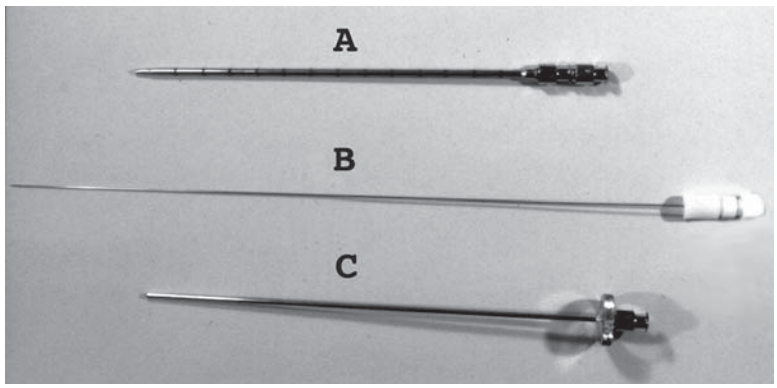

Fig. 5. Coaxial trephine system. (Geremia, Cook, Bloomington, IN.) (A) Coaxial introduction cannula. (B) 22-Gauge guiding needle with removable hub. (C) Trephine needle.

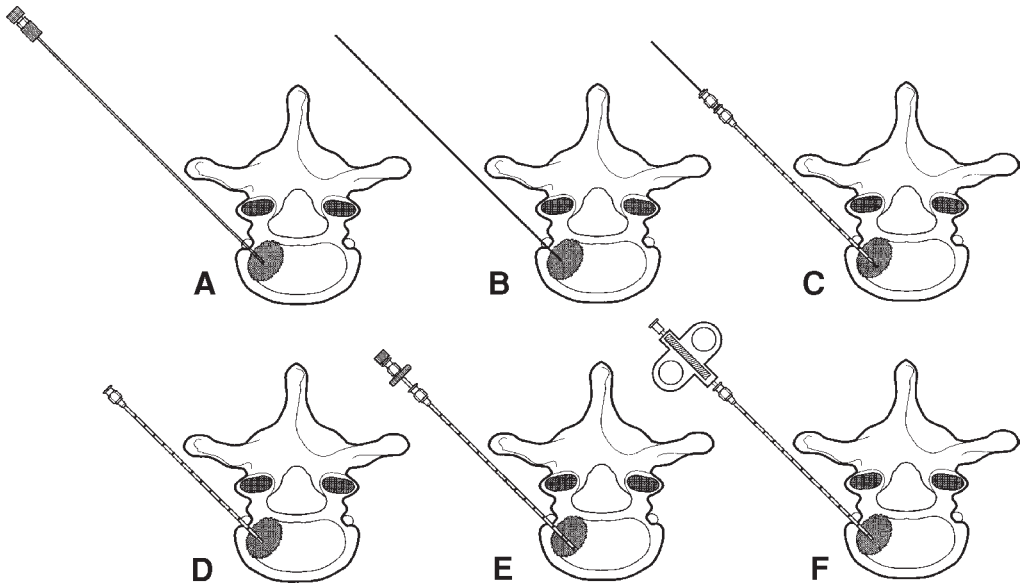

Fig. 6. Diagram of coaxial trephine needle system. After local anesthesia, the 22-gauge needle is advanced to the desired site on the bony surface **(A)**. The stylet is removed and the periosteum is anesthetized through the needle with local anesthesia. Subsequently, the hub is removed and a coaxial introduction cannula is advanced over the needle to the site **(B,C)**. (The Geremia system replaces the stylet with a hubless stiffing stylet prior to the coaxial canula placement). After removal of the 22-gauge guiding needle and inner cannula, the trephine needle is advanced through the outer cannula to the lesion **(D,E)**. The coaxial placement allows the trephine needle to follow the predetermined safe pathway made by the 22-gauge guiding needle. In addition, coaxial biopsy through the outer cannula can be performed with FNA or automated cutting needles **(F)**.

mined safe pathway made by the 22-gauge guiding needle. In addition, coaxial biopsy through the outer cannula can be performed with FNA or automated cutting needles (Fig. 6F).

Combination Needles Combination needles combine features of cutting and trephine needles *(42)*. They are a two-part needle with an outer hollow cutting needle and an inner trocar-boring needle (Fig. 7). (Jamshidi, Manan Medical Products, Northbrook, IL; Ostycut, CR Bard, Covington, GA; Osteosite Cook, Bloomington, IN). They vary in the size and the tip configuration of the outer and inner needles. Interlocking handles are attached to both the inner and outer needles and allow advancement of the needle using a clockwise rotary motion similar to a drill. For bone marrow aspiration, the needle is advanced as a unit through the cortical bone into the medullary space. The inner trocar is removed and negative pressure is applied to the outer needle using a syringe to obtain an aspirate. For a cancellous bone biopsy, the needle is advanced as a unit to engage the bone surface at the desired site. The trocar is removed and the outer needle is advanced using either a manual clockwise (drilling) motion or tapping on the needle handle with an orthopedic hammer. The outer needle is removed and the inner trocar needle is used to remove the specimen. The outer needle can be reintroduced through the previous tract and act as a guiding cannula for coaxial biopsies using cutting and FNA needles *(12)*.

The Osteo-Rx needle (Cook, Bloomington, IN) represents an adaptation of the combination needle to provide a broader access to the vertebral body (Figs. 8 and 9). A 10-gauge combination needle is advanced through the outer cortical bone into the vertebral body. The inner trocar needle is removed and a steerable 13-gauge nitinol beveled needle with a 90° curved tip is advanced coaxially through the outer needle into the vertebral body. After the inner stylet is removed, an aspiration syringe is attached and the needle can be advanced to multiple locations within the vertebral body. This needle allows biopsy of multiple sites within the vertebral body from a single access (Fig. 9). The needle was originally devel-oped for use in vertebroplasty but has been limited by its rela-tively large size.

MRI-Compatible Needles With advances in MRI and its superior soft tissue contract resolution, interventional MRI potentially has a promising future *(16,17,61–69)*. Although commercially available stainless steel needles do not generate significant torque during MRI, they create large imaging artifacts. Needle alloys of stainless steel and nickel reduce a needle's magnetic susceptibility and imaging artifacts. Recent articles have described successful biopsies with MRI-compatible needles using FNA (18- to 22-gauge, E2-EM, Westbury, NY) and core (Comatex, Berlin, Germany—Biogun, E-2-EM, Westbury, NY—Daum, Schwerin, Germany) biopsy systems *(16,17)*.

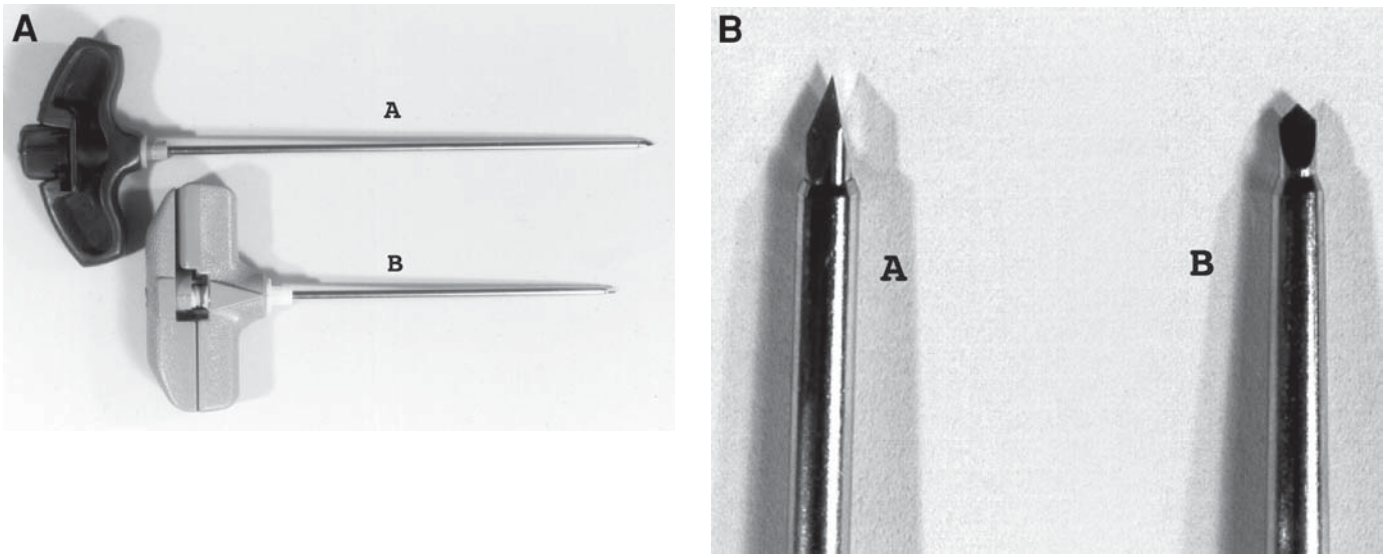

Fig. 7. **(A, B)** Combination needles. (A) Osteo-site bone biopsy needle. (Cook, Bloomington, IN.) (B) Bone marrow biopsy needle. (MDTech, Gainesville, FL.)

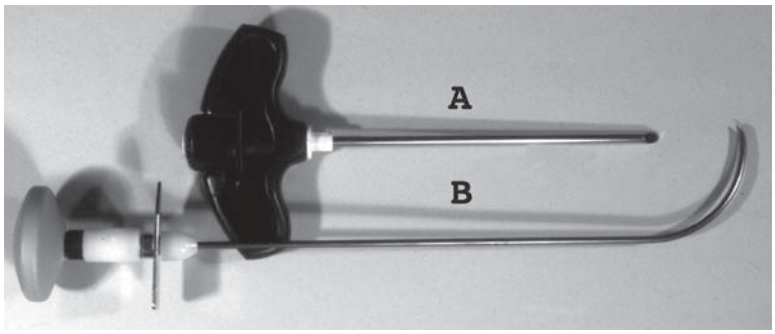

Fig. 8. Combination needles. (Osteo-Rx needle, Cook, Bloomington, IN.) (A) 10-Gauge combination needle. (B) Steerable 13-gauge nitinol beveled needle.

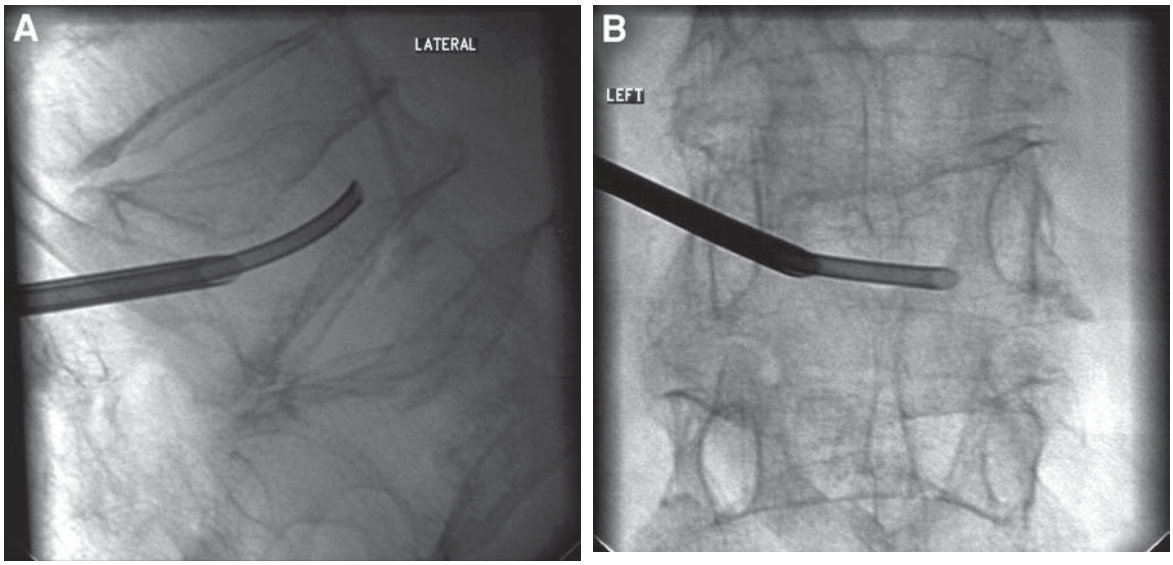

Fig. 9. **(A, B)** Anteroposterior and lateral views of the Osteo-Rx needle.

IMAGING MODALITIES FOR NEEDLE GUIDANCE

Fluoroscopy, CT scan, nuclear medicine, ultrasound, and MRI have been used for imaging guidance in vertebral biopsies. The lesion morphology, size, and location as well as the interventional radiologist's experience and the availability of equipment often determine the type of imaging used during a biopsy. Ultrasound has a limited role in vertebral biopsy but has proven to be effective with superficial lesions and aggressive lesions with extraosseous extension *(10,26,70,71)*.

MRI Advances in MRI-compatible needles and open-configuration MRI units have improved the feasibility of MRI-guided needle biopsy *(16,17,61–69)*. Multiplanar imaging capability, excellent tissue contrast, lack of radiation, and real-time imaging are advantages of MRI-guided biopsies. Unfortunately, interventional MRI procedures are at a disadvantage because of the cost of dedicated interventional MRI suites, nonmagnetic instruments and anesthesia equipment, and lengthy procedure times. Currently, MRI has a limited role in vertebral biopsy but represents an alternative when lesions are not easily amenable to biopsy by other imaging modalities.

Nuclear Medicine Bone scintigraphy remains a common nuclear medicine procedure for the diagnosis of metastatic disease to the spine. A multitude of vertebral lesions can be identified on single photon emission computed tomography (SPECT) bone scan imaging including benign and malignant primary tumors, metastasis, osteomyelitis, and osteoporotic compression fractures *(18–22)*. Multiplanar high-resolution SPECT bone scans can aid in determining the vertebral level involved as well as the location of the lesion within the vertebrae (pedicle, body, spinous process). Bone scan imaging is limited, however, because certain lesions cannot be identified including multiple myeloma and acute osteoporotic compression fractures. In addition, 50% of areas of abnormal uptake on bone scans cannot be identified on radiographs or fluoroscopy *(20)*, which limits the use of fluoroscopically guided biopsy in such lesions.

Several articles have described techniques of using bone scintigraphy immediately prior to biopsy to localize lesions. Tc-99mMDP is injected 2 h prior to the biopsy and a small photo-attenuating marker is used to localize the lesion under a gamma camera or by using a gamma probe *(19,20)*. With the site identified, either fluoroscopy or CT can be used to place the needle.

Fluoroscopy and CT Fluoroscopy and CT represent the most commonly used imaging modalities for vertebral biopsy. The first fluoroscopic guided biopsy was performed in 1949 *(7)*. With advances in fluoroscopic imaging and C-arm technology, fluoroscopic guided vertebral biopsy became popular in the 1970s and 1980s. Following development of CT, CT has rapidly become the guiding modality of choice for many interventional radiologists. Both fluoroscopy and CT have been proven effective for vertebral biopsy but each has strengths and weaknesses. Fluoroscopy provides real-time imaging as needles are advanced through bone, providing accurate needle placement relative to bony landmarks *(11)*. Fluoroscopy is limited by its inability to visualize surrounding soft tissue structures. This is particularly problematic in areas of high risk such as biopsy of the thoracic and cervical spine where vessels, nerves, and lung will be in close proximity to the needle path *(13,14,32–34)*. If the interventional radiologist has adequate experience and knowledge of surrounding anatomical structures, fluoroscopy guided needle biopsy in these areas can be done safely *(11)*. CT is able to visualize both bone and soft tissues and delineates a safer path for needle placement by avoiding vital structures (Fig. 10). Lesion morphology and size may influence the guiding modality used as well *(72)*. Larger sclerotic or lytic lesions can be identified and biopsied by either fluoroscopy or CT.

Biopsy of the extraosseous component of aggressive tumors, the soft tissue portion of complex cystic and solid lesions, and regions of least sclerosis in osteoblastic lesions improves the diagnostic yield in such lesions *(51,55,72–74)*. CT can be used to place the needle precisely into these areas as well as in very small lesions not identifiable on fluoroscopy. Disadvantages of CT guidance include the lack of real-time imaging as the needle is advanced and longer procedural times owing to repeated needle adjustments and imaging sequences. In addition, the lower lumbar vertebral bodies and disc spaces (i.e., L5; L5–S1 disc space) may be inaccessible by CT guidance owing to the acute gantry angle needed for the lumbar lordosis and the surrounding pelvic bony structures *(29)*. With the development of faster CT scanners and stereotactic guiding devices, CT-guided vertebral biopsies are becoming faster, safer, and more accurate than ever before *(75,76)*.

BIOPSY TECHNIQUES

INTRAVENOUS CONSCIOUS SEDATION

During the procedure, the nursing and medical staff need to follow the patient's cardiac and respiratory states including frequent pulse, blood pressure, heart rate, and pO_2 saturation checks. Typical iv sedation include midazolam, which is a short-acting benzodiazepine that acts as a central nervous system depressant that produces amnesia and sedation. A dosage of 1 mg iv over 2 min is

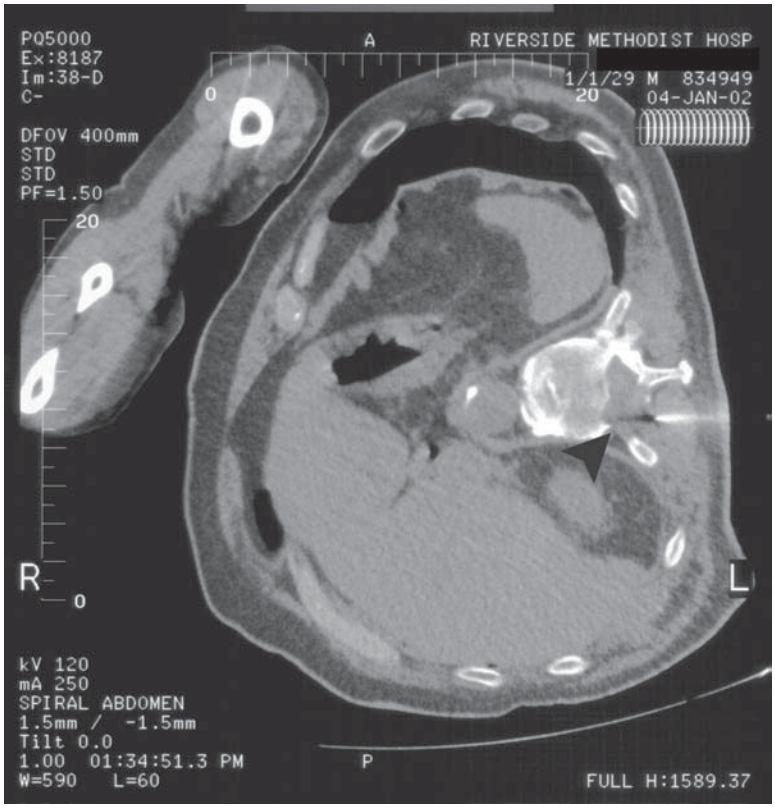

Fig. 10. Metastatic lesion involving the veterbral pedicle with extension into the surrounding soft tissues. CT allows visualization of both bone and soft tissues and safe and accurate needle placement.

typically given with sedative effects noted in 3–5 min. Interval dosing of 0.5–1.0 mg iv is recommended to a maximum of 5 mg to avoid acute respiratory depression. Flumazenil may be used to reverse midazolam-induced respiratory depression (0.2 mg iv over 15 s repeated at 60-s intervals to a total dose of 1.0 mg). Fentanyl is a narcotic analgesic with a 30- to 60-min duration of action and is typically administered in 25- to 50-mg iv doses to a total dose range of approx 2–20 U/kg. The drug can produce respiratory depression and can be reversed with 0.4 mg of naloxone iv repeated at 2- to 3-min intervals as needed to a total of 2.0 mg. As in all cases of conscious sedation, medications need to be titrated to the patient's needs with constant monitoring of the patient's vital signs.

NEEDLE PLACEMENT TECHNIQUES

Three basic needle placement techniques are used. The direct needle placement technique simply involves advancing the desired needle system directly to the biopsy site using the desired imaging modality (Fig. 11). The tandem needle technique uses a 22-gauge needle advanced along the desired needle path to the lesion *(29)* (Fig. 12). The needle biopsy system is subsequently advanced parallel and tandem to this needle. Once the biopsy needle is in the appropriate position, the 22-gauge needle is removed and the biopsy is performed. The coaxial trephine needle system technique uses a removable hub 22-gauge guiding needle for local anesthesia and advancement to the lesion *(29)* (Fig. 6A). The hub is removed and the coaxial introduction cannula is advanced over the 22-gauge needle to the biopsy site (Fig. 6B, C). The 22-gauge guide needle and inner cannula of the coaxial introduction system are removed, and the trephine bone cutting needle is advanced through the outer cannula to the bone for biopsy (Fig. 6D, E). After the trephine needle and bone core have been removed, FNA and cutting needles can be advanced coaxially through the outer canula and bony (cortical) defect into the medullary cavity for additional cytologic and histologic material (Fig. 6F).

ANATOMIC CONSIDERATIONS

Cervical Spine Biopsy Anterolateral and posterolateral approaches are used in cervical vertebral biopsy. Fluoroscopic, CT, and MRI guidance has been used with cervical biopsy *(29,32,33,77)*. Fluoroscopic guidance requires adequate knowledge of cervical anatomy to be performed safety. CT and MRI allow visualization of the soft tissue structures of the neck during needle placement

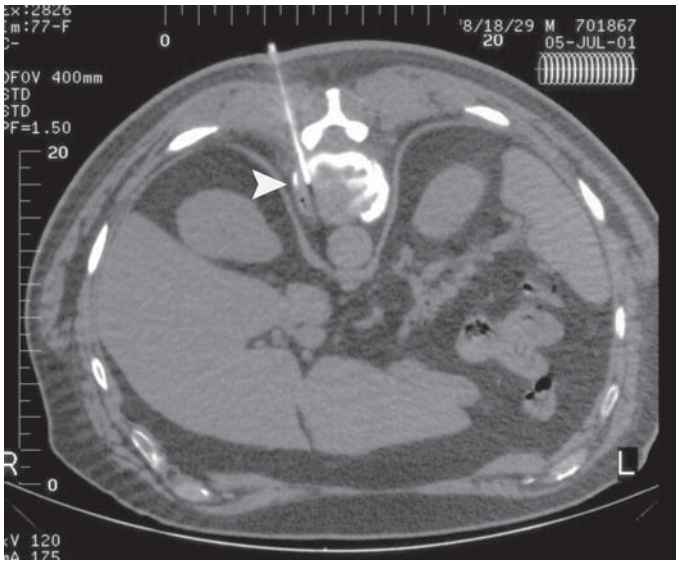

Fig. 11. Biopsy techniques. CT-guided direct posterolateral approach.

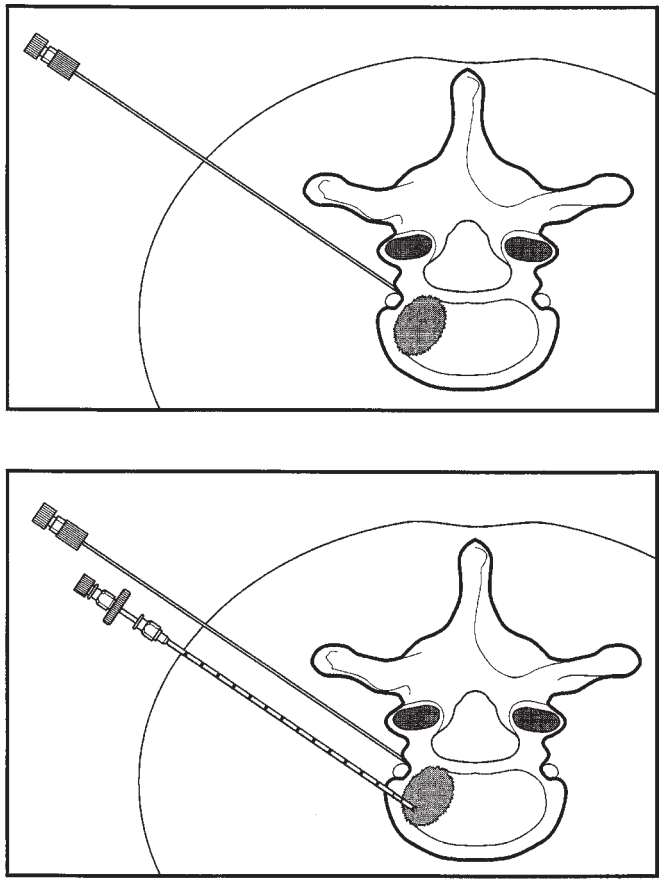

Fig. 12. Tandem needle technique. **(A)** 22-gauge anesthetic needle is advanced along the desired path to anesthetize the periosteum. **(B)** The bone biopsy needle is advanced parallel and in tandem with the previously placed needle.

and CT is preferred by most interventional radiologists. Coaxial trephine systems are typically used to provide a more accurate and safe needle placement. If an extraosseous soft tissue component is present, smaller cutting or FNA needles are preferred to ensure greater safety and diagnostic accuracy. Many authors recommend surgical and anesthesia backup if expanding precervical or epidural hematomas develop following cervical biopsy *(40)*.

The cervical vertebrae have large articular masses and posterior elements that limit a posterolateral approach to the vertebral body. The position of the carotid sheath in the cervical spine determines whether a posterolateral or anterolateral approach is used.

An anterolateral approach is recommended for lesions located in the upper cervical spine and allows access to the anterior vertebral body and disc space. Typically a 22-gauge needle using a tandem or coaxial guiding technique is introduced medial to the anterior margin of the sternocleidomastoid muscle. The carotid sheath and sternocleidomastoid muscle are manually retracted laterally and the needle is advanced between the airway and the carotid sheath to the desired location (Fig. 13). A coaxial trephine needle system can be placed over the guiding needle and subsequent core biopsy can be performed. Once the core is obtained, the trephine system can remain in place and cutting or FNA needle biopsy can be performed.

The posterolateral approach is used for lesions of the lower cervical spine (C4–C7) and posterior elements *(29,77)*. Needle systems similar to those used for the anterolateral approach can be used and are introduced posterior to the sternocleidomastoid muscle.

A transoral or pharyngeal approach has been recommended by several authors for C1–C3 biopsies. Fluoroscopic and MRI-guided biopsies under general anesthesia have been described using fine needle and core biopsy techniques at this location. Such areas are often difficult if not impossible to access surgically and a transoral approach represents an alternative *(40,77)*.

Thoracic Spine Biopsy The transcostovertebral and transpedicular approaches using fluoroscopic or CT guidance are typically used in the thoracic spine *(34,36,78)* (Figs. 14 and 15). The close proximity of the lung, aorta, and dural sac presents the dominant challenge to biopsy at this level. The use of CT or fluoroscopy is operator dependent based on personal experience and comfort with each imaging modality. This author prefers fluoroscopic guidance when a transpedicular approach is used because the movement of the needle through the pedicle into the vertebral body is visualized in real time. The transpedicular approach is recommended for lesions involving the pedicle and the posterior half of the vertebral body (Figs.

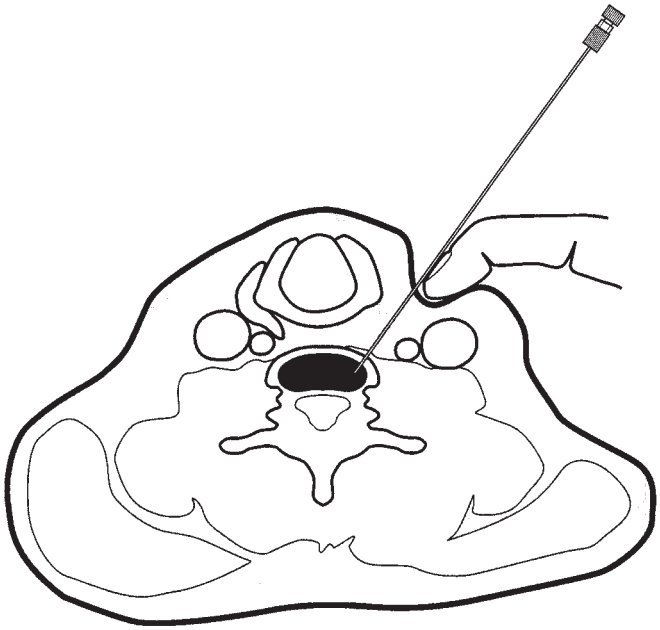

Fig. 13. Anterolateral approach for cervical spine biopsy. The sternocleidomastoid and carotid sheath are manually retracted and the needle is advanced between the airway and carotid sheath.

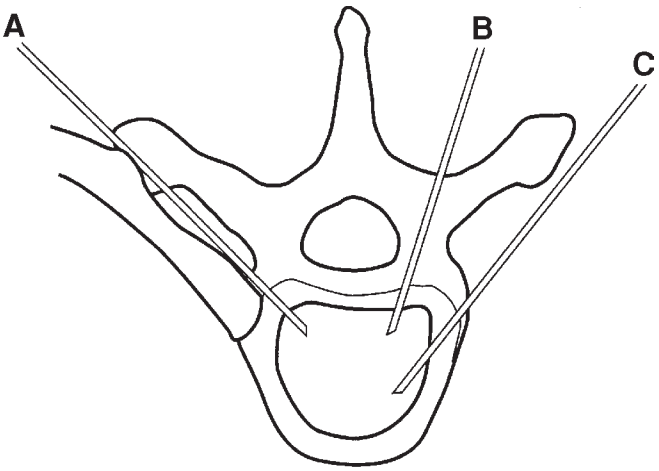

Fig. 14. Diagram of approaches to the vertebral body or intervertebral disc. **(A)** Transcostovertebral approach; **(B)** transpedicular approach; **(C)** posterolateral approach.

14 and 15). The transcostovertebral approach is recommended for lesions of the disc space and the lower aspect of the vertebral body (Fig. 14). If a paraspinal mass or extraosseous extension of tumor is present, CT-guided biopsy with FNA or cutting needles is preferred. Transcostovertebral biopsies can be performed with either CT or fluoroscopy but many radiologists prefer CT guidance because of the close proximity of the lungs. For very small or complex lesions, CT guidance is recommended

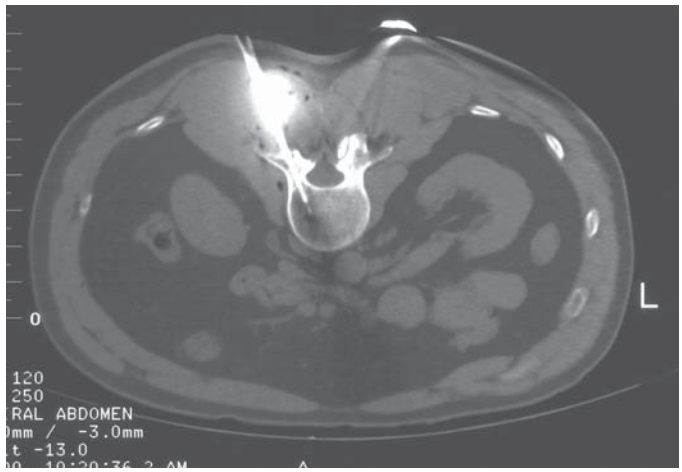

Fig. 15. CT-guided transpedicular approach to biopsy a localized lesion in the right hemivertebrae.

to document the precise placement of the needle into the lesion.

The Transpedicular Approach. The patient is placed in the prone or lateral position. When using fluoroscopy, the needle system (coaxial trephine or combination) should be positioned directly down the pedicle in a manner approximating a "bulls eye" appearance *(12)*. The needle system is advanced to the superior lateral aspect of the pedicle to avoid injuring nerve roots or entering the spinal canal (Fig. 16) *(29,35,36)*. Because of the smaller size of the pedicle compared to the lumbar spine, a small-gauge coaxial trephine and combination needles are recommended. The advancement of the trephine needle after initial coaxial placement of the outer cannula is performed with a clockwise–counterclockwise motion through the pedicle. Combination needles such as the osteosite (Fig. 7) (Cook, Bloomington, IN) are advanced into the proximal pedicle with the inner boring trocar in place. The trocar is removed and the outer cutting needle is advanced through the bone while tapping an orthopedic hammer on the handle or with manual clockwise rotation. The needle is withdrawn and the specimen is removed with a blunt obturator. The outer cutting needle can be reintroduced through the biopsy tract and act as a guiding cannula for further cutting and FNA needle biopsies. This technique has proved invaluable in obtaining pathologic specimens prior to vertebroplasty in patients with compression fractures of uncertain etiology.

The Transcostovertebral Approach. With the patient in the prone or lateral position, a 22-gauge needle is advanced between the anterior part of the transverse process of the vertebrae and the posterior part of the neck of the rib to the lateral margin of the vertebral body (Fig. 14) *(29,34)*. The 22-gauge needle acts as a guiding needle

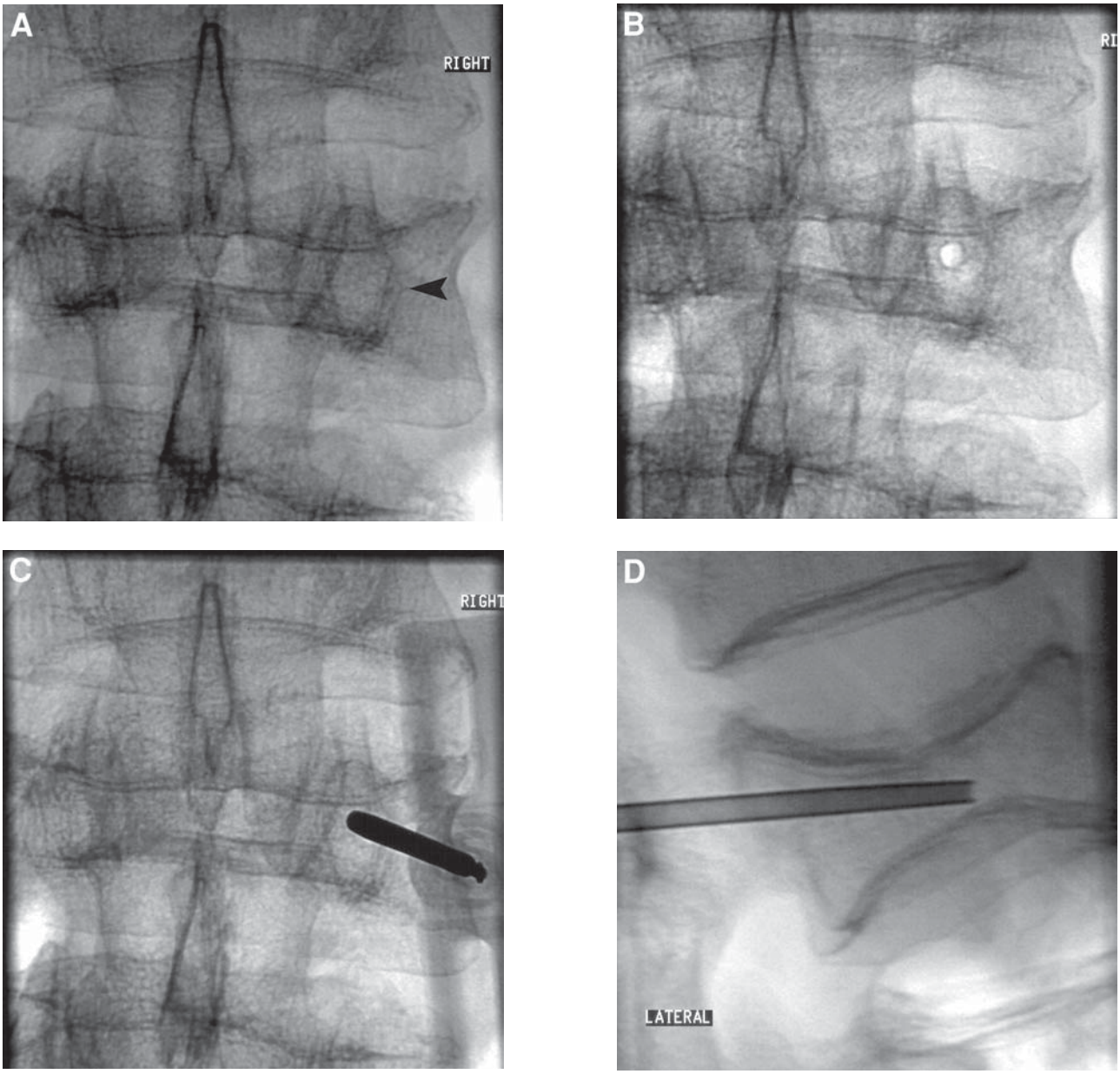

Fig. 16. **(A–D)** Fluoroscopically guided transpedicular approach. **(A)** Initial localization of pedicle in a slightly oblique view. **(B)** "Bull's-eye" view used for needle placement. **(C)** Actual needle placement in the superior lateral aspect of the pedicle. **(D)** Lateral view with transpedicular needle in place.

for coaxial trephine systems or tandem needle placement techniques. Following core bone biopsy with combination and trephine systems, coaxial cutting and FNA biopsies can be performed. The transcostovertebral approach avoids the intercostal neurovascular bundle, exiting nerve roots, lung, and aorta and provides access to the anterior vertebral body and disc space.

Lumbar and Sacral Spine Biopsy The transpedicular and posterolateral approaches are typically used for lumbar and sacral biopsies. The transpedicular approach has been described earlier in the chapter. With the posterolateral approach, the needle is placed posterolaterally to the spine and advanced to the lateral border of the vertebral body under CT or fluoroscopic guidance. The posterolateral approach is preferred for biopsy of the disc space and the anterior and lateral aspects of the vertebral body (Fig. 11). The lumbar lordosis and angle necessary to access the lower lumbar vertebrae and disc spaces may limit CT effectiveness at this location *(29)*. Fluoroscopy is generally used for disc space biopsy owing to the narrow window the needle needs to traverse to reach the disc space. Several articles have described the use of fluoroscopically guided or automated percutaneous lumbar discectomy devices (APLD) for the diagnosis of infec-

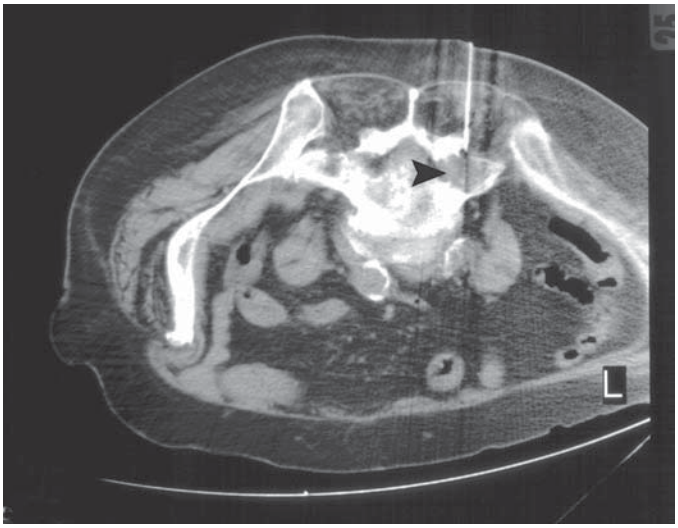

Fig. 17. CT-guided direct posterior approach to a sacral lesion.

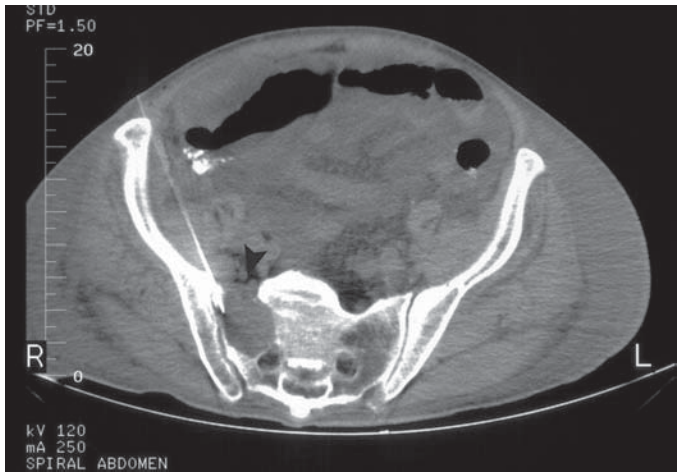

Fig. 18. CT-guided direct anterior approach to sacral lesion using FNA needle.

tious discitis *(79,80)*. Fluoroscopy was used to monitor constantly the APLD placement and deployment within the disc space. As discussed earlier, CT scan is used for smaller lesions, complex lesions, and extraosseous soft tissue tumor extension.

The transpedicular approach can be performed with either CT or fluoroscopic guidance (Figs. 14 and 15). The trans-pedicular approach allows access to the pedicle, posterior, lateral, and anterior aspects of the vertebral body at the lumbar level.

The Osteo-Rx needle allows broader access to the vertebral body by using a steerable curved needle coaxially placed through a combination style needle via a transpedicular approach (Figs. 8 and 9).

A lateral CT-guided approach to the lumbar spine has been described with the patient in the lateral decubitus position *(81)*. This approach allows a wide field for needle placement including the vertebral body, disc space, and paraspinal soft tissues.

A direct posterior or anterior approach can be used to biopsy the posterior elements or presacral space region (Figs. 17 and 18).

POSTPROCEDURAL CARE

Patients are typically observed for approx 1 h following an uncomplicated needle biopsy. If the biopsy was performed under general anesthesia, the patient is observed for several hours in the Post-Anesthesia Care Unit and subsequently discharged. The biopsy site and patients vital signs are monitored every 15 min to detect any potential complications. Once the patient is fully alert and vital signs are stable, he or she can be discharged. Coumadin, nonsteroid antiinflammatory, and antiplatelet (clopidogrel bisulfate) medications can be resumed the evening following the procedure. Subcutaneous low molecular weight heparin can be used as a "bridging" anticoagulant agent until the patient's coumadin therapy (INR) is therapeutic. Any discharge instructions or follow-up appointments are reviewed with the patient, and on discharge the patient may resume a normal diet and activity level.

COMPLICATIONS

The literature estimates serious complications occur in percutaneous bone biopsies in approx 0.2% of cases. Complications include bleeding, infection, pneumothorax, and neurologic damage *(29,40,82,83)*. Neurologic complications occur in 0.08% of patients and include quadriplegia, foot drop, paraspinal hematoma, and meningitis *(40)*. Infection has been reported in 0.3% of cases, making adherence to aseptic technique essential. Pneumothorax has been reported in as many as 4% of cases of rib and vertebral biopsies and is generally managed conservatively.

Although the possibility of tumor spread along the needle tract exists, there have been no documented cases of this complication in more than 15,000 biopsies reported *(38,84)*.

RESULTS

Several recent articles report the accuracy of percutaneous bone biopsy to be 72–97% *(15,40,55,73,85–89)*. The diagnostic accuracy varies depending on the lesion size, morphology, and location. In general, accuracy is

highest with metastatic lesions and lowest with primary and benign bone tumors. Cystic or densely osteoblastic lesions have lower diagnostic yields and every attempt should be made to biopsy the soft tissue component or areas of least sclerosis in these lesions to improve results. Because cartilaginous tumors are difficult to grade histologically, percutaneous needle biopsy of such lesions may have limited success. Nondiagnostic biopsies result more often in the thoracic and cervical spine owing to smaller vertebral size and the accompanying technical difficulties encountered. The recent use of combined bone coring biopsy and cutting and FNA biopsy has been shown to improve diagnostic yield in a variety of lesions.

CONCLUSION

Percutaneous needle biopsy of the spine is a safe and accurate method of obtaining tissue for cytologic, histologic, and bacteriologic analysis. The procedure represents a team effort that includes the patient, interventional radiologist, pathologist, oncologist, and surgeon. With future advances in imaging technology and biopsy systems, percutaneous vertebral biopsy will continue to be the procedure of choice for diagnosing pathologic lesions of the spine.

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15 Percutaneous Vertebroplasty

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INTRODUCTION

Percutaneous vertebroplasty for the treatment of osteoporotic compression fractures was initially introduced in the late 1980s in Europe *(1,2)* and in the early 1990s in the United States *(3)*. Since that time the procedure has enjoyed a phenomenal growth. Indeed, vertebroplasty is now considered routine in most areas throughout the United States. The procedure has been shown to be rapid, safe, and effective for the treatment of painful osteoporotic compression fractures *(3–22)*. The purpose of this chapter is to review the indications, preprocedural workup, procedural details, postprocedural care, and outcomes for the treatment of osteoporotic compression fractures with percutaneous vertebroplasty.

INDICATIONS AND CONTRAINDICATIONS

Percutaneous vertebroplasty can be utilized in both osteo-porotic compression fractures as well as neoplastic involvement of the spine. This chapter is focused primarily on osteoporotic compression fractures. The primary indication for vertebroplasty is for treatment of painful, osteoporotic compression fractures that have not responded to medical therapy *(3–22)*. However, the definition of "failed medical therapy" is in flux at the present time. When the procedure was initially introduced, most patients were treated with vertebroplasty only after a relatively prolonged course of failed medical therapy, on the order of 6 wk to several months. With the increased use of vertebroplasty, the definition of failed medical therapy varies substantially from institution to institution. Indeed, some practitioners will even treat acute fractures in some cases, particularly when patients are unresponsive to narcotic analgesics or have developed complications from immobilization, for example, pneumonia or thrombophlebitis *(17,18,23,24)*. However, in most cases patients have been given a course of medical therapy including bedrest and analgesics for at least several weeks. Only patients who fail this treatment are considered classically indicative for vertebroplasty. Some practitioners have considered chronic fractures several months to years in duration as not appropriate for vertebroplasty. However, recent data suggest that even patients with pain for up to 12 mo may derive substantial benefit from vertebroplasty *(25)*.

Retropulsion of bony fragments represents a relative contraindication to vertebroplasty *(17,24)*. Concern in cases of retropulsed fragments arises not only from the fear that cement extravasation into the spinal canal might occur, but also that surgical decompression, if needed, would be compromised by the presence of cement in these fragments. The exact degree of "acceptable" retropulsion, measured as the percent area compromise of the spinal canal, must be customized to each patient. For example, retropulsion in the mid- and lower lumbar spine, below the level of the conus, would be considered less risky than that in the thoracic spine, where damage to the spinal cord would be more likely. When treating vertebrae with retropulsed fragments, placing the needle as far ventrally as possible is desirable. Cement deposition should be terminated when the material extends dorsally to the midportion of the vertebral body.

Severe fractures, on the order of 70% collapse or greater, are considered by some practitioners to be inappropriate for vertebroplasty. However, other investigators have achieved good pain relief even in cases of

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vertebra plana *(26,27)*. Special technical considerations must be used in severe fractures. Even small errors in angle of approach may result in the needle tip residing in the adjacent disc space rather than the marrow. The needle tip should be placed as far lateral as possible, as most severe fractures demonstrate near total obliteration of the central aspect of the vertebral body. The bipedicular approach and small volumes of cement for each hemisphere are more likely to be used in these cases.

VERTEBROPLASTY IN NONFRACTURED VERTEBRAE

Cement infusion into nonfractured vertebrae has been considered in at least three scenarios. Vertebroplasty of adjacent levels may be performed prior to surgical reconstruction of acute kyphotic angulations resulting from vertebra plana. In these cases, the surgeon requests infusion of cement into noninvolved vertebra above and below the fractured level for placement of orthopedic hardware. Biomechanical testing has determined that the cement provides a more robust substrate for placement of pedicle screws and other fixation devices *(28)*. In these few cases, outcomes have been favorable but there are no data to support the widespread practice of vertebroplasty.

Second, vertebroplasty of unaffected levels in patients with significant kyphosis due to thoracic compression fractures has been suggested *(24)*. The rationale in these cases is that further kyphotic deformity will lead to respiratory difficulty; however, no data are forthcoming. The authors have not performed vertebroplasty for this indication.

The last scenario is vertebroplasty of nonfractured vertebrae adjacent to a fractured level ("prophylactic" vertebroplasty). Experimental data suggest that treatment of one vertebra with cement infusion may place adjacent vertebrae at increased risk of spontaneous fracture, given decreased compliance of the local spinal segment *(29)*. One clinical study *(20)* showed a small but statistically significant increased risk of vertebral fracture in the vicinity of a cemented level, although "vicinity" was not defined, and may not necessarily have been adjacent. Indeed, it remains common for patients treated with vertebroplasty to return with new fractures. The authors note that approx 17% of patients develop new fractures following vertebroplasty, at variable locations in relation to the treated level (*unpublished data*). These new-onset fractures may be unrelated to the vertebroplasty, as approx 20% of osteoporotic patients who suffer from one fracture and are treated conservatively will present with a new fracture within 1 yr *(30)*. Furthermore, one cannot reliably determine whether an adjacent level or a remote level will be the site of the next compression fracture. Without further data, prophylactic vertebroplasty cannot be supported at this time.

SURGICAL CONSULTATION IN VERTEBROPLASTY

The management of back pain in the elderly is extremely complex. Vertebroplasty is considered appropriate only for patients with documented, painful vertebral fractures. However, patients often present with pain that may be fully or partially explained by coexisting pathologies such as spinal stenosis or facet disease. In the authors' early experience, the majority of patients were referred from spine surgeons. As such, these early patients had usually been screened, and in some instances, treated for these coexisting pathologies. Continued pain was then readily ascribed to the spinal fracture.

The majority of patients now referred for vertebroplasty are sent directly by primary care physicians, without intervening consultation with spine surgeons. The vast majority of patients can be treated without surgical consultation, provided that other causes of pain have been considered and eliminated. However, practitioners should have a relatively low threshold for obtaining preprocedure surgical consultation in cases where physical examination suggests spinal cord or nerve root compromise, or if imaging studies demonstrate spinal stenosis or significant retropulsion of fracture fragments.

PREPROCEDURAL WORKUP

HISTORY AND PHYSICAL EXAMINATION

History and physical examination are key components in the evaluation of patients being considered for percutaneous vertebroplasty. A focused history and examination concentrating on the patient's back pain, mobility level, and medication use (including analgesics, steroids, and osteoporosis antagonists) is recommended. Presenting symptoms, pertinent medical, surgical and allergy histories, a list of current medications, and evidence of failed medical therapy are documented. Use of visual analog scales for determining pain levels, dermatome drawings for pain localization, and standardized questionnaires are helpful for collecting data pre- and postprocedure.

Contraindications to the procedure should be excluded. Vertebroplasty contraindications include evidence of substantial spinal canal compromise as indicated by clinical symptoms and signs that suggest spinal cord or nerve root impingement *(17,24)*. This would include, but not be limited to, radicular pain, sensory level, or bowel or bladder dysfunction. Further imaging workup should be pursued

if neurological dysfunction is suspected. In certain instances, the history of radicular pain is not considered a contraindication to vertebroplasty. These cases are fairly unusual, and often indicate an unstable fracture with the presence of a cavity (Kummell's osteonecrosis) *(31)*.

Physical examination should at least include documentation of motor and sensory dysfunction as well as reflexes where appropriate. Another component of the physical examination is that of manual palpation of the spine. Early practitioners of vertebroplasty considered that patients who would be expected to respond to vertebroplasty would demonstrate localized pain on palpation of the spinous process of the involved vertebra. However, the authors have found no statistically significant difference in treatment outcomes between a group of patients with localized tenderness and a group with nonspecific or nonlocalizing pain *(31a)*. Indeed, patients may present with pain that is several levels away from the fracture site, or may even present with pain that is entirely subjective in nature and is not elicited with manual palpation. Although back palpation remains a part of the physical exam, patients without focal pain should not be excluded from treatment.

LABORATORY

Preprocedure laboratory testing often includes hemoglobin, hematocrit, electrolyte levels, coagulation parameters, and complete blood count with differential. A creatinine level should be included if vertebrography will be performed. Elderly patients may not mount the usual immunologic responses to infection, or may harbor low-grade infections without fever. Although nonspecific, an elevated sedimentation rate may point to a chronic infectious process and further testing may be indicated.

IMAGING

The imaging workup of patients being considered for vertebroplasty can be done in several ways. The simplest type of preprocedural imaging is a plain film study, and is a good starting point in patients who have sudden onset of acute back pain, particularly when it is associated with minor trauma. In osteoporotic female patients with a new compression fracture noted on serial films, focal pain, point tenderness, lack of spinal stenosis or fragment retropulsion, and no history of malignancy, proceeding directly to vertebroplasty is appropriate. Although osteoporotic compression fractures occur in men, the lifetime risk of a symptomatic fracture is only 5% for males *(32)*. A compression fracture in a male patient with no underlying cause for osteoporosis, for example, steroid use, should raise a flag to the evaluator, and performing magnetic resonance imaging (MRI) to exclude a malignancy is reasonable.

Patients with single, uncomplicated fractures comprise the minority of our practice. Typically, multiple fractures of uncertain age are seen in conjunction with a new fracture. Even in the setting of a fairly straightforward physical examination, it is often useful to review serial plain films and obtain adjunctive imaging. This can be done either with MRI or bone scan imaging, although computed tomography (CT) may be helpful in some cases. Bone scan has been shown to be extremely useful in pinpointing which are the painful fracture levels in the setting of multiple fractures *(33)*. In these cases, treating the levels that demonstrate increased activity on bone scan imaging is associated with a high likelihood of pain relief (Fig. 1). Conversely, it is reasonable to perform MRI to look for edema, particularly on short tau inversion recovery (STIR) images (Fig. 2), or for enhancement on fat-saturated, gadolinium enhanced T1-weighted images *(34)*. MRI has the advantage of offering morphologic evaluation of suspected canal compromise from retropulsed fragments, recognition of concomitant processes such as herniated discs, and detection of malignancies. However, in straightforward cases, either a bone scan or MRI would be considered appropriate in most cases of multilevel fracture.

CT scanning has relatively little relevance in the prepro-cedure workup of patients being considered for vertebroplasty. CT is best used for evaluation of complex fractures, where the fracture lines may significantly involve the pedicles or posterior wall, and for osteolytic processes such as metastases. It may also be useful in the evaluation of hemangiomas with significant bony loss (Fig. 3).

PROCEDURAL DETAILS

PATIENT PREPARATION

Following the informed consent process, the patient is taken to the radiology suite. Often patients are reluctant to lie prone on the table, and 20–50 μg of fentanyl (Sublimaze, Abbott Labs, North Chicago, IL) 5 min prior to positioning may be helpful. The patient is then placed prone on the procedure table, and physiological monitors including electrocardiogram (EKG) leads, blood pressure cuff, and pulse oximeter are attached. Oxygen via nasal cannula is recommended as patients may have difficulty breathing in this position. The vast majority of vertebroplasty cases can be performed with conscious sedation, usually small doses of fentanyl and midazolam (Versed, Roche Pharma, Manati, Puerto Rico). General anesthesia would be considered in patients with compromised pulmonary function or those in extreme pain who are unable to lie in the prone position for any period of time.

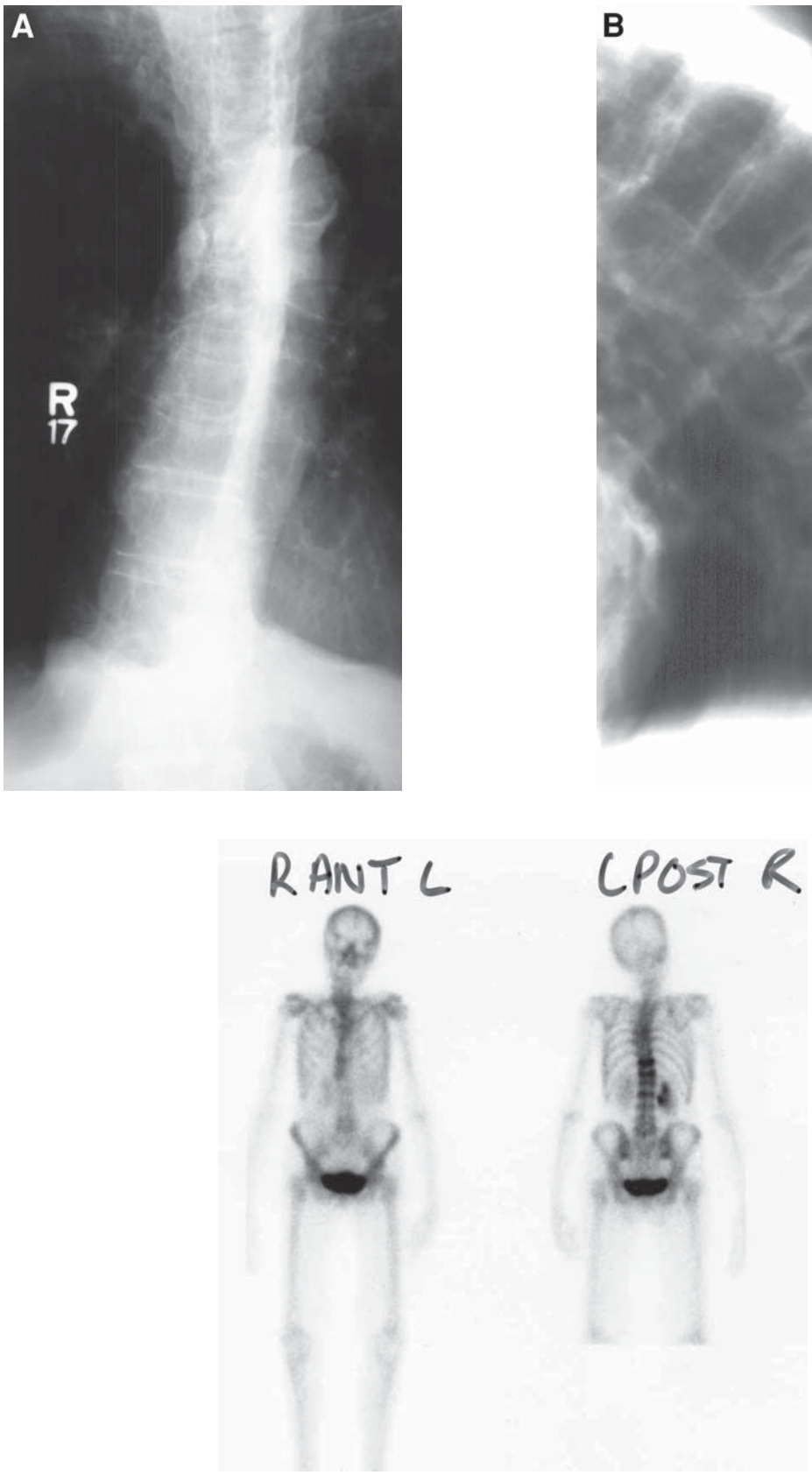

Fig. 1. **(A–C)** Elderly woman with chronic obstructive pulmonary disease and severe osteoporosis. PA **(A)** and lateral **(B)** chest plain films show multiple thoracic vertebral compression fractures from T4 to T12, of indeterminate age. The patient's pain was difficult to localize. Anterior and posterior bone scan **(C)** shows intense uptake of radionuclide in T9 and T10, with significant uptake in T11 and T12. Following vertebroplasty of these four levels, the patient described marked relief of her pain.

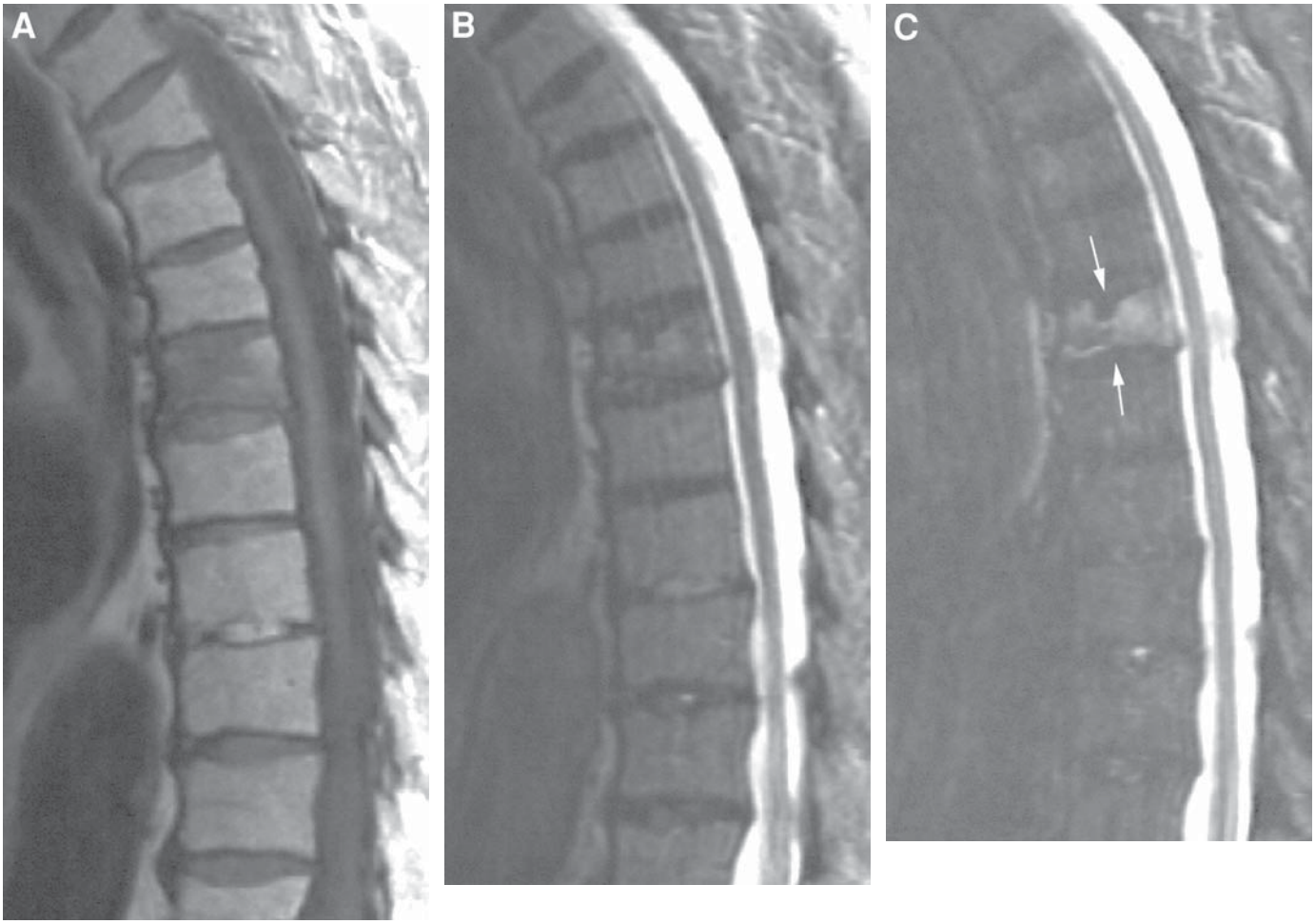

Fig. 2. **(A–C)** Middle-aged man with osteoporosis secondary to steroid use and a new T5 compression fracture. T1–WI **(A)**, T2–WI **(B)**, and STIR **(C)** sagittal imaging was performed. Although the fracture edema is seen on all three sequences, it is most easily detected on the STIR image as a high signal intensity involving the entire vertebral body (*arrows*).

PATIENT POSITIONING

Most patients are treated in the prone position. Typically, to become comfortable, patients need to turn their heads to one side or the other. This causes some obliquity of the spine itself, especially in the upper and midthoracic region. Special headholders such as those used for cervical myelography may help to keep the head positioned forward and downward. The patient's arms must be positioned above his or her head, or off to the side but lower than the spine. Padded armboards or slings can be used to move the arms out of the way. For thin patients, use of an egg crate mattress may increase comfort; however, too much elevation of the patient on the angiography table occasionally makes imaging in the lateral plane difficult or impossible.

Before the patient is draped, lateral fluoroscopy of the target level is performed to ensure that the patient is lying in a true lateral position. Accurate visualization of the posterior vertebral wall during cement injection is key in the avoidance of complications. For lower thoracic or lumbar vertebral fractures, some operators hyperextend the patient by placing wedges under the chest and hips, in anticipation that some ver-tebral body height may be restored. Simply placing the patient prone will often expand unstable fractures without the additional use of wedges.

For those patients who cannot tolerate the prone position and who are not good candidates for general anesthesia, vertebroplasty can be done in the decubitus position, although it is cumbersome and awkward for the physician.

EQUIPMENT REQUIREMENTS

Needle placement may be accomplished using standard fluoroscopy *(8,11,17)*, CT guidance *(5)*, or CT fluoroscopy; however, the cement injection should always be performed under direct fluoroscopic control. It is critically important to have state-of-the-art fluoroscopic

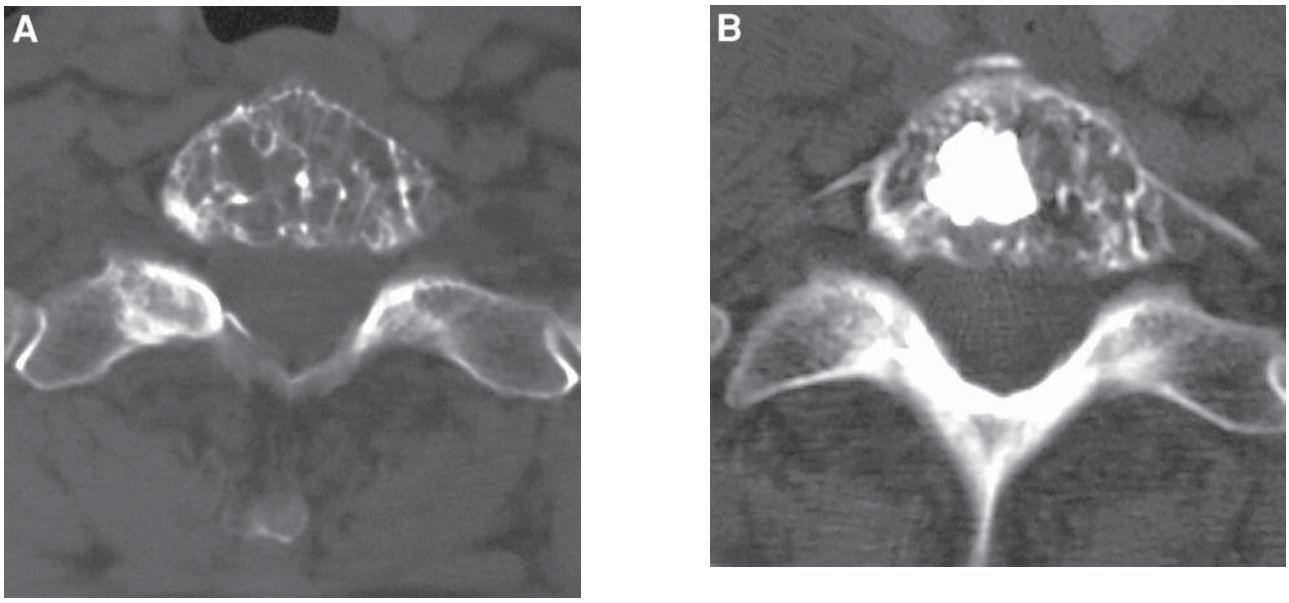

Fig. 3. **(A, B)** Middle-aged woman with a painful C7 hemangioma. CT scan through the affected area shows the typical osteolytic appearance with a "polka-dot" pattern of residual bony struts. Following vertebroplasty, the cement is noted to fill the largest cavity within the vertebral body with no paravertebral extravasation at this level.

equipment available, with multiple levels of magnification and small focal spot sizes. The most significant complications with vertebroplasty are related to untoward migration of cement into an extraosseus compartment, which can be avoided only through the use of excellent fluoroscopic imaging and adequate opacification of the cement. Portable low-quality analog fluoroscopy units are to be avoided. Digital subtraction angiography capability is needed if vertebrography is planned. Most operators perform vertebroplasty using single-plane fluoroscopy; biplane fluoroscopy speeds the procedure but is not considered essential.

MATERIALS

Needles Various "bone biopsy" needles may be used for vertebroplasty. Most practitioners use 11-gauge needles, but 13-gauge and 15-gauge needles may be used as well. Larger diameter needles are less compliant than smaller diameter needles, and thus may be more readily advanced through strong, bony tissues. Furthermore, viscous cement will tend to clog small-diameter needles. When the pedicles are small, such as in the mid- and upper thoracic region, placement of 13-gauge needles may be preferred over 11-gauge needles in this region. However, there are no data to support that using one size instead of the other results in a decreased complication rate *(35)*. Most needle systems offer a single trocar with a variety of stylets (Accuthread, Parallax Medical, Scotts Valley, CA; Osteo-site, Cook, Bloomington, IN). Often one of the stylets has a pointed tip, which facilitates initial placement of the needle system through the cortex of the pedicle. Once the needle is within the vertebra, a beveled stylet can be used to deflect the needle tip, allowing slight modifications of the needle trajectory *(17)*. A self-tapping screw stylet tip (Accuthread) can also be used to obtain purchase in thick cortical bone. Both needles can be used as conduits for smaller biopsy needles *(36)*; conversely, a large core can be removed using the vertebroplasty needle alone, which is then readvanced down the same puncture site.

Cement Currently, the only product used clinically for vertebroplasty is polymethylmethacrylate (PMMA). PMMA has a long history of use in the orthopedic and neurosurgical specialties for spinal and cranial reconstruction *(37–39)*. PMMA appears to offer an ideal mix of the ability to be injected as well as the ability to strengthen and support the vertebral body *(40)*. Typically, PMMA is supplied as a two-component device with a powdered, polymerized MMA and a liquid monomer MMA. The powdered component is combined with an opacifying agent and possibly antibiotic powder, mixed with the liquid monomer to a desired consistency, and injected. At least four PMMA formulations are commercially available; however, none are approved by the Food and Drug Administration (FDA) for use in vertebroplasty. Any PMMA products in the practice of vertebroplasty are used in an off-label fashion, and the patient should be notified. It is recommended that practitioners who are starting new vertebroplasty practices consult with their local investigational review board to clarify issues regarding off-label

use of this device. If PMMA were to be used as part of a prospective clinical trial then an investigational device exception would be required.

The four types of PMMA formulations currently available include Secour (Parallax Medical), Codman Cranioplastic Slow Set (CMW Laboratories, Blackpool, England), Osteobond (Zimmer, Warsaw, IN), and Surgical Simplex P (Howmedica, Rutherford, NJ). There are differences among these products regarding polymerization time. Simplex P and Osteobond have a rapid polymerization time, which may render the material too viscous for injection after 5 min of use. Prolongation of the polymerization time can be achieved with refrigeration of the product prior to use. Cranioplastic Slow Set and Secour offer relatively long polymerization times that can facilitate prolonged injections or injection of two levels sequentially.

Simplex P is the only PMMA is mixed with barium sulfate for opacification, but the amount is not sufficient for visualization for vertebroplasty, and additional sterile barium is added prior to its use.

Opacifying Agents Vertebroplasty can be performed safely only if outstanding radiopacity has been achieved for the injected cement, and is therefore of paramount importance. Most practitioners use barium sulfate to opacify cement. Earlier reports detail the concomitant use of powdered metallic opacifying agents such as tungsten *(1,2,4–6)*, but many practitioners have abandoned the use of the fine-powdered opacifying agents. In our practice we rely on relatively large particles of barium sulfate to facilitate visualization of cement injection. At least two sterile barium sulfate products are available commercially. Tracers (Parallax Medical) is an FDA approved cement opacifier that comes prepackaged in 5-g aliquots in a capped, graduated cylinder in which the cement can be prepared. This material consists of different sized particles, which allows easy identification of cement movement during injection. A barium sulfate product of same-sized particles from Bryant Corporation (Woburn, MA) can also be purchased. Regardless of the product used, it is recommended that approx 30% of the total cement volume be barium sulfate for adequate opacification of the material. Although the addition of an opacifier decreases the overall compressive strength of the cement *(40)*, it is not clinically significant.

Antibiotics The use of antibiotics in vertebroplasty is considered routine by most practitioners but has never been subject to comparative studies. The earlier practitioners recommended mixing 1.2 g of tobramycin *(3)* into the cement, based on surgical literature demonstrating decreased infection rates in patients with implanted tobramycin-impregnated methacrylate *(37,41)*. Many practitioners also use some administration of intravenous antibiotics focused on skin contaminants, typically giving 1 g of cephazolin 30 min prior to cement injection *(23)*. Both of these practices are considered prudent although there is no compelling evidence that they diminish infection rate.

Injection Devices A variety of cement delivery systems are commercially available, including the DynaFlow Injection Syringe (Parallax Medical) and the OsteoForce injector (Cook). Other manufacturers, including Spinal Specialties, Allegiance Medical, and Stryker-Howmedica, also have injection devices available for purchase. Differences in speed of cement delivery, length of injection tubing, and self-purging capabilities are noted, but none of the injection devices give the same tactile feedback as a 1-cc syringe during cement injection. The major advantage of injection devices is the removal of the operator's hands from the radiation field.

NEEDLE APPROACH

Needle placement is fairly straightforward in the lower lumbar spine, given the relatively large size of the pedicles and vertebrae in that region. Mid- and upper thoracic vertebroplasty may be more challenging owing to small pedicle size, kyphotic angulation, and risk for pneumothorax *(35)*.

Several approaches have been utilized to access the vertebral body, including transpediculate, parapedicular, and paravertebral. The transpedicular approach has been considered the safest, as the needle traverses only skin, soft tissues, and bone to enter the vertebral body. Injury to adjacent nerve roots, vessels, and the spinal cord is impossible if the needle track remains in the pedicle.

Early reports of vertebroplasty *(3)* detailed a bipediculate needle approach, wherein a relatively parasagittal needle trajectory was used to place needles sequentially in both hemivertebrae. More recently, however, a unipediculate approach has gained acceptance *(42)*. In this approach, one uses an oblique-angled approach to place the needle tip in the midline of the vertebral body. In the lumbar region the appropriate trajectory is attained with the anteroposterior (AP) tube angled 20–30° toward the pedicle to be punctured. This obliquity brings out the "scotty dog" outline of the pedicle, transverse process, superior and inferior articular processes, and the pars interarticularis. The needle passes through the pedicle near the "eye" of the "scotty dog" outline (Fig. 4). In the thoracic region, where the "scotty dog" is less obvious, the tube is typically angled 20° or less.

To facilitate needle placement, both AP and lateral fluoro-scopy is used. The superior–inferior position of the skin entry site is determined with lateral fluoroscopy, to define an appropriate trajectory through the pedicle. As vertebral body fractures usually have an anterior wedged

component, the needle placement should be initially positioned in the middle or superior portion of the pedicle (Fig. 5). This location allows a downward trajectory, with the needle often paralleling the endplate. On the AP view, the needle tip is initially positioned laterally or in the center of the pedicle to prevent transgression of the medial wall. It is useful to determine the correct placement of the needle in both planes with the 25-gauge anesthetic needle. Once the starting point is determined, 5–7 cc of 0.25% bupivacaine hydrochloride is injected into the periosteum. The anesthetic needle is removed and, using the same trajectory, the vertebroplasty needle is placed.

As the needle moves through the pedicle, frequent AP fluoroscopy is done to ensure that the needle remains within the confines of the pediculate outline, and is traveling in a straight or slightly lateral-to-medial direction. A steady back-and-forth twisting motion is used to advance the needle tip; gentle tapping one the needle handle with a sterile orthopedic hammer is another alternative. Once the needle is within the trabecular bone, less pressure is required to advance the needle tip and care must be taken not to violate the endplates or the anterior vertebral wall. Needle movement through the vertebral body is checked frequently with lateral fluoroscopy; the tip of the needle is advanced until it is within the anterior quarter of the vertebral body (Fig. 6). If the needle tip approximates the midline on the AP view, then a single injection should adequately fill the center of the vertebral body, and a contralateral puncture will not be necessary.

If the bipediculate approach is used, the operator can puncture and inject each pedicle separately, or both needles can be placed and injected sequentially. If the latter option is chosen, the second needle may obscure cement movement through the first needle during injection. The stylet should not be removed from the contralateral needle during an ipsilateral injection, as the cement will flow up the contralateral needle, rendering it useless and resulting in a poor vertebral fill.

VENOGRAPHY

The marrow space into which cement is injected during vertebroplasty is a venous compartment with numerous connections to the epidural and paraspinal venous plexus. Safe vertebroplasty can be performed only by avoiding untoward migration of cement into these extraosseous venous compartments. Venography performed through the vertebroplasty needle prior to cement infusion may allow identification of sites of communication between the marrow and the adjacent venous outlets *(43)* (Fig. 7). Venography is performed by injection of 3–5 cc of contrast while performing digital subtraction imaging at 2 frames/s. Patient motion may degrade image quality, especially in the region of the diaphragm. Controversy

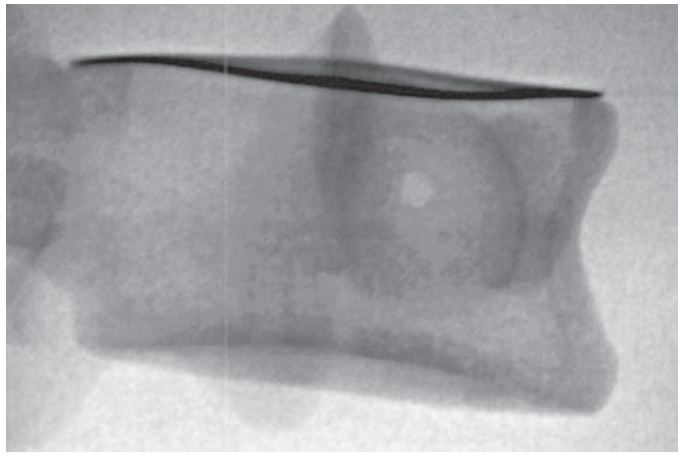

Fig. 4. AP oblique view of a lumbar spine model demonstrates the "scotty dog" obliquity with the needle track through the pedicle.

over the necessity of antecedent vertebrography is considerable *(43–48)*. Proponents of the technique cite its value in outlining the venous egress *(3,43)* and predicting the fill pattern *(43)*. This knowledge may avoid the need for a second puncture *(43,47)* or reduce complications from venous extravasation *(47)*. McGraw et al. performed 135 intraosseous venograms during 96 vertebroplasty procedures. Several venographic patterns were described: bilateral or unilateral marrow blush with or without venous filling, direct venous filling, leakage of contrast through an endplate or cortical defect, and stasis within the marrow space. Venograms that demonstrated a bilateral marrow blush predicted flow of PMMA across the midline to fill the contralateral hemivertebrae adequately 95% of the time. A unilateral marrow blush predicted the necessity of a second puncture 97% of the time *(43)*.

Others state that venography does not significantly improve the effectiveness or safety of percutaneous vertebroplasty performed by qualified, experienced operators *(44–46)*, that it does not accurately predict venous egress of cement, that stagnant contrast may obscure visualization during injection, and that it exposes the patient to a risk of contrast reaction. The latter problem can be eliminated through the use of carbon dioxide or gadopentetate dimeglumine as a contrast agent *(49)*. In short, as one's experience with vertebroplasty increases, the need for routine venography may diminish; but when indicated, it can be performed safely and provide useful information.

INJECTION DETAILS

Preparation of the cement has been previously described *(3,17)*. Individual operators have their own preferred "recipes" but minimal variations do not appear to alter significantly the use or strength of the material *(40)*.

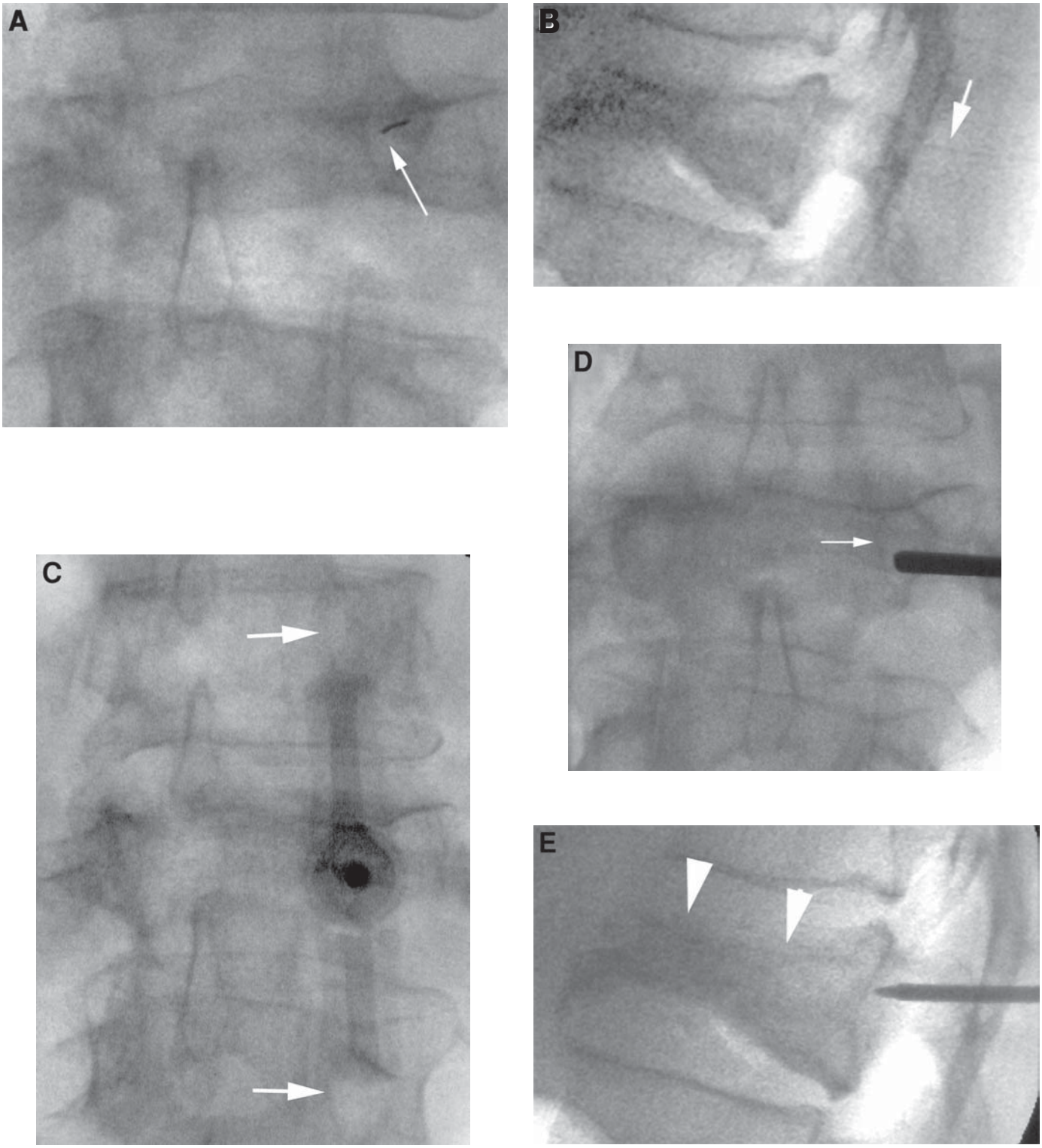

Fig. 5. **(A–E)** This elderly female patient with a severely compressed L1 vertebral body presented for treatment. The 25-gauge anesthetic needle (*arrows*) is used to determine the initial needle trajectory on the AP **(A)** and lateral **(B)** views. Owing to the degree of compression, the needle is positioned more superiorly on the posterior pediculate surface as a downward trajectory is anticipated. The handle of the vertebroplasty needle may obscure the medial wall of the pedicle as it is advanced **(C)**. The medial borders of the adjacent pedicles (*arrows*) may be used as a guide. Alternatively, the pedicle can be visualized in the AP view. If the needle tip crosses the medial pediculate border (*arrow*) before the vertebral body is entered, then it has entered the spinal canal. On the lateral view **(E)**, the needle trajectory parallels the superior endplate (*arrows*) to prevent inadvertent puncture of the endplate.

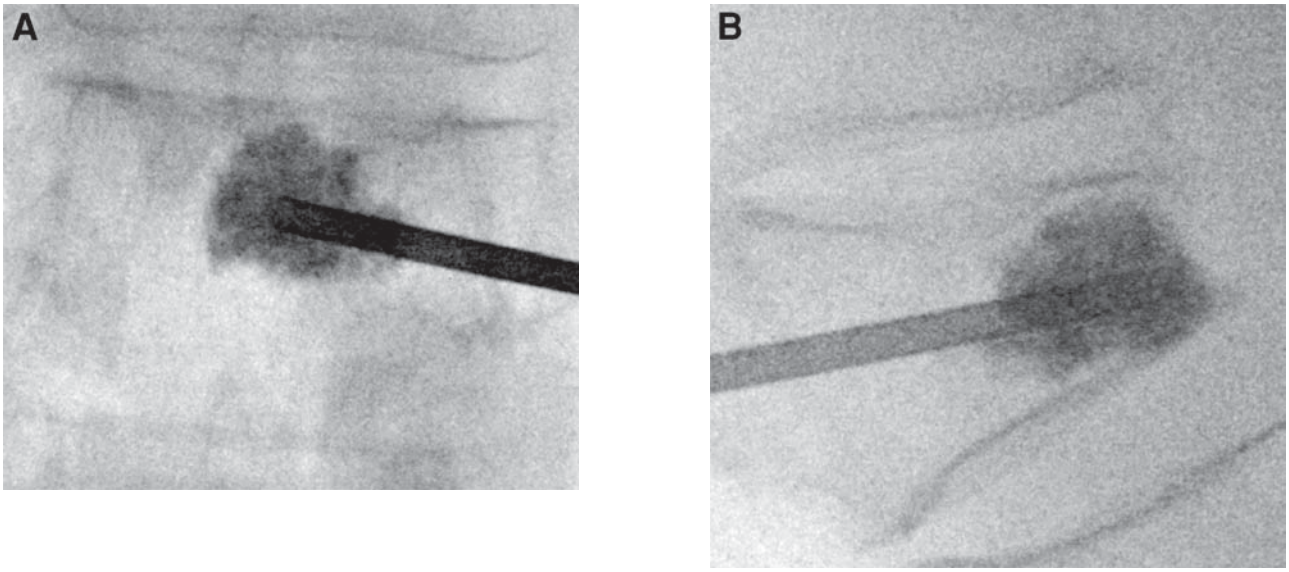

Fig. 6. **(A, B)** Unipediculate needle placement shows central filling of the vertebral body with cement. The injection was discontinued when the cement reached the posterior quarter of the vertebral body.

The authors' practice includes the mixing of antibiotic powder with the powdered PMMA and combining it with the barium sulfate which comes in a graduated cylinder. The cylinder is filled to the 15-cc mark and shaken vigorously to mix the contents. Approximately 6.0–6.2 cc of the liquid monomer is added to the cylinder and it is shaken again, until a thin, cake-glaze consistency is obtained. Alternatively, the contents of the cylinder can be mixed in a bowl with the liquid agent, allowing the operator to visualize the consistency better. Adjustments can be made during mixing by adding small amounts of powder or liquid. Once the material is ready, it can be loaded into 1-cc Luer-lock syringes (Becton-Dickinson, Franklin Lakes, NJ; Merit Medical, South Jordan, UT), or poured into a commercially available injection device.

Vertebroplasty is an embolization, and cement should be injected only under continuous fluoroscopic control. We monitor cement infusion primarily under lateral fluoroscopy, as epidural or foraminal cement extravasation is seen most readily in the lateral plane. However, venous connections to the paravertebral veins may exit along the lateral aspect of the vertebral body. Lateral vertebral extravasation is best seen with the AP tube, so we perform intermittent AP fluoroscopy during injection.

As the injection proceeds, the needle is pulled back whenever injection becomes difficult or cement flow is obscured. If the cement does not readily egress out the needle, a plug may have formed at the tip of the 1-cc syringe or the injector tubing. The syringe/tubing is disconnected and the plug is cleared; if the obstruction remains, then the cannula is cleared with the stylet. This maneuver is done under fluoroscopic control, as the dead space of the cannula is 0.7 cc, and the material within it is being advanced into the vertebral body. If the cannula is obstructed, it is removed and replaced with a new needle down the same track. The injection continues until cement enters the posterior quarter of the vertebral body. Cement often flows preferentially into endplate fractures. In the authors' experience, small amounts of extravasation across the endplate often correlates with pain improvement. However, deposition of a large amount of PMMA into the disc space should be avoided because of the potential increased risk of fracture of the adjacent vertebra from diminished compliance in the disk space (A. Evans, *personal communication*).

The exact volume of cement used for vertebroplasty is considered less important than adherence to the principles of safe cement deposition. In vitro biomechanical testing shows that only 2 cc of PMMA is needed to increase vertebral strength, but 4–8 cc is required to restore stiffness *(50)*. Previous reports have quoted mean cement volumes on the order of 7 cc per level *(3)*, but the authors have noted no difference in clinical outcomes between the high cement volume (>3 cc) and low cement volume patient population (*unpublished data*). If the operator feels that an inadequate amount of cement has been deposited, then the contralateral hemisphere can be treated. Multiple fractures may be treated in a single session. The authors routinely perform two- or three-level vertebroplasty, and have occasionally performed four-level vertebroplasty in one sitting.

Once the injection is completed, the cannula is removed. The stylet is not replaced prior to removal as this pushes more material into the vertebral body. Instead,

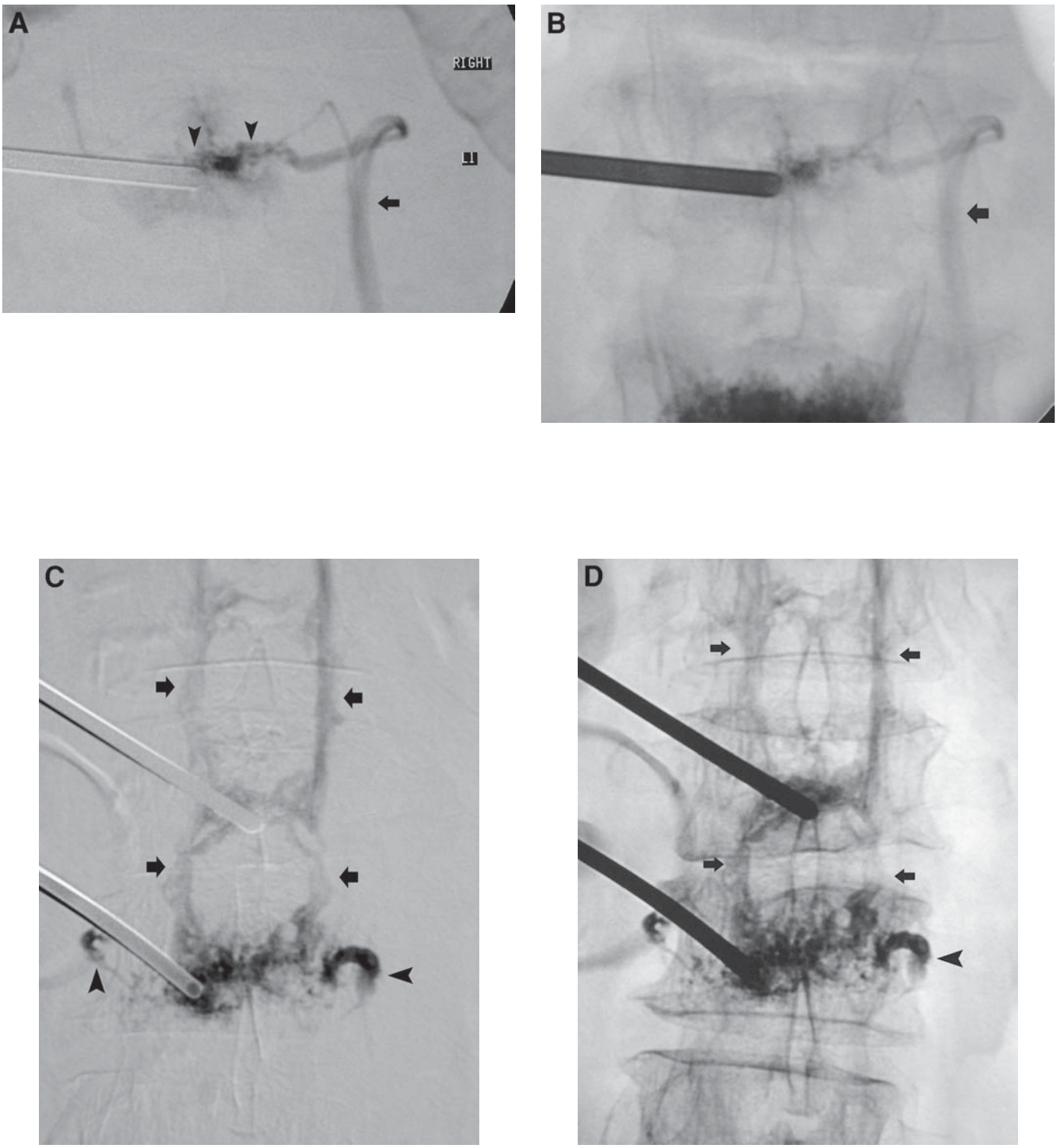

Fig. 7. **(A, B)** Digital subtracted and nonsubtracted images of vertebrogram showing marrow blush (*arrowhead*) and paravertebral vein (*arrow*). **(C, D)** Subtracted and nonsubtracted vertebrogram showing epidural venous plexus (*arrows*) and paravertebral veins (*arrowheads*).

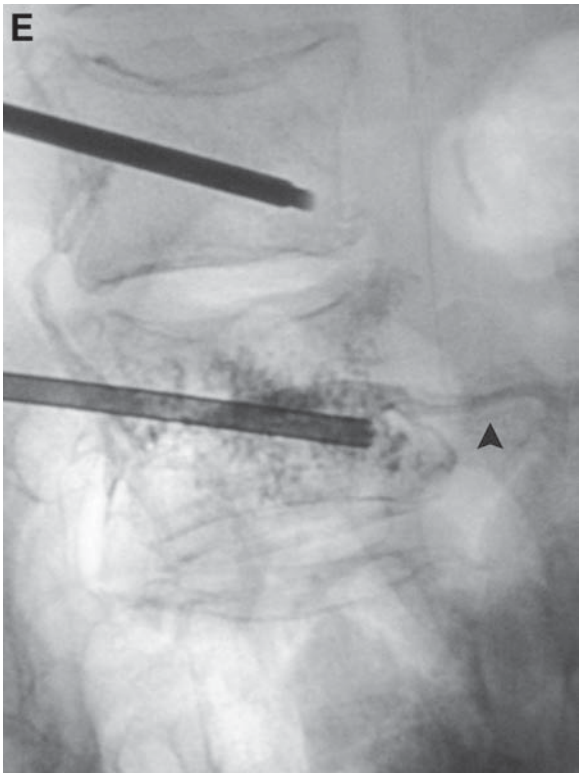

Fig. 7. *continued* **(E)** Lateral vertebrogram showing marrow blush and a paravertebral vein (*arrowhead*).

the needle is rotated several times to disconnect the cement inside the cannula from the cement in the vertebral body, and the needle is withdrawn. Firm pressure is applied over the puncture site for a few minutes to prevent the formation of a subcutaneous hematoma.

POSTPROCEDURE CARE

Immediately following the procedure patients are transferred to a stretcher and remain supine for 1 h. Subsequently they are slowly mobilized and discharged. Patients are instructed that they may feel discomfort of a different character than the fracture pain previously experienced, which we ascribe to mild trauma from needle placement. A small bandage is placed over the dermatotomy site. Patients are encouraged to use nonsteroidal antiinflammatory pain medications as needed, but to limit narcotic use so efficacy can be determined. Prior to discharge patients are evaluated for new chest or back pain, new neurological symptoms, or other complaints that may indi-cate a complication. Most significant complications are due to inappropriate cement deposition, and the patient will quickly become symptomatic. Early recognition is key so that treatment can be instituted, and suspected complications should be considered an emergency. Immediate access to CT scanning and surgical consultation are key components of any vertebroplasty service.

Telephone follow-up 1–3 d after vertebroplasty is considered adequate in most cases. No dedicated imaging follow-up is needed unless complications are suspected. Patients are instructed to keep the puncture site clean and dry, and to notify the physician of any erythema or discharge at the puncture site, recurrent or new back pain, chest pain, shortness of breath, unexplained fever, or neurological dysfunction. People who have been at bed rest for an extended period are encouraged to increase their activity gradually. Short-term physical therapy or back bracing may be indicated. Patients who are not receiving preventative medical therapy are referred to endocrinology or geriatrics for evaluation and treatment.

RESULTS

Patient outcomes following vertebroplasty, measured as decreases in subjective intensity of pain, have been outstanding. Using semiquantitative or visual analog pain scales most studies have reported short-term improvement in 70–97% of patients *(3–5,9,11–13,16,18,20–22, 25,33,35,51)*. McGraw et al. performed a prospective study on 100 patients who underwent vertebroplasty on 156 levels. The mean follow-up period was 21.5 mo in 99 patients. Ninety-two patients (93%) reported significant improvement in back pain previously associated with their compression fractures as well as improved ambulatory ability. Before vertebroplasty the average visual analog scale score (VAS) was 8.91±1.12 compared to a score of 2.02±1.95 at follow-up *(51)*. Efficacy of vertebroplasty is substantiated further by high rates of new patients sent by refer-ring physicians as well as by how frequently patients treated with vertebroplasty seek additional treatment with subsequent fractures. Rates of pain improvement are highly dependent on patient selection. Patients with "classic" histories of single, subacute painful fractures can be expected to improve in 90% of cases; success rates may be 50% or lower with complicated histories and coexisting spinal disease. There remain many aspects of patient outcome following vertebroplasty that merit further study. These include the use of validated, functional outcome scales; long-term follow-up; and prospective, randomized trials of vertebroplasty vs best medical therapy, or ideally, a sham intervention *(52)*. Each of these studies is ongoing at the present time.

COMPLICATIONS

New pain that develops following successful vertebroplasty may present challenges in patient management, and several scenarios must be considered. First,

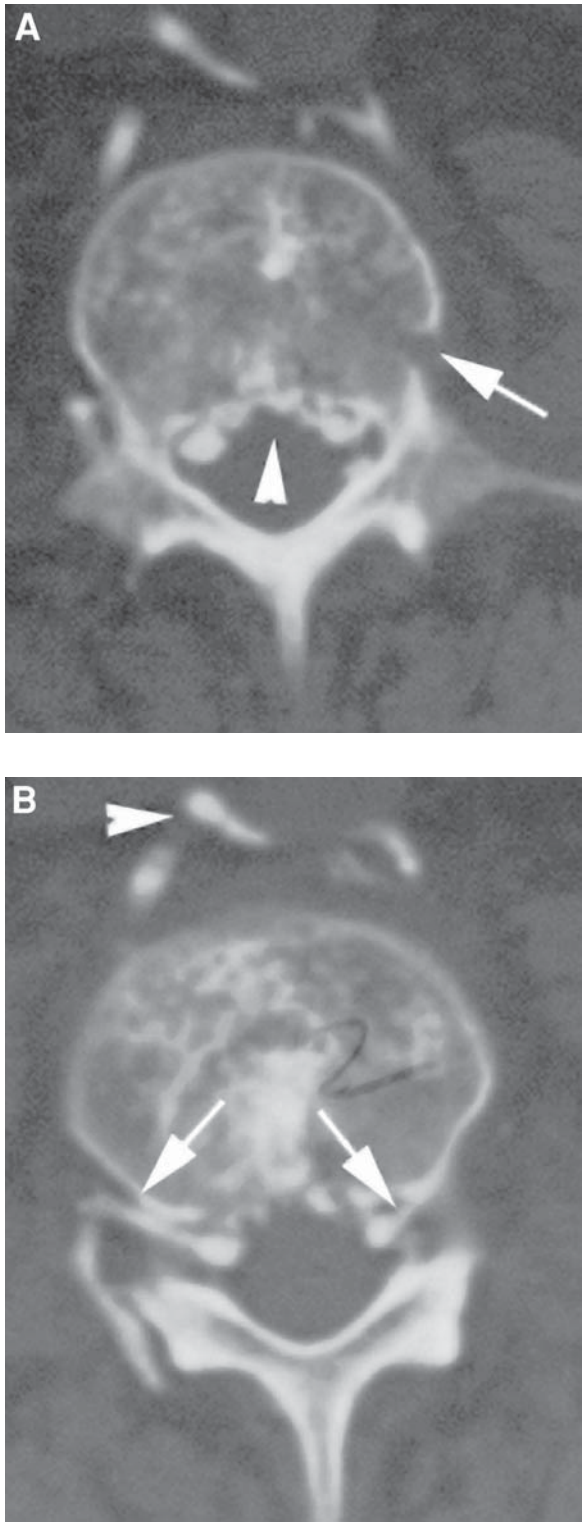

Fig. 8. **(A, B)** An elderly woman with L2 compression fracture underwent vertebroplasty from a left paravertebral approach (**A**, *arrow*). Cement leakage into the epidural venous plexus (**A**, *arrowhead*), the foraminal veins (**B**, *arrows*), and into the inferior vena cava (**B**, *arrowheads*) is noted. After awakening from general anesthesia, the patient had severe left-sided radicular pain requiring nerve root blocks for pain control.

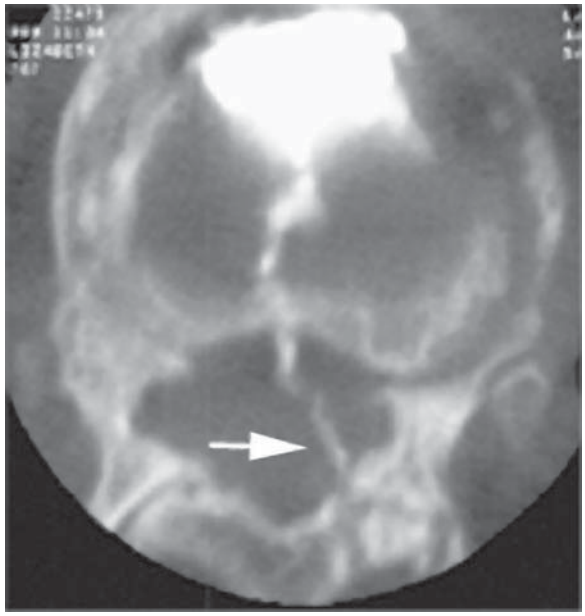

Fig. 9. During vertebroplasty of T12, the patient experienced severe back and leg pain followed by bilateral hip flexor weakness. Spiral CT scan shows the needle track through the left T11 lamina and spinal canal and into the T11–T12 disc space, where the majority of the cement had been deposited. The cement decompressed along the needle track and was applied to the lateral aspect of the conus (*arrow*). MR (not shown) did not show cord edema, but tenting of the conus against a fracture fragment may have been responsible for the neurological deficit.

successful vertebroplasty may "unmask" pain that was preexisting but overwhelmed by the severe fracture pain. This pain may result from muscle spasm, facet disease, or other etiologies. Bracing, physical therapy, or injection therapy may be indicated. As stated previously, new fractures are frequent in all osteoporotic fractures, whether or not initial fractures are treated with vertebroplasty *(53)*. Diagnosis of new, subtle endplate fractures may be difficult or impossible with plain radiographs. MRI is extremely useful in cases of suspected new fracture not evident on plain radiographs.

Pain may also be directly related to the vertebroplasty procedure. Cement extravasation into the epidural or foraminal space may irritate nerve roots and cause excruciating pain (Fig. 8) or paralysis *(54,55)*. Such pain, often radicular in nature, may respond to nerve root blockage but may also require surgical resection of cement. CT scanning is considered the test of choice for evaluating suspected nerve root irritation. Transgression of the medial pedicle wall can result in violation of the thecal sac, with resultant cerebrospinal fluid leak or cord damage (Fig. 9). Vertebral fractures may also result from vertebroplasty; CT scanning would be considered the

initial test for evaluating suspected fractures of the vertebral elements. Fracture of other osteoporotic bones from lying prone has also been reported, including rib *(3)* and sternal *(52)* fractures. Iatrogenic infection with resultant osteomyelitis/diskitis represents a severe complication that almost certainly requires surgical intervention. Suspected infection would be best evaluated by MRI.

Other complications from vertebroplasty include migration of cement into the systemic venous circulation *(56)*. Every attempt should be made to avoid such extravasation. If cement travels to the vena cava without resultant pulmonary emboli, conservative therapy with antiplatelets may be all that is required. Pulmonary embolism from cement extravasation warrants supportive therapy. In the rare instance where a patent foramen ovale is present, cement can enter the arterial system with disastrous results such as stroke *(57)*.

Surgical packing of PMMA has resulted in cardiovascular derangement, primarily hypotension *(58)*. There has been a reported case of transient hypotension during vertebroplasty that was thought to be due to the cement injection *(59)*; however, in the authors' experience, there is no generalized association between PMMA injection and systemic cardiovascular derangement *(60)*.

When reviewing all major vertebroplasty series, the complication rate ranges from 1% to 10%, but most complications are seen in the neoplastic population. Murphy and Deramond estimate the complication rate associated with osteoporotic fractures as 1.3% *(61)*. This small number should not lull one into a false sense of security. Complications are most commonly associated with poor patient selection, poor visualization from inadequate fluoroscopic equipment or poor cement opacification, operator inexperience, lack of patient monitoring, and improper aseptic technique. Avoidance of these problems will minimize the complications encountered in a vertebroplasty practice.

VERTEBROPLASTY FOR SPINAL NEOPLASMS

Vertebroplasty was first performed for painful spinal hemangiomas *(1,61–69)*. European practitioners have continued to treat large numbers of patients with spinal neoplasms *(2,9,61,70–72)*. In North America, however, treatment of neoplastic disease of the spine has failed to gain widespread acceptance *(73)*.

Treatment of neoplasms may be requested in the case of malignant fractures with pain refractory to medical and radiation therapy *(2,9,61,70–72)* or in cases of impending fracture *(18)*. The overall approach of vertebroplasty in treatment of neoplasms differs substantially from that for treatment of osteo-porotic fractures. First, preprocedure imaging should include CT and/or MRI to assess tumor extent and degree of bony involvement. Destruction of the posterior vertebral cortex renders vertebroplasty of higher risk, because of potential for cement extravasation into the spinal canal (Fig. 10) *(9)*. However, osteolysis of the posterior wall is not an absolute contraindication. Only when frank epidural tumor is present should vertebroplasty be avoided *(9,24,70–72)*. Second, patients with multifocal spinal metastases may have great difficulty in lying in the prone position and general anesthesia should be strongly considered. Third, the routine transpedicular approach may be difficult or impossible in cases of pediculate involvement with tumor, and may require CT for needle placement *(73)*. Fourth, venography may lead to large amounts of contrast leaking directly through areas of cortical destruction into the paravertebral and epidural spaces. This contrast cannot be readily removed from these spaces and thus may obscure cement deposition. Last, routine postprocedure CT scanning is considered prudent not only to assess location of cement but also to show changes in position of the tumor mass (A. Evans, *personal communication*).

The risk/benefit ratio of vertebroplasty for neoplastic disease is less favorable than that for osteoporotic fractures. Improvement in pain is seen in 50–80% of cases *(1,2,9, 18,61,70–72)*; nerve irritation from cement extravasation is the most common complication *(8,9)*.

KYPHOPLASTY

A variation of vertebroplasty, called kyphoplasty, has recently been gaining popularity, particularly in the surgical community. In this procedure, cannulas are placed down both pedicles, and two inflatable bone tamps are inserted into the vertebral body. The bone tamps are inflated to >200 psi, the trabeculae are crushed, and a cavity is created. The tamps are removed and the cavity is filled with viscous cement. Proponents of this technique state that it is safer than vertebroplasty because the cement filling is done under low pressure and therefore less extravasation and fewer complications occur *(74,75)*. No biomechanical or clinical data exist to support this claim. In fact, one symptomatic pulmonary embolus has been reported *(76)*, and in the only published, peer-reviewed study of 30 patients, one suffered a myocardial infarction *(75)*. Minimal height restoration in some vertebral bodies has also been noted *(75)*. However, positive outcomes as determined by pain relief and improved mobility are similar to the vertebroplasty experience, and there are no data to support the argument that minimal height restoration is an added benefit. Furthermore, the bone tamps are very expensive, and most operators perform the procedure with the patient under general anesthesia followed by a short-stay hospital admission. The increases in risk and cost are

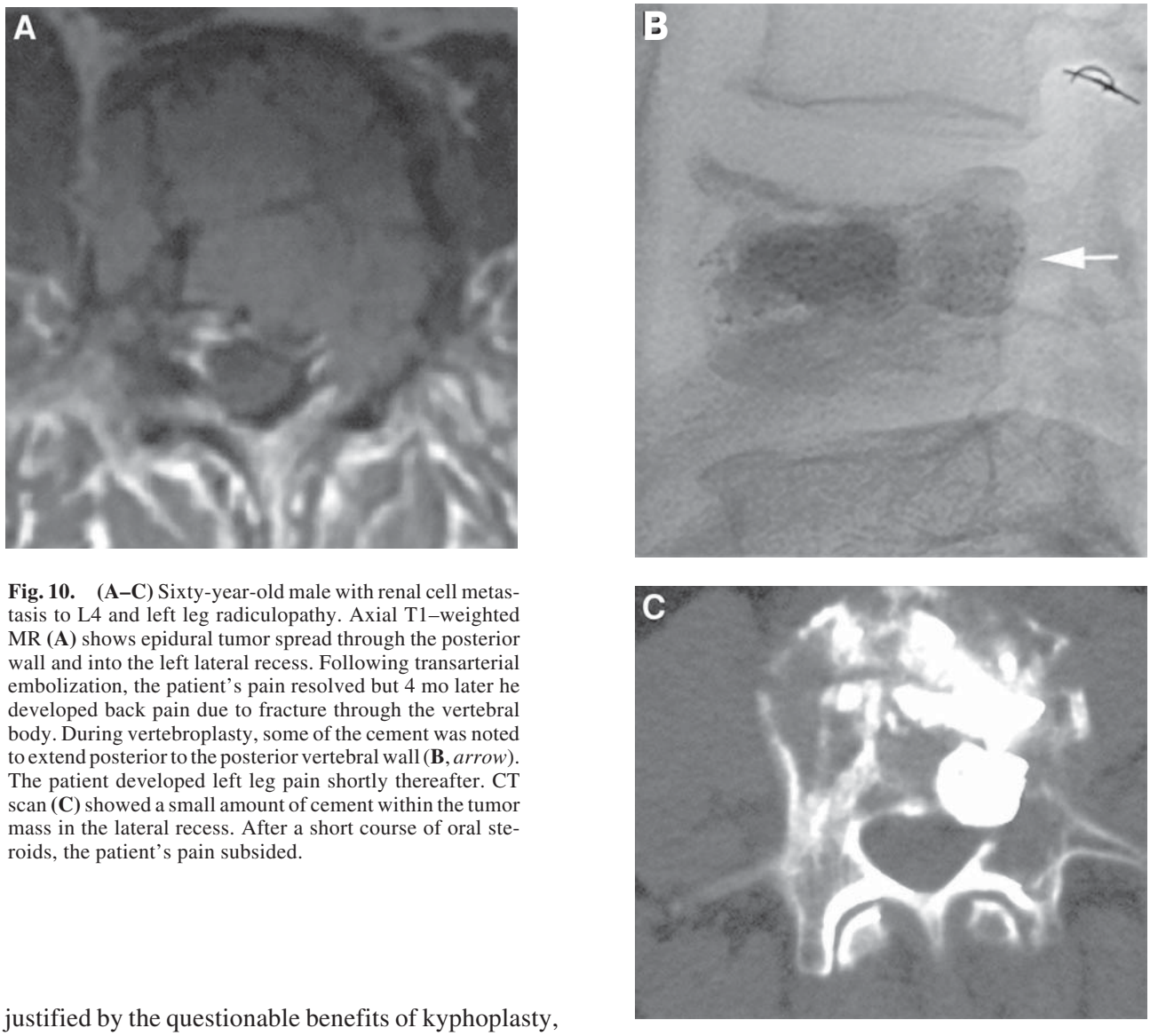

Fig. 10. **(A–C)** Sixty-year-old male with renal cell metastasis to L4 and left leg radiculopathy. Axial T1–weighted MR **(A)** shows epidural tumor spread through the posterior wall and into the left lateral recess. Following transarterial embolization, the patient's pain resolved but 4 mo later he developed back pain due to fracture through the vertebral body. During vertebroplasty, some of the cement was noted to extend posterior to the posterior vertebral wall (**B**, *arrow*). The patient developed left leg pain shortly thereafter. CT scan **(C)** showed a small amount of cement within the tumor mass in the lateral recess. After a short course of oral steroids, the patient's pain subsided.

not justified by the questionable benefits of kyphoplasty, and more serious study must be performed before it is accepted as an alternative to or improvement on vertebroplasty.

CONCLUSION

Percutaneous vertebroplasty is an innovative and successful approach to the treatment of painful compression fractures associated with osteoporosis and malignancies involving the vertebral body that are refractory to more conservative therapy. The authors encourage all interested radiologists to incorporate this exciting procedure into their current practice.

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16 Transcatheter Therapy for Tumors of the Spine

PETER J. PEMA, MD AND RONALD F. BUDZIK, MD

INTRODUCTION

Common metastatic hypervascular tumors involving the spinal column originate from renal cell carcinoma and, less commonly, thyroid carcinoma *(1)*. Metastatic breast, liver, and squamous cell carcinoma as well as melanoma and metastatic angiosarcoma *(2)* can also be hypervascular *(3)*. The most common primary tumors of the spine that are hypervascular are aggressive hemangiomas and aneurysmal bone cysts (ABCs). Many have recommended routine preoperative embolization for these tumors to decrease blood loss at surgery with the additional hope of making the tumor resection more complete *(1–18)*. Other rarer tumors known to be hypervascular, and for which embolization may also be indicated, include benign tumors (osteoblastoma *[19]*, osteoid osteoma *[20]*, chondroma), malignant tumors (giant cell tumor *[12]*, chordoma, osteogenic sarcoma, chondrosarcoma, hemangiopericytoma *[21]*, lymphoma, multiple myeloma, plasmacytoma), and spinal cord tumors (hemangioblastoma) (Fig. 1) *(22,46)*. According to the Accreditation Council on Graduate Medical Education *(22)* training program requirements, more than 95% of the spinal column embolization procedures should be performed for these diagnoses. Patients suffering from these bone tumors often present with pain or neurological deficits (weakness, numbness, loss of bowel or bladder function). This is usually secondary to compression of the spinal cord or nerves by soft tissue spread of the osseous process or by expansion of the vertebral body margins. This chapter details the indications for treatment, pertinent anatomy, preprocedure care, embolization technique, and postprocedure care of patients with hypervascular tumors of the spine.

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EMBOLIZATION AS PART OF THE TREATMENT ARMAMENTARIUM

The treatment options for patients with symptomatic spinal osseous and/or adjacent soft tissue disease include surgical excision, curettage, radiation therapy, and embolization, or a combination thereof. Surgical excision and/or curettage are the preferred treatment options in most cases *(1,23–25)*. Preoperative embolization is recommended for vascular lesions as an adjunctive therapy. In addition, when excision or radical curettage is not possible because of the location or extent of the lesion, embolization can be performed. Although it is not curative for metastatic foci, embolization can reduce pain and improve the neurological status *(9–12)*. Although embolization can rarely cure hemangiomas and ABCs, in most patients it is only palliative without subsequent sugery *(26–35)*. When curative, embolization completely devascularizes the tumor, leading to tumor necrosis and death. When palliative, embolization decreases tumor vascularity, leading to decreased tumor bulk and decreased compression on adjacent structures with pain relief and improved neurologic function *(2,27,33,34,36,37)*. Palliative embolization can be combined with radiation therapy in treating unresectable lesions. However, by far, embolization is used primarily as a preoperative tool to reduce blood loss and assess vascular anatomy angiographically. Surgery then becomes possible in previously inoperable tumors. It also becomes safer in operable tumors secondary to better visualization, and minimizes the need for transfusion and

extended operative time. In addition to the advantages of reduced tumor vascularity during surgery, surgical planning can be optimized based on analysis of angiographic vascular anatomy determined preoperatively.

FUNCTIONAL VASCULAR ANATOMY IMPORTANT TO THE INTERVENTIONIST

Arterial supply to the spine arises at segmental levels based on embryologic development of the somites. In the adult, arterial origins are variable based on the level of the spine. From the T3–5 to the L4 vertebral levels, segmental arteries arise from the thoracic or abdominal aorta. In the cervical region, supply to the segments is predominantly from the vertebral arteries as well as the ascending and deep cervical branches of the thyrocervical and costocervical trunks of the subclavian artery, respectively. The upper thoracic segmental supply is in balance between the uppermost segmental/intercostal branch of the aorta (the supreme intercostal) and the costocervical and thyrocervical trunk branches. At the skull base and in the upper cervical region supply can be from the occipital and ascending pharyngeal systems as well as from the posterior inferior cerebellar and vertebral arteries. Supply to the lower lumbosacral region including L5 and sacrum arises from iliolumbar, middle (median) sacral, and lateral sacral arteries of the distal aorta and internal iliac systems.

For most of the thoracic and lumbar spine, paired posterior segmental arteries arise from the posterolateral aorta and course from anterior to posterior along the vertebral body. Several small central branches pierce the cortical bone. Before continuing posterolaterally to join the neural structures to form the subcostal neurovascular bundle (intercostal artery), the dorsospinal artery arises medially. In the cervical and lower lumbosacral region where the arteries supplying the spine originate more laterally, the dorsospinal branch also arises near the neural foramen. The dorsal artery supplies adjacent osseous and soft tissue structures, while the more medial spinal artery courses into the foramen. The spinal artery gives rise to a posterior central branch with its superior and inferior division. These divisions meet with branches from adjacent vertebral bodies and with its counterpart from the opposite side to create a vascular anastamosis in the center of the posterior surface of the vertebral body. The spinal artery gives rise to a prelaminar artery, which follows the dorsal aspect of the vertebral canal, and to anterior and posterior radicular branches. These anterior and posterior radicular branches supply the ventral and dorsal nerve roots, respectively.

Supply to the spinal cord itself arises predominantly from the radicular arteries (Fig. 2). The anterior spinal artery is a midline artery that runs on the anterior surface of the cord and supplies the anterior two thirds of the cord including the deep "medullary" portion containing the primary motor fibers. An arterial "pial" plexus that encompasses the posterior one third of the cord supplies the posterior cord. Radicular arteries supplying the anterior spinal artery are called radiculomedullary arteries. Radicular arteries supplying the posterior spinal plexus are called radiculopial arteries. The number and location of feeding radicular branches are highly variable in any individual. There are roughly two to four, two to three, and zero to four cervical, thoracic, and lumbosacral radiculo*medullary* arteries, respectively. There are three to four, six to nine, and zero to three cervical, thoracic, and lumbosacral radiculo*pial* arteries, respectively. The dominant supply of the lower anterior thoracic cord is the artery of Adamkiewicz or artery of lumbar enlargement, which arises 85% of the time from the left T9–L2 radicular branches. But because it can arise from T4–L2 or L3, it is imperative to exclude its presence at a potential embolization site. The dominant supply to the cervical anterior spinal artery is the artery of cervical enlargement, which arises from either right or left midcervical vertebral artery.

The cord parenchyma drains into anterior and posterior spinal veins, which run the surface of the cord. At some levels, these join the anterior and posterior radicular veins on the exiting roots and coalesce to join the foraminal intervertebral vein. The majority of the venous drainage of the vertebral body is into the anterior internal (epidural) venous plexus along the posterior margin of the vertebral body. The anterior (epidural) plexus, with the smaller posterior internal (epidural) plexus along the anterior margin of the posterior elements, drain into the intervertebral vein exiting the neural foramen. Drainage then is into the posterior intercostal, superior intercostal, and subcostal veins. From there, drainage is into the innominate vein and azygos system depending on the level.

PREEMBOLIZATION EVALUATION AND ANGIOGRAPHIC WORKUP

Because diagnostic arteriography is often performed in conjunction with subsequent embolization, informed consent with discussion of embolization needs to be done first. Complications of spinal and vertebral arteriography as well as embolization would include the following: pain, stroke including death, paralysis, loss of sensation, bowel/bladder dysfunction, or sexual dysfunction. In addition, depending on the complexity of the case, many prefer the patient be placed under general anesthesia often with constant monitoring of "somatosensory" evoked poten-

tials to evaluate posterior column (cord) integrity. In addition, using general anesthesia greatly increases the ability to visualize the small vessels of the cord, making angiography and subsequent embolization safer and more effective. The need for anesthesia should be addressed preoperatively as well. Baseline neuro-logical physical exam should be performed focused on extremity and truncal strength, sensation, and reflexes. This examination should be meticulously performed so that an accurate evaluation of improvement or deterioration can be made.

After identifying patients who may benefit from tumor embolization, spinal angiography is necessary. In the cervical region, at a minimum, the costocervical and thyrocervical trunks of the subclavian artery, external carotid arteries, and vertebral arteries need to be evaluated by selective angiography. There are three objectives of performing angiography. First, the abnormal feeding vessels supplying the tumor must be identified. The size, tortuosity, and relationship to adjacent normal vessels should be documented. Second, it must be made clear that the abnormal vessels do not also directly supply the anterior or posterior spinal artery and spinal cord. Third, relationships of the vessel supplying the tumor to the vertebral artery or other dangerous anastamoses also need to be considered to prevent inadvertent embolization of normal structures.

Angiographic features of vessels supplying hypervascular tumors include some or all of the following characteristics: dilation of feeding arteries, increased number of arteries, early dense vascular stain (greater than the normal vertebral blush) extending beyond the expected hemivertebrae into the entire vertebral body or into the adjacent soft tissue, multiple pools of contrast in the capillary phase, and arteriovenous shunting. Anatomic correlation with cross-sectional imaging is imperative in determining whether mild hypervascular angiographic stain indeed represents tumor or normal tissue.

The catheters most useful for selecting spinal segmental arteries arising from the aorta are the spinal catheters HS1 and HS2, or a cobra C2 curve. A spinal catheter that tapers from a standard 5- to 6-French shaft to a tip that accepts only an 0.025-in. wire is often helpful for diagnostic angiography in engaging the small origin of segmental arteries. Depending on the angle of origin of a particular vessel, other useful catheters include a Simmons I, SOS Omni I and II, Mikaelson, and an H1H headhunter. The straight anteroposterior view is used for angiography so that vessel relationship to vertebral body landmarks can be correlated. Oblique views can be obtained to supplement the anteroposterior view. Lateral views can be helpful but are often difficult to obtain owing to the small size of the vessels.

THE TECHNIQUE OF TUMOR EMBOLIZATION

After the abnormal vessels are identified, a guide catheter platform through which interventional tools (catheters, wire, embolics) will be advanced needs to be positioned. Commonly a 5- or 6-French type guide catheter is positioned at the segmental artery origin or as far into the vertebral artery (or other) as possible. The guide is outfitted with a rotating hemostatic valve, to which a three-way stopcock adaptor is connected, where a continuous heparin saline flush is run (4000–5000 IU heparin/L). The other port is available for contrast injections for angiographic runs or roadmap. Usually systemic anticoagulation is performed with an ACT value of 250–300. Next, the abnormal vessel is selected, usually with a 0.0180 to 0.021-in. lumen microcatheter advanced over an 0.014-in. microwire. Commonly used microcatheters include the Rapid Transit and the Prowler Plus (Cordis Neurovascular) or Renegade (Target, Boston Scientific). Flow-directed catheters are not as useful owing to the often less robust flow and the relatively smaller inner lumen which can limit the size of particles used. The 0.021-in. lumen catheters allow particles up to 500–700 μm in size and sometimes even larger particles. Commonly used wires include the Transcend 0.010 and 0.014 wires, the Fasdasher 0.014 wire (Target, Boston Scientific), Agility 0.010 and 0.014 (Cordis Neurovascular), Synchro 0.014 (Preciscion Vascular Systems), and Silver Speed 0.010 and 0.014 wires and the 0.008 Mirage (Microtherapeutics).

The microcatheter is advanced as distally as possible toward the tumor in the abnormal vessel. Although usually not needed, provocative testing can be performed to help determine if the vessel can be sacrificed by occlusion. The patient would have to be awake, or monitored with evoked potentials if under neuroleptic anesthesia. A spinal WADA test involves injecting a short-acting barbiturate (i.e., 50 mg of sodium amytal) which would suppress gray matter neuronal activity leading to flaccid paralysis. If negative, 30 mg of 2% lidocaine can be injected which will inhibit nerve conduction through the white matter spinal tracts leading to flaccidity, hyperreflexia, and thigh fasciculations. The duration of action of these agents is approx 5–10 min.

Provocative testing as described can be done in or near radicular arteries (supplying the cord) as well as in circulations with potential intracranial anastomoses (i.e., the external caro-tid artery). In the vertebral or internal carotid arteries with direct brain supply lidocaine is not used. If provocative testing yields a deficit, embolization should probably not be performed from this location and

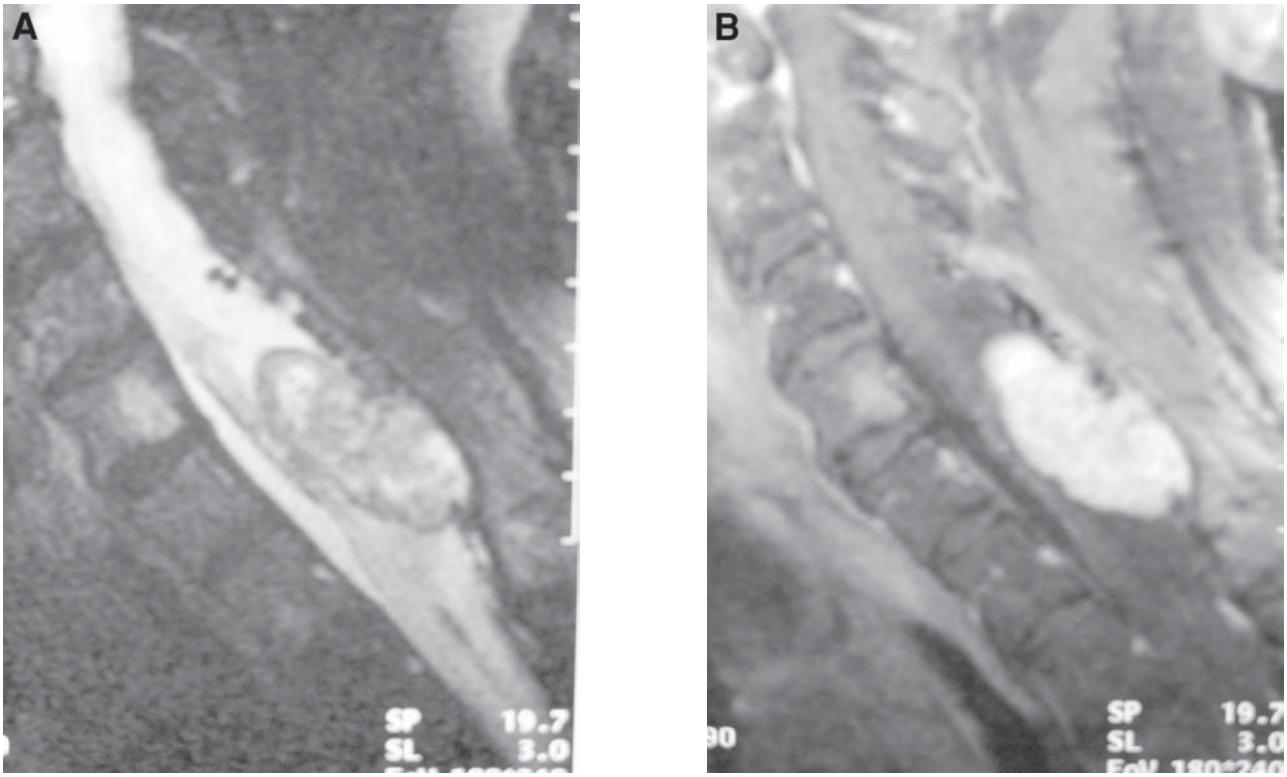
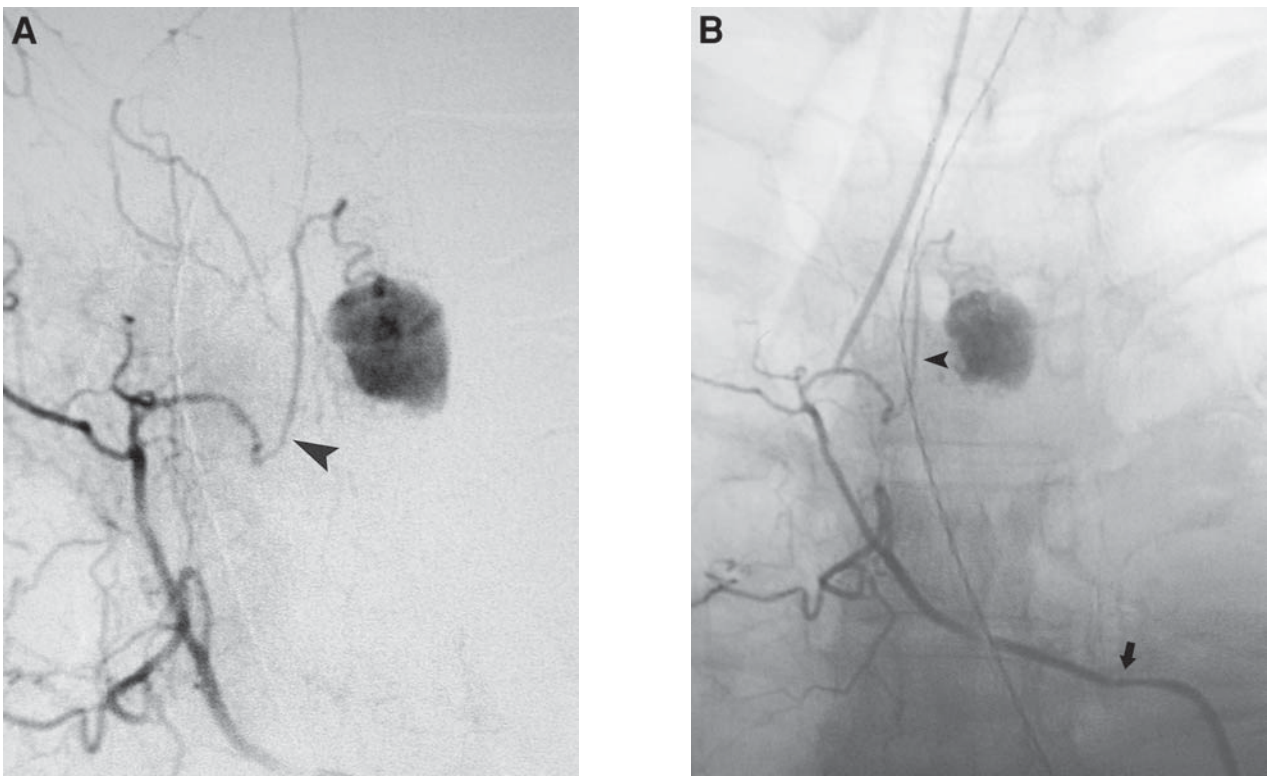


Fig. 1. Hemangioblastoma magnetic resonance imaging (MRI). **(A)** T2-Weighted MR image shows a relatively dark heterogeneous oval mass within the cervical spinal canal. Note the T2 dark vascular flow voids superior to the tumor along the posterior spinal canal. **(B)** T1-Weighted MR image after gadolinium administration shows intense enhancement of the mass.



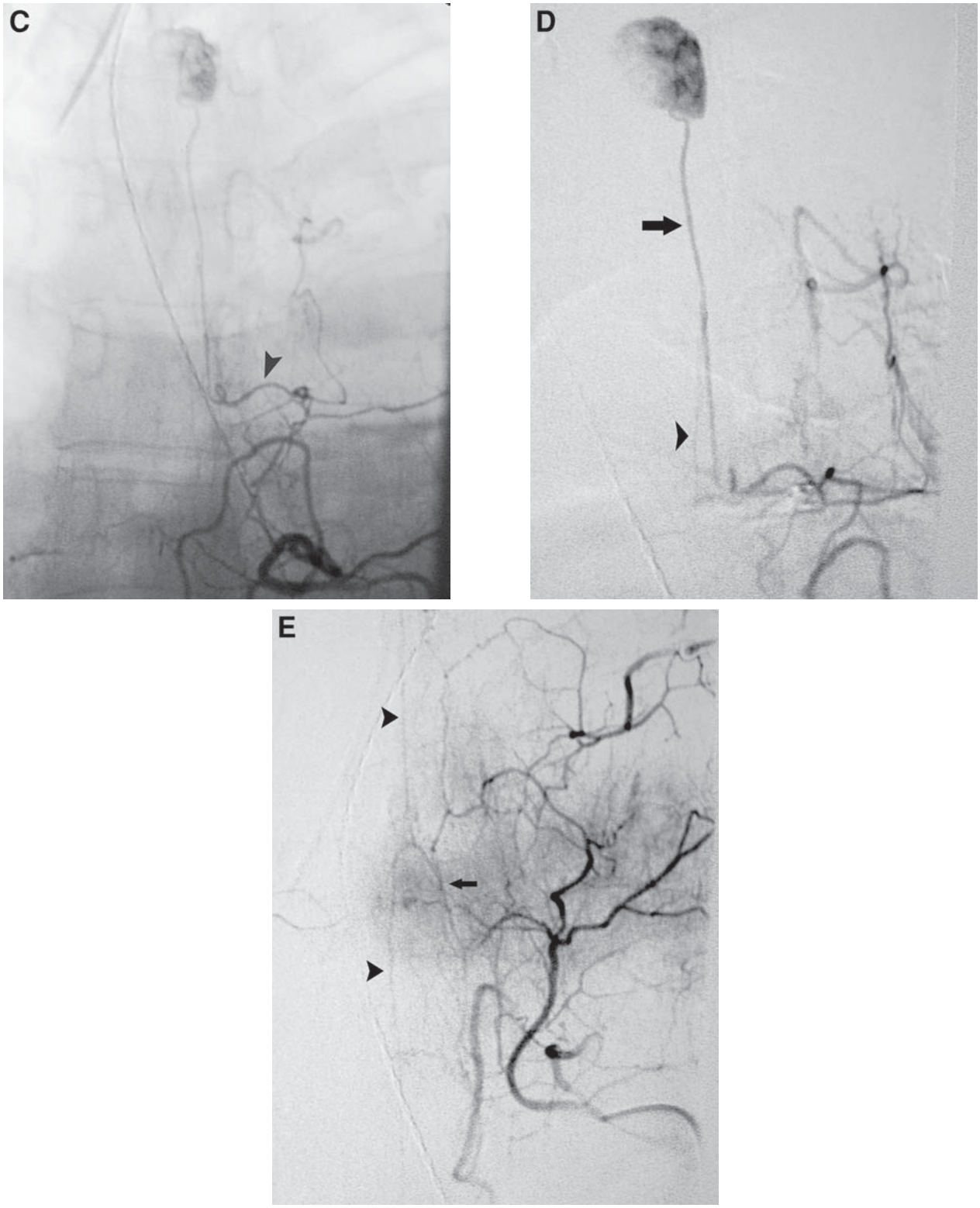


Fig. 2. Hemangioblastoma angiogram. **(A, B)** Frontal subtracted **(A)** and unsubtracted **(B)** angiograms of right supreme intercostal/T3 pedicle injection. An obvious hypervascular mass is seen within the spinal cord with supply from the right T3 radicular branch supplying the posterior spinal artery axis. Note the radicular branch, which follows the nerve root below and medial to the right T3 pedicle (*arrowhead*). Also note the guiding catheter tip in the origin of the segmental branch arising from the aorta (*arrow*). **(C, D)** Unsubtracted frontal angiogram **(C)** of left T6 segmental artery injection shows left T5 redicular branch (*arrowhead*) coursing under the pedicle to enter the spinal canal and supply the hypervascular mass at T3. Subtracted frontal angiogram at the same level shows the hypervascular mass to greater effect. Note the ascending posterior spinal artery (*arrow*) supplying the tumor and the descending branch of the posterior spinal artery (*arrowhead*) supplying the normal posterior cord below the level of the tumor. These are often difficult to visualize without general anesthesia. **(E)** Subtracted frontal angiogram **(E)** of the left supreme intercostal/T3 pedicle injection shows radiculomedullary branch (*arrow*) coursing under and medial to the left T3 pedicle to supply the anterior spinal artery ascending and descending branches of the cord (*arrowheads*). This is on the left at the same level as the tumor as seen in **(A)** and **(B)**. The anterior spinal artery did not supply the tumor and is normal in size.

advanced techniques may be required. These advanced techniques include:

1. Position catheter more distal, beyond the dangerous anastamosis.
2. Embolize if particles are larger than the size of the dangerous anastamotic vessel.
3. Embolize using gelform the origin of the dangerous anastamosis.
4. If the tumor is supplied off a branch of a normal vessel (en passage) occlude using gelform the normal vessel just beyond the tumor.
5. If the en passage supply is by the internal carotid or vertebral artery perform temporary balloon occlusion in that vessel *(43)* and embolize proximately with copious irrigation after the vessel is occluded and before the balloon is taken down to prevent residual intraluminal particles from inadvertently embolizing distally. Constant neurologic assessment is mandatory.

When the catheter is repositioned to a safe location embolization can proceed. Dion *(3)* does not believe provocative testing is warranted when using particles >150 μm in size because particles of this size should not injure the vasa nervorum.

After safe catheter position has been obtained where normal vessels and tissues do not appear in jeopardy, the operator is ready to choose an embolic agent. Many studies report the use of polyvinyl alcohol particles and gelatin powder or sponge with less frequent use of microfibrillar collagen, liquid acrylic *n*-butylcyanoacrylate (nBCA), and dehydrated alcohol. Injection of particles <150 μm in size or liquid agents allows the most distal penetration into the tumor bed, however, with the greatest chance of injuring the vasa nervorum of the spinal nerves and capillary beds of adjacent tissues. Dion *(3)* favors particulates >150 μm in size and <350 μm to provide satisfactory distal penetration but sparing of the vasa nervorum. Particulates are mixed with iodinated contrast for visibility. When utilized, nBCA is mixed with ethiodol and/or tantalum powder. Injections of particles should be pulsatile to allow flow to carry them to the hypervascular tumor. This decreases the chance of streaming into unwanted territories by opening potential collaterals. During injection of particulates, constant fluoroscopic evaluation is used to visualize contrast flowing away from the catheter tip and to see vessel runoff. It is also used to watch for the early signs of vessel occlusion: contrast stagnation, as well as reflux of particles proximally in the feeding vessel. If injection continues beyond this point the particles can reflux proximally into normal vessels not intended to be embolized. Embolization is performed in all abnormal vessels until a tumor blush is no longer visualized, which is the endpoint of embolic therapy. The main feeder vessel can then be occluded with gelfoam sponge or fibered coils to increase the likelihood of complete lasting thrombosis (Fig. 3).

During the procedure vasospasm can occur especially after vigorous catheter or wire manipulation. Vasospasm can lead to premature termination of embolization as the resultant decrease in inflow and outflow may be interpreted as secondary to vessel occlusion from embolization. It also limits effective particle embolization due to lack of flow. A dangerous situation arises when the microcatheter tip is in a wedged position or the vessel spasms around the catheter tip causing poor runoff. Vigorous injection in this situation can inadvertently overcome dangerous anastamotic collaterals or cause vessel rupture. Vasospasm can be treated with 1–2 in. of nitropaste administered transdermally, 30–60 mg of papaverine intraarterially, or 50–200 μg of nitroglycerin intraarterially.

POSTPROCEDURE CARE

Besides complications arising from inadvertent or planned embolization of normal neurologic structures with the resultant deficits, patients can have exacerbated pain and transient fever postembolization thought secondary to acute tumoral swelling and necrosis. Intensive care unit monitoring for 12–24 h is recommended, or until surgery. Tumors often swell after embolization. Intraprocedure administration of 10 mg of decadron iv followed by postembolization steroids minimizes complications from swelling. Prophylactic steroid administration is recommended, but if not given, worsening symptoms can be treated with 4–6 mg of decadron every 4–6 h and a 0.25–1.0 g/kg bolus of mannitol. Pain control may also be required.

DISCUSSION

Pain and/or neurological compromise are often the presenting complaints of patients with metastatic spine disease or a primary spine tumor. Cord or nerve root compromise causes the neurological deficit and is usually secondary to soft tissue extension into the epidural space with resultant compression of the cord or nerve roots. Spinal narrowing from vertebral body expansion or compression fractures are other mechanisms of symptomatology. Embolization of metastatic vertebral body lesions is recommended most commonly as a preoperative adjunct to decrease blood loss at surgery *(1–18)*. It is also performed for palliation, often in conjunction with radiation therapy *(2,9)*. Sundaresan *(24)* suggested that patients with spinal metastases from renal cancer should undergo spinal angiography and embolization prior to surgical resection of the tumor as well as prior to radiation therapy. Given the benefit of reduction of blood loss at surgery, preoperative embolization also allows more complete

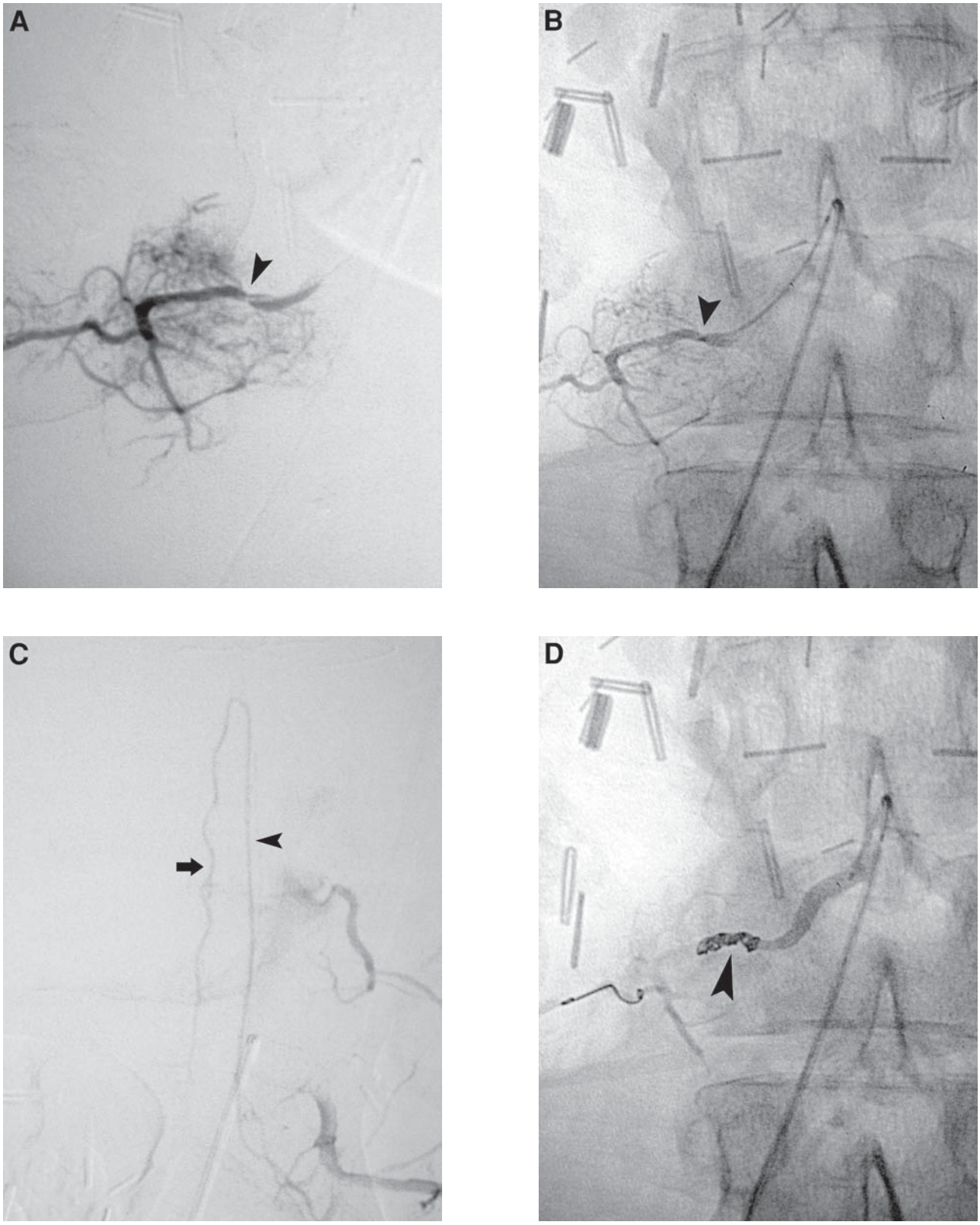


Fig. 3. Renal cell carcinoma metastasis to L3. **(A, B)** Frontal subtracted **(A)** and unsubtracted **(B)** angiograms of right L3 segmental artery injection via a microcatheter prior to embolization. Note the microcatheter tip (*arrowheads*) and the hypervascular tumor blush or stain, best seen on the subtracted **(A)** image in the vertebral body and right paravertebral region. **(C)** Before embolization the anterior spinal artery (*arrow*) and its supply from the left L1 radicular branch (*arrowhead*) are seen well away from the planned site of embolization at right L3. **(D)** Unsubtracted angiogram **(D)** after particulate embolization followed by fibered coil (*arrowhead*) occlusion of the segmental artery shows no residual angiographic tumor blush. The patient subsequently underwent successful surgery.

tumor resection secondary to improved visualization, and presumably fewer complications to the closely surrounding neurologic tissue.

Embolization to decrease or alleviate neurologic symptoms or relieve pain (palliation) is often successful in patients with unresectable lesions *(9,11,41,42)*. Smit *(9)* described rapid reduction in pain and neurologic symptoms after embolizing metastases from follicular thyroid cancer. Soo et al. *(11)* also reported reduction in pain after embolization in 12 of 13 patients for metastatic disease of the lumbar spine and pelvis. The reduc-tion of symptoms is thought to occur because of tumor shrinkage and subsequently less compression of adjacent neurologic structures.

Curative embolization is occasionally the goal in primary tumors of bone such as ABC, giant cell tumor, and symptomatic vertebral hemangioma. This is often the case when surgery or radical curettage is not considered a viable option as the primary treatment. Usually after embolization, patients experience less pain, improvement in their neurologic deficits, and lesion ossification *(31)* or calcification over the next several months, which suggests healing *(26–28,31–33)*. Neurologic improvement can be dramatic *(27,33)* even with resolution of cord block symptomatology. However, most patients with symptomatic, compressive primary tumors undergo embolization as an adjunct to surgery, or radiation therapy mainly because of the decreased blood loss of surgery, as in patients with refractory pain with metastatic lesions.

An alternative to surgery, radiation, or traditional transarterial embolization includes chemoembolization (in which a chemotherapeutic agent is injected with or without particulates), although no recent data have been published. Other embolic alternatives include percutaneous intralesional injection of absolute ethanol *(37)*, methylmethacrylate, nBCA *(44)* or an alcoholic embolizing emulsion (ethibloc) *(45)*.

CONCLUSION

In summary, this chapter has attempted to expand one's knowledge base regarding embolization of spinal tumors. The indications, patient selection process, as well as preprocedure care, intraprocedural technique, and postprocedure care have been discussed.

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