IMAGE-GUIDED SPINE INTERVENTIONS



JOHN M. MATHIS

Image-Guided Spine Interventions

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Preface

The field of interventional radiology is constantly undergoing change, and its procedures evolve over time. There is currently tremendous pressure on our specialty, as cardiology and vascular surgery appropriate existing vascular interventions. We need to be looking constantly for new procedures that will replace this loss. In the 1980s, the introduction of vascular access provided new procedures that included the placement of temporary venous catheters, ports, tunneled catheters, and dialysis maintenance. As a result of vascular access the number of procedures performed in some interventional labs doubled. The same revolution is occurring again with the advent of image-guided spine intervention. Five percent of the American population at any one time has back pain. This huge patient population is seeking help for this disabling and persistent problem.

Image-Guided Spine Interventions describes the varied and numerous procedures that are available to the image-guided interventionist, who may provide these therapies for the spine. This book embraces clinical evaluation, pharmacological requirements, procedural recommendations, and a spectrum of procedures that will be of interest to the image-guided spine interventionist. It covers a broad range of material that is presented by experts in each field, including discography, intradiscal electrothermal therapy (IDET), percutaneous discectomy, vertebroplasty and ballon kyphoplasty, epidural steroid injections, selective nerve root blocks and autonomic nerve blockade, diagnostic epidurography and therapeutic epidurolysis, sacroiliac and facet joint injections, implanted drug delivery systems, and epidural blood and fibrin patches for CSF leaks. Some of the techniques described, such as ozone therapy are expected to evolve further in the next decade. This book will be useful to all physicians who deal with back pain, including pain anesthesiologists, spine neurosurgeons, orthopedists, and radiologists.

As a previous president of the American Society of Spine Radiology and as a physician who has worked to develop image-guided spine intervention in academic and clinical practice, my entire practice is now devoted to providing these interventions. My clinical practice has more than doubled because of the introduction of these spine procedures. This is the next huge opportunity for the image-guided interventional community. I sincerely hope this work will be useful in helping you establish and grow a minimally invasive spine interventional practice. It has been a rewarding area for me.

John M. Mathis, MD, MSc

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1

Spine Anatomy

John M. Mathis, Ali Shaibani, and Ajay K. Wakhloo

The spine and its anatomical components are complex. Authors have approached it from a variety of perspectives including surgical, anatomical, and diagnostic (imaging). Our interest in spinal anatomy concerns the treatment of pathological processes affecting the spine. This chapter describes spine anatomy that is of interest to the imageguided interventionist.

Physical Components

Bones

The spine is composed of 33 bones: there are 7 cervical vertebra, 12 thoracic vertebra, 5 lumbar vertebra, 5 sacral segments (fused), and 4 coccygeal segments (variably fused).¹ Natural curvature is found throughout the spine (Figure 1.1). Viewed from the side, the cervical spine is convex forward, the thoracic spine is convex backward (centered at T7), the lumbar spine is convex forward, and the sacral bone is convex backward. The vertebrae progressively enlarge from the cervical through the lumbar regions. There is also variability in vertebra size at any particular level based on the individual's body size (Figure 1.2). The size of a vertebra is of extreme importance when one is performing vertebroplasty or kyphoplasty. In these procedures the most common side effects are created by cement leak. This results from natural or pathological holes in vertebra as well as overfilling. To avoid overfilling it is important to appreciate the volume range of vertebral bodies between the cervical and lumbar regions (Table 1.1). Theoretical volume calculations show vertebral body volumes ranging from 7.2 mL in the cervical spine to 19.6 mL in the lumbar region. These volumes are computed for a hollow cylinder with dimensions taken from each spine region. Because of the thickness of cortical and trabecular bone, the fillable volume is on the order of 50% of the theoretical volume. The fillable volume will again be diminished by the amount of the vertebral collapse following a compression fracture. As seen in Table 1.1, the 50% compressed volume for a C5 vertebra is between 1.8 and 2.2 mL. In the thoracic spine (T9), the 50% compressed volume is



FIGURE 1.1. The spine viewed from the lateral projection. Natural curvature varies from convex forward in the cervical and lumbar region to concave forward in the thoracic and sacral regions. The thoracic curvature is particularly prone to kyphosis with vertebral compression fractures in this territory.

3.8 mL. At L3 the 50% compressed volume is 4.9 mL. It is easy to see why very small volumes of cement sometimes can achieve adequate biomechanical augmentation for pain relief. These volumes differ considerably from region to region in the spine.

The spinal canal is formed by the posterior wall and the posterior elements of the vertebral body (pedicles and lamina). The pedicles join the vertebral body to the posterior lamina. The vertebral pedicle is a



FIGURE 1.2. Representative vertebrae from the cervical, thoracic, and lumbar regions. Relative vertebra body sizes and configuration changes are shown.

complex three-dimensional cylindroid structure that consists of a thin shell of compact bone (which is thickest on the medial surface) that surrounds a much larger center that is filled with cancellous bone.^{2–8} The pedicles are extremely important because they provide a safe tunnel through which the interventionist can gain access to the vertebral body for biopsy, vertebroplasty, and kyphoplasty. The pedicles in the cervical region are small and present a poor access to the vertebral body in this region. However, the thoracic and lumbar pedicles provide good potential access. Pedicles progressively increase in size from the upper thoracic (T4) to the lower lumbar (L5) spine. The angle of

 TABLE 1.1. Vertebral volume estimates from the cervical to lumbar regions

Vertebral level	Theoretical volume (mL)	Fillable volume (mL)	50% Compressed volume (mL)
C5	7.2	3.6	1.8
Т9	15.3	7.65	3.8
L3	19.6	9.8	4.9

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В

FIGURE 1.3. Axial CT scans of three vertebrae. (A) Scan of a T11 vertebra demonstrates the sagittal configuration (straight posterior to anterior) of the pedicle with respect to the vertebral body. The line demonstrates the general tract that a needle would take during vertebroplasty by means of a transpedicular approach. In the scan of an L5 vertebra (B), the transpedicular approach (black line) is nearly 45° away from the sagittal plane. In the scan at T1 (C), the transpedicular angle with the sagittal plane (black line) approaches 45°, simiar to the angle found in the lowest lumbar vertebra.



FIGURE 1.3. Continued.

the pedicles relative to the vertebral body changes as does their size. From T4 to T12 the pedicles have a relatively straight sagittal (anterior-to-posterior) orientation (Figure 1.3A). In the lumbar spine from L1 to L4 there is a slow but progressive angle away from the sagittal orientation. At L5 the angle is extreme and can approach 45° away from the sagittal plane (Figure 1.3B). Progressive angulation also occurs from T4 toward the cervical region (Figure 1.3C). Therefore, both pedicle size and angulation are important when one is planning a transpedicular approach during intervention. Though the size of the pedicles varies from region to region and from individual to individual, one can be comfortable that a 13-gauge cannula (0.095 in., outside diameter) will fit through essentially all adult pedicles from T4 to L5. In most individuals a 10- to 11-gauge cannula (0.134–0.120 in., outside diameter) will safely pass through pedicles from T12 to L5.

When the size of the pedicle (or its absence in neoplastic disease) precludes a transpedicular approach, a parapedicular route may be necessary. This route takes the entry device along the lateral margin of the pedicle and above the tranverse process. In the thoracic spine, this trajectory is generally along the junction of the rib with the adjacent transverse process and vertebral body (Figure 1.4). The articulation of the rib and vertebral body forms the costovertebral joint. The costotransverse joint is the junction of the rib and transverse process, with the intervening space filled with the costotransverse ligament. The parapedicular needle entry point will be along the lateral and posterior vertebral border in the paraspinal soft tissues. The paraspinus

С



FIGURE 1.4. The parapedicular approach. (A) In this lateral view, notice that the needle enters above the transverse process. (B) Needle placement position for a parapedicular approach in vertebroplasty.

space is filled with fatty tissue and venous structures. Venous bleeding is common here, but this is usually self-limiting as long as no coagulopathy exists. Occasionally, the posterior costophrenic sulcus contains lung that bulges beyond the border of the rib, making pneumothorax also possible.

The bones of the vertebra make up part of the central skeleton, inside of which the elements of the blood are made. This occurs in the intertrabecular (marrow) space. The venous system connects to this marrow space (Figure 1.5). This connection provides one of the main avenues for cement leakage during vertebroplasty or kyphoplasty. The venous route most important for potential leakage is through the posterior vertebral wall, communicating with the veins in the epidural space. Leakage into this location can create compression of the cord or nerve roots. Venous leak anterior or laterally can result in cement migration into central veins carrying blood to the lungs (resulting in pulmonary emboli).



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FIGURE 1.5. (A) The venous communications typical in a vertebra: AEVP, anterior external venous plexus; IVV, intervertebral vein; ARV, anterior radicular vein; PRV, posterior radicular vein; PIVP, posterior internal venous plexus; PEVP, posterior external venous plexus; BVV, basivertebral vein. (B) Axial CT scan demonstrating the posterior wall opening (black arrows) that allows the major veins of the interior of the vertebra (BVV, basivertebral vein) to communicate with epidural veins.

Intervertebral Discs and Joints

The intervertebral discs and joints interface with the various vertebrae in the spine. Together with the ligamentous attachments, these elements allow the vertebrae to move through bending and rotation. However, these discs and joints wear and may be the source of pain caused by degeneration. The image-guided interventionist must deal with these structures during discography, percutaneous discectomy, intradiscal electrothermal therapy, facet blocks, and dorsal ramus neurolysis.

The intervertebral discs are composed of an outer ring of fibrocartilage called the annulus fibrosis (Figure 1.6A,B). The annulus is attached to the cartilaginous endplates of the vertebrae and constrains the inner disc core called the nucleus pulposus. The annulus is thickest anteriorly. It is thin posteriorly, which coincides with the area most commonly associated with annular tears and disc herniations. The outer annular fibers, which are more densely packed, are referred to as Sharpey's fibers. The nucleus pulposus is made of cells that are notochordal remnants. It is composed of collagen fibrils that are embedded in a proteoglycan matrix that contains water. With aging and degeneration, water is lost and the nucleus becomes progressively fibrotic and smaller.

Because of the spine curvature (Figure 1.1), the angle of the plane of the disc between the vertebral endplates is variable through the spine. This variation requires different imaging angulation to enter the disc without obstruction by the adjacent vertebral margins. Appropriate imaging angulation is necessary for accurate needle placement in discography and percutaneous disc therapy.

The apophyseal or facet joints are paired joints between the posterior elements of two adjacent vertebrae. They are curved joints that are oriented obliquely to the sagittal plane (Figure 1.6C). The joints are asymmetric in about 30% of the population.⁹ Each joint consists of an articular process from each of the adjacent vertebra. The joint has a synovial lining with a fibrous capsule (Figure 1.6A,B). The nerve supply is from the medial division of the dorsal ramus of the spinal nerve that reaches the joint from the nerve above and below the joint on the ipsilateral side (Figure 1.7A). The joint is believed to be a source of nonradiating axial pain that is typically aggravated by hyperextension and rest. Because the joint is curved, image guidance can be confusing and entry into the joint may be difficult, particularly when there is degenerative disease. A small synovial recess along the superior and inferior margins of the joint will allow access without passing through the curved bone margins. Facet blocks are used for diagnostic confirmation of the pain source. As they rarely have prolonged therapeutic benefit, neurolysis of the joint nerve supply with chemical or radiofrequency (RF) ablation is most often used for long-term pain control.

FIGURE 1.6. The intervertebral disc. (A) Lateral drawing depicting the disc components and their association with the adjacent hyaline cartilaginous endplates. (B) Axial drawing demonstrating that the annulus fibrosus is thickest anteriorly. The capsule and lining of the facet joint also are shown. (C) Axial CT scan showing the complex configuration of the facet joints (black arrows).









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FIGURE 1.7. (A) Axial drawing of the nerve exiting the neural foramina of a lumbar vertebra and giving off the posterior ramus. A medial branch of this nerve will supply the capsule of the facet joint. These innervations arise from medial branches from both above and below each joint. The gray and white rami communicantes connect the autonomic ganglia with the anterior division of the spinal nerves. (B) Axial MR scan showing the neural foramina (white arrows) of a lumbar vertebra containing the dorsal root ganglia (white arrowhead).





D

FIGURE 1.7. *Continued.* (C) Axial drawing of a cervical vertebra. This highlights the close proximity of the vertebral artery with the exiting spinal nerve. (D) Axial MR scan of a cervical vertebra demonstrating the vertebral artery (black arrow) along the anterior neural foramina. IJ, internal jugular vein; CA, carotid artery; VA, vertebral artery.

Spinal Nerves

Entire books have been written about the anatomy of the spinal nerves. For the purpose of this text, we emphasize the elements that are of prime importance to the interventionist.

In the spine, as in the brain, there are central (spinal cord) and peripheral components (peripheral nerves) of the nervous system. The peripheral nerves are the components that are of major importance from the standpoint of potential therapy. The peripheral nerves are responsible for somatosensory, somatomotor, and autonomic nerve function. The spinal nerves exiting the neural foramina are composed of an anterior and a posterior division that coalesce into a single nerve in the neural foramina (Figure 1.7A). The anterior division of the spinal nerve contains the motor fibers that originate in the cell bodies in the anterior horn of the spinal cord. Preganglionic autonomic fibers course in this anterior division as well and originate in the anterolateral horn of the spinal cord. These fibers branch to become the white rami communicantes and synapse with postganglionic autonomic fibers in the autonomic ganglia along the spine to form the sympathetic trunk or extend to ganglia adjacent to end organs (celiac, mesenteric, etc.) via the splanchnic nerves. The sensory neurons (primary afferent) are found in the dorsal root of the spinal nerve. The dorsal root ganglia contain sensory cell bodies; the axons of these sensory nerves originate in specialized sensory structures (Golgi tendon organs, Ruffini endings from the joints, muscle spindles, pacinian corpuscles in fascial planes, etc.) and carry somatic sensory information about touch, proprioception, stereognosis, pain, and temperature. Visceral afferent information is also returned through the dorsal horn. The sensory nerves separate within the cord and take characteristic routes to the brain, where they reach varying levels of consciousness based on their type.

The various types of peripheral nerve are different not only because of their relative function but also because of physical size and conduction velocity. The motor fibers are the largest and have the fastest conduction velocity. General sensory fibers mediating touch and proprioception are intermediate in size, while pain and nocioceptive fibers are the smallest and have the slowest conduction velocity. To block these fibers an anesthetic must bind to (and block) three consecutive sodium channels (nodes of Ranvier). This means in clinical practice that a smaller amount of anesthetic is needed to block smaller fibers (pain) and that regular sensory and motor fibers are more resistant to anesthetic block. This provides us with the ability to obtain differential blocking that allows pain to be blocked without the loss of motor function (if appropriate amounts of anesthetic are chosen).

Selective nerve root blocks are used for diagnostic and therapeutic purposes. The injectate (chosen for a specific effect) is introduced into or just lateral to the neural foramina. This places the injected agent around or peripheral to the dorsal root ganglion. In the lumbar region, the foramina are larger than in the thoracic and cervical spine. Venous vascular structures are common in the lumbar foramina, but a much lower chance of an arterial injection exists here (Figure 1.7A,B). In the cervical region, the vertebral artery lies along the anterior border of the foramina (Figure 1.7C,D). Great care must be exercised when one is doing nerve blocks in this region, since direct injury (dissection) to the vertebral artery can occur and injection of anesthetics or steroids into the artery can create seizure or stroke, respectively.

Nerve blocks of the autonomic nerves are also of great use in the mediation of visceral pain in processes such as cancer and pelvic inflammatory disease or to provide relief from reflex sympathetic dystrophy. To specifically block the autonomic nerves, leaving the somatosensory and somatomotor nerves intact, injections are placed around the autonomic ganglia in the location where the problem exists. The autonomic nervous system has two components that are called the parasympathic and the sympathetic nerves (Figure 1.8). There are no sympathetic cells in the brain. Parasympathetics originate from the brain (and run in the cranial nerves) and the sacral cord (S2-S4). The sympathetics originate in the spinal cord between T1 and L2. Both systems synapse in peripheral ganglia, and each carries both motor and sensory nerves to visceral organs (blood vessels, glands, heart, bowel, etc.). The parasympathetic and sympathetic systems function antagonistically. The parasympathetic system constricts the pupil, decelerates the heart, lowers blood pressure, relaxes the sphincters, and contracts hollow visceral organs. The sympathetic system dominates in periods of excitement and causes dilation of the pupil, accelerates the heart, increases blood pressure, contracts sphincters, and relaxes smooth muscle of the hollow viscera.^{10–12}



FIGURE 1.8. Artist's conception of the autonomic nervous system, with its sympathetic and parasympathetic components. Note that these elements have very different origins within the central nervous system.

Most organs receive innervations from both parts of the autonomic system. Though sympathetics do not exist in the brain, they reach the organs of the head and neck through ganglia located in the cervical region with preganglionic fibers arriving via the sympathetic track and coursing into and through the inferior (stellate), middle, and superior cervical ganglia. Postganglionic fibers are distributed along blood vessels to the various end organs. Nerves to thoracic, abdominal, and pelvic viscera arrive from the sympathetic chain (traveling along the lateral vertebral bodies) or splanchnic nerves to the ganglia adjacent to end organs such as the heart or pancreas. Once again, blockade of selected ganglia can reduce visceral pain or hyperactivity of the sympathetic system.

Anatomical Spaces

The anatomical spaces around the spine that are of primary interest to the image-guided interventionist are those found around the thecal sac (epidural space) and the outlet space for the exiting nerve roots (foraminal space).

The epidural space begins immediately inside the bony spinal canal and extends from the foramen magnum to the caudal hiatus of the sacrum (Figure 1.7A,C). It surrounds the thecal sac and the exiting nerve roots pass through it into the neural foramina. It is filled with fibrofatty areolar tissue and vascular elements, mostly venous. The arterial supply that traverses the epidural space is basically limited to spinal arteries that enter along spinal nerves to supply the cord, nerve roots, and the parts of the vertebrae adjacent to and circumscribing the epidural space. The epidural space varies in size. It is smallest in the cervical region (1-2 mm) and enlarges progressively toward the lower lumbar and sacral area. At L2-3 the space is 5 to 6 mm wide. If the neck is flexed, the cervical epidural space can increase to 3 to 4 mm.^{13,14} The epidural space is easily accessed in the sacral and lumbar regions via needle placement through the intralaminar, transforaminal, and caudal (caudal hiatus) routes. Access is via the intralaminar and transforaminal routes for the thoracic and cervical epidural space. The epidural space can be septated naturally. Postoperative scarring, which can locally obliterate the space, commonly occurs along the posterior and lateral borders of the thecal sac in the site of the operative field. When this occurs, the intralaminar approach is of reduced utility, and puts puncture of the thecal sac at higher risk. Transforaminal epidural access then becomes the most dependable method.

The neural foramina of the spine exist bilaterally from the cervical through the sacral regions. In the sacral region, the foramina are bounded by sacral bone on all sides with exit points both dorsally and ventrally. From the cervical through the lumbar spine, each foramen is bounded by a vertebral body and disc anteriorly, the pedicle superiorly and inferiorly, and facet articular processes posteriorly. The nerve root passes through foramina accompanied by small branches of the spinal artery and veins and surrounded by fatty tissue. The veins communicate with the epidural venous plexus. In the cervical spine, the vertebral artery runs immediately anterior to the exiting nerve root in the foramen transversarium (Figure 1.7C,D). This close association of the nerve and artery can put the artery at risk during transforaminal approaches for epidural injections and nerve blocks. Direct injury can result in dissection or occlusion. Anesthetic or steroid injection into the artery may cause seizure or stroke, respectively.

Vascular Anatomy of the Spinal Cord

Neuroradiologists, and interventional neuroradiologists in particular, need an accurate understanding of the normal vascular anatomy of the spine and spinal cord. This is especially true because spinal angiography is less commonly performed than cerebral angiography, and safe and adequate performance of spinal angiography and intervention is predicated on accurate and complete knowledge of the normal vascular anatomy. This section provides a concise and accurate vascular anatomy of the spine and spinal cord, with guidelines for performing spinal angiography in a safe and complete manner.¹⁵

Arterial supply can be divided conceptually into a macrocirculation (the supply up to the cord surface) and a microcirculation (the supply beyond the anterior and posterior spinal arteries).¹⁶

Macrocirculation

Conceptually, the arterial supply to the cord can be described from the "outside in" as a segmental supply based on the embryological development of the body. In the first few weeks of development in the embryo, the embryo is divided into 31 somites in a rostral–caudal direction. These 31 somites correspond to the 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal).

The segmental artery, through its branches, supplies blood to all the ipsilateral derivatives of its corresponding metamer (neural crest, neural tube, and somites), that is, muscle, skin, bone, spinal nerve, and spinal cord. Each segmental/metameric artery is named for the nerve it accompanies in the neural foramen. In the beginning of embryological development, each segmental artery has a branch supplying the cord, but most regress over time and only a few are left to provide flow to the spinal cord. The remainder will remain unimetameric, supplying the related nerve, dura, vertebral body, and paraspinous muscles. At the end of embryological development, of the 62 metameric arteries (31 pairs), 4 to 8 will supply the ventral spinal axis (anterior spinal artery), and 10 to 20 the dorsolateral/pial network (posterior spinal arteries). The process of regression of cord supply is more pronounced caudally, which results in fewer sources of medullary supply, such as the dominant artery of Adamkiewicz. The simplified algorithm for the vascular supply at each segmental level is: major arterial trunk \rightarrow spinal/segmental artery (31 pairs) \rightarrow radicular artery OR radiculopial, or radiculomedullary artery \rightarrow paired posterior or single anterior spinal artery (Figure 1.9).



FIGURE 1.9. Illustration depicting (1) a segmental artery, (2) the somatic branches (vertebral body supply), (3) an intercostal artery or muscular branch, (4) the dorsospinal trunk, (5) paravertebral longitudinal anastomosis, (6) a radiculomedullary artery, (7) the dorsal somatic branch, (8) nerve, (9) the dura, (10) the radicular branches to the dorsal nerve root, (11) the radicular branches to the ventral nerve root, (12) the ventral spinal axis (ASA), (13) a radiculopial artery (dorsal radiculomedullary), (14) the dorsolateral spinal network (the posterior spinal arteries).

The segmental arteries form extraspinal and extradural longitudinal anastomoses, which can be divided as follows:

- 1. *Ventrolateral.* An example is the ascending cervical artery (from the thyrocervical trunk) in the neck.
- 2. *Pretransverse (anterior to transverse processes).* An example is the vertebral artery in the cervical region, or lateral–sacral arteries. These supply the sympathetic system in the thoraco-lumbar area (Figure 1.10).
- 3. *Dorsal–longitudinal*. These anastomoses branch to the midline insertion of the spinous process muscles. The deep cervical artery from the costocervical trunk is an example.

The major arterial trunks supplying the radicular arteries at each level are the following:



FIGURE 1.10. Selective intercostal artery injection showing longitudinal pretransverse anastomosis between segmental arteries (open arrow).

- 1. *Cervical*. Vertebral arteries, ascending cervical branch of the thyrocervical trunk, deep cervical branch of the costocervical trunk, occipital branch of the external carotid artery (ECA), and ascending pharyngeal branch of ECA.
- 2. *Thoracic*. Branches of the costocervical trunk, internal thoracic branch of the subclavian artery, supreme intercostal branch of the aorta, and intercostal branches of the aorta.
- 3. *Lumbosacral.* Lumbar branches of the aorta, middle sacral branch of the aorta, lateral sacral branches of the internal iliac arteries, and iliolumbar branch of the common iliac arteries.

At each of the 31 levels, each segmental artery supplies blood to the dorsal and ventral nerve roots, thereby being given the designation "radicular" artery. At some levels, the segmental artery supplies blood not just to the nerve root but also beyond, to the spinal cord, via branches connecting either to the pial/coronal arterial network, or directly to the anterior spinal artery. In the former condition these segmental arteries are named "radiculopial," and in the latter "radiculomedullary."

At the level of the surface of the spinal cord there is a single anterior spinal artery (ventral spinal axis) and paired posterior spinal arteries. Connecting these two networks is the pial/coronal (centripetal) network of small arteries.

Some experts consider the paired posterior spinal arteries to be part of the pial/coronal network, representing more dominant craniocaudally oriented channels. According to this definition, those segmental arteries providing supply to the posterior spinal arteries are more accurately designated as radiculopial rather than radiculomedullary. We will use this definition for this chapter.

The flow in the spinal arteries, anterior and posterior, is bidirectional, depending on the dominant medullary artery at each level, as well as the time needed for the aortic systolic pulse wave to reach each radiculomedullary or radiculopial artery (more distal arteries will experience the aortic systolic pulse wave later, which also contributes to bidirectional flow).

Radicular Arteries

At each of the 31 levels, the spinal/segmental artery provides branches to the dorsal and ventral nerve roots, after giving off branches to the paraspinous musculature, vertebral body, and dura. The only exception is the C1 level, where there may be congenital absence of the radicular branches. Under normal physiological circumstances, the radicular branches are usually too small to be seen angiographically.

Radiculopial Arteries

The radiculopial arteries supply the nerve roots (via radicular branches), then run ventral to either the dorsal or the ventral nerve root to supply blood to the pial/centripetal (vasa corona) network. These arteries do not supply the anterior spinal artery (ventral axis) directly. They do have anastomoses with pial branches of the anterior spinal artery, however. There are more dorsal than ventral radiculopial arteries. The dorsal radiculopial arteries (called dorsal radiculopial arteries by some authors) are more important, and are the ones referred to as the radiculopial arteries henceforth in this chapter. Their number varies from individual to individual. On average, there are 3 to 4 dorsal radiculopial arteries in the cervical region, 6 to 9 in the thoracic region, and 0 to 3 in the lumbosacral region.

Radiculomedullary Arteries

The radiculomedullary arteries provide the only segmental supply to the ventral spinal axis (anterior spinal artery) and are the dominant source of supply to the cord over several functional segments.

	Artery diameter (mm)			
Artery	Cervical	Thoracic	Lumbosacral	
Artery of cervical enlargement	0.4–0.6			
Artery of Adamkiewicz	0.55–1.2			
Ventral spinal axis (anterior spinal artery)	0.2–0.5	0.2–0.4	0.5–0.8 (artery of the filum)	
Dorsolateral spinal arteries (posterior spinal arteries)	0.1–0.2	0.2–0.25	0.1–0.4	

TABLE 1.2. Diameter of spinal arteries

Sources: Modified from Lasjaunias, P, Berenstein, A, TerBrugge KG. Surgical Neuroangiography. 2nd ed. 2001. With permission from Springer-Verlag New York. After giving off their radicular branches to the nerve roots, they run along the ventral surface of the nerve root, occasionally giving off a pial collateral, then supply the anterior spinal artery. Their number varies from individual to individual. On average, there are 2 to 4 (ventral) radiculomedullary arteries in the cervical region, 2 to 3 in the thoracic region, and 0 to 4 in the lumbosacral region. Classically, two radiculomedullary arteries have received special attention: the arteries of the cervical and lumbar enlargements. The artery of the lumbar enlargement is also known as the artery of Adamkiewicz (Table 1.2).

In 75% of patients, the artery of Adamkiewicz arises between T9 and T12, more commonly on the left. When its origin is above T8 or below L2, there is another major contributor to the anterior spinal artery either caudally or cranially. In 30 to 50% of cases, it also gives a major contribution to dorsolateral pial system (paired posterior spinal arteries) (Figure 1.11).

The connection of the radiculomedullary artery to the ventral spinal axis is Y shaped in the cervical area because the artery does not have



FIGURE 1.11. Selective injection of an intercostal branch supplying the ventral spinal axis showing the artery of Adamkiewicz [artery of the thoracolumbar enlargement (small arrow)] and the ventral spinal axis [anterior spinal artery (arrowhead)], and classic hairpin loop of the radiculomedullary artery (open arrow).

to ascend very high before it meets the ventral spinal axis. The classic hairpin anastomosis is seen at the thoracic and lumbar levels.

The single ventral spinal axis (anterior spinal artery) is continuous from the basilar artery to the artery of the filum terminale. The artery of the filum terminale is the caudal extension of the anterior spinal artery. The anterior spinal artery may be focally discontinuous, especially at the thoracic level. The ventral spinal axis runs in the subpial space in the ventral sulcus of the spinal cord, dorsal to the veins. In the cervical region, there may be congenital lack of fusion of the embryological dual ventral spinal axes, resulting in a short unfused segment.

Microcirculation

The circulation beyond the level of the ventral spinal axis and the dorsolateral pial network (posterior spinal arteries) is conceptually divided into a centrifugal (from the center of the cord out) and a centripetal (from the pial surface toward the center of the cord) system.

Centrifugal System

The centrifugal system is also known as the sulcocommisural system. The ventral spinal axis (anterior spinal artery) gives rise to 200 to 400 sulcocommissural arteries within the ventral sulcus of the spinal cord. These arteries penetrate the sulcus and enter the central gray matter, where they give off branches radiating outward toward the peripheral white matter. Each sulcocommissural artery usually supplies one half (right or left) of the cord. The sulcocommissural system will supply the majority of the gray matter and the ventral half of the cord. Before entering the cord substance, each sulcocommissural artery gives off cranial and caudal anastomotic branches to other sulcocommissural arteries. Craniocaudal anastomoses are also seen within the substance of the cord. Early in development, before the disproportional elongation of the spinal column in relation to the cord, the sulcal arteries have a completely horizontal course. With growth and the disproportionate elongation of the spinal column, they assume an ascending course. Yoss found that occlusion of the artery of the lumbar enlargement in primates caused severe damage to the ventrolateral two thirds of the cord, where the artery entered, and for a distance above and below.¹⁷ The territory of the cord supplied by the centrifugal system (from the ventral spinal axis) is comparatively as large as that supplied by the internal carotid artery relative to one cerebral hemisphere (Figure 1.12).

Centripetal System

The centripetal system is also known as the dorsolateral pial supply (from posterior spinal arteries). This network covers the dorsal and dorsolateral surface of the cord and has two dominant craniocaudal channels known as the posterior spinal arteries. At the craniocervical junction, supply to this system is directly from the transdural vertebral arteries, or from posterior inferior cerebellar arteries when their origin is below the dura. Below this level, arterial supply is from radiculopial arteries (Figure 1.13). FIGURE 1.13. The "centripetal" arterial system. (1) The radiculomedullary artery, (2) the ventral spinal axis, (3) the sulcocommissural artery, and (4) the coronary arteries from the dorsolateral spinal network (posterior spinal arteries).


This system has a dorsal component and a lateral component (located between the dorsal and ventral nerve roots), which are interconnected. This network gives rise to radial/coronal arteries (vasa corona), which extend around the circumference of the cord and have anastomoses to the ventral spinal axis.

The radial/coronal arteries give off perforating branches to the cord all along their course. These short perforating branches extend axially, into the white matter and a portion of the gray matter of the dorsal horns. The perforating branches of the radial/coronal arteries have intramedullary anastomoses with branches of the sulcocommissural arteries dorsolaterally, ventrolaterally, and ventrally.

There are also short, extramedullary longitudinal (craniocaudal) anastomoses between the radial/coronal arteries. These anastomoses are relatively small, however, and cannot provide adequate craniocaudal supply in the case of arterial occlusion. The dorsolateral pial network must therefore be regarded primarily as an axial system of arterial supply.

Somatic Arterial Supply

The metameric/segmental artery is centered at the level of the intervertebral disc, the corresponding nerve, and the myelomere (cord). Therefore, the vertebral body is fed by two consecutive segmental arteries on each side (for a total of four). Each of the four will supply approximately 25% of the vertebral body. However, extensive anastomoses within the substance of the vertebrae often permit all or most of the vertebral body to be seen from one arterial injection.

The somatic arteries anastomose on the posterior surface of the vertebral body, making a characteristic hexagon or diamond-shaped network on anterior–posterior angiography (Figures 1.14 and 1.15).

Angiography

- 1. *Lumbar and lower thoracic.* Usually a hemivertebral blush is seen from one segmental arterial injection; this effect is evident only 25% of the time.
- 2. *Upper thoracic.* The right intercostal artery will opacify the right hemivertebra and the ventral half of the left hemivertebra.
- 3. *Cervical and sacral*. Symmetry is the rule, with opacification of the ipsilateral hemivertebra.

Spinal Venous Anatomy

We will approach the description of the venous anatomy of the spinal cord from the inside out. Venous drainage of the cord is divided into an intrinsic system (in proximity to the centrifugal arterial system but, naturally, with an opposite direction of flow) and the extrinsic system (in proximity to the centripetal arterial system). In general, the ventral dominance of the arterial system is not seen in the venous system. The venous drainage of the cord is relatively equally divided dorsally and ventrally.

The intrinsic venous system comprises dorsal and ventral sulcal (sulcocommissural) veins that collect the venous outflow from the central gray matter.



FIGURE 1.14. Retrocorporeal hexagonal anastomosis of dorsal somatic branches to the vertebral body. (1) Vertebral body, (2) nerve root sleeve, (3) pretransverse longitudinal anastomosis, (4) segmental artery, (5) radicular artery, (6) disc, and dorsal somatic branch (open arrow).

The extrinsic venous system can be thought of as containing the venous perforators draining into the radial/coronal veins, which in turn drain into the primary dorsal and ventral longitudinal collecting veins. These longitudinal collecting veins in turn drain into the radicular veins (analogous to the radiculomedullary and radiculopial veins), which eventually empty into the ventral epidural venous plexus. In addition to the main dorsal and ventral draining veins, there are short intersegmental lateral longitudinal veins linking adjacent radial veins. These lateral longitudinal channels are not large enough, however, to form a functional dominant craniocaudal channel like the dorsal and ventral systems.

Flow in the thoracic longitudinal channels is bidirectional, with cervical drainage of its most cranial portion and lumbar drainage of its most caudal part. There can be multiple longitudinal venous channels, especially in the thoracic region, and ventrally (Table 1.3). The main ventral longitudinal venous channel is known as the anterior median vein (Figure 1.16).

The radicular (radiculomedullary) veins drain into either spinal nerve venous channels in the neural foramina or a dural venous pool, both of which eventually empty into the ventral epidural venous plexus.

The epidural (extradural) venous system has a prominent ventral component and a small, much less important, dorsal component. The

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FIGURE 1.15. (A) Subtracted and (B) unsubtracted selective injection of the lumbar artery (solid arrow) showing hexagonal dorsal anastomosis of dorsal somatic arteries (open arrows) (supply to the vertebral body).

Number of longitudinal veins	Region					
	Cervical	T1– T8	T9– T12	Lumbo- sacral		
Ventral surface:	3 > 1	3 > 1	1 > 3	1		
Dorsal surface:	1 > 3	3 > 1	1	1		

TABLE 1.3. Number of spinal veins^a

^a3 > 1: in most patients, three veins would be present; some would have only one; 1 > 3: in most patients, one vein would be present; some would have three.

ventral epidural veins receive venous drainage from the vertebral bodies (through anterior and posterior venules), the spinal cord (via radiculomedullary veins), the dura, and are also involved in some resorption (via arachnoid granulations along the nerve root sleeves) of the cerebrospinal fluid. The ventral epidural venous plexus forms a valveless, retrocorporeal, hexagonal anastomotic plexus, which is essentially continuous craniocaudally. The direction of flow within this plexus is not



FIGURE 1.16. The venous drainage of the spinal cord. (1) The dorsal root, (2) the ventral nerve root, (3 and 10) the coronal venous plexus (radial veins), (4) the anterior median vein of the ventral longitudinal venous system, (5) a dorsal longitudinal vein, (6) a transmedullary anastomotic vein, (7) a dorsal sulcal vein, (8) a radiculomedullary vein, (9) a ventral longitudinal vein.

unidirectional; rather, it depends upon the location of the outflow vein at each anatomic level.

The ventral epidural venous plexus drains into multiple different outflow veins, depending upon the anatomical level. These are as follows.

- 1. *Cervical.* Drainage is into the vertebral veins, which in turn empty into the innominate veins.
- 2. *Thoracic.* Drainage is into the intercostal veins, which then empty into the azygous and hemiazygous systems and subsequently the inferior vena cava.
- 3. *Lumbar*. Drainage is multiple, involving the ascending lumbar vein (on the left), the azygous and hemiazygous systems, and the left renal vein. The final common pathway is generally the inferior vena cava.
- 4. *Sacral.* Drainage is into sacral veins, emptying into the lateral sacral veins, and subsequently the internal iliac veins.

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Materials Used in Image-Guided Spine Interventions

John M. Mathis

Imaging Equipment

Most image-guided spine interventions are accomplished well with fluoroscopic guidance. It goes without saying that good visualization of the anatomical area being treated is necessary. Most modern fluoroscopic equipment will provide this capability. It is important to view the target anatomy from multiple projections, and therefore a C-arm configuration is need. Fixed-plane fluoroscopic equipment (commonly used for gastrointestinal work) is not sufficient. The most sophisticated equipment in the multidirectional category is the fixed-base, biplane fluoroscopic room (Figure 2.1A). These rooms are common for interventional neuroradiologists but are not routinely available otherwise. The ability to view the target anatomy in two projections at once is a definite luxury and offers the fastest possible needle insertion capability. However, single-plane C-arm systems are fine for all these procedures. The greatest disadvantage is the reduced speed experienced with vertebroplasty and kyphoplasty, but these procedures can also be performed adequately without biplane capability. Fixed-base C-arm (dedicated angiographic) rooms (Figure 2.1B) are more desirable than portable C-arms (Figure 2.1C). This is primarily because of image quality but also because of the ease of use by the operating physician. Fixedbase angiographic equipment is motorized and can be controlled by the physician. By contrast, in most portable units projection changes must be made manually by a technologist. This requirement has the disadvantage of requiring the physician to describe the desired projection rather than being able to select it personally and generally slows the process. Also, projections that are repeatedly used can be programmed into memory on a fixed-base machine and automatically retrieved with the press of a button. These features make the use of the fixed-base rooms simpler and faster.

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FIGURE 2.1.



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FIGURE 2.1. (A) Biplane fluoroscopic equipment is the most sophisticated and useful of the possible room setups. However, it is extremely expensive and not generally available for the average spine imaging operator. (B) A fixed, single-plane fluoroscopic arrangement that affords a fluoroscopic image of excellent quality. The C-arm is motor driven and computer controlled for ease of operation. It will be slower than the maximally efficient biplane room seen in (A). (C) A modern, mobile C-arm fluoroscopic arrangement commonly used in operating room situations. This apparatus offers good imaging capability but is much more cumbersome to use than the fixed-base systems. Though acceptable, it is the least desirable setup.

New fluoroscopic equipment generally has good image quality. This may not be true of older equipment; therefore old equipment should be checked by a certified radiological physicist for image quality and radiographic exposure or output. Additionally, portable equipment may not have enough power to penetrate thick body areas. This can limit visualization in some situations and reduce the safety of procedures. Ultimately, all fluoroscopic images face this limit. Large patients or difficult locations, such as the high thoracic region (lateral T1–T4, which are blocked by the shoulders), will have limited visualization. In these situations, alternate imaging should be considered.

The use of computed tomography (CT) has grown both because of its availability and because of the limitations of fluoroscopy. Some operators use CT simply because it is what they have available. Certain regions of the body that may be hard to image with fluoroscopy are better suited to CT imaging. Additionally, complex clinical situations, such as percutaneous vertebroplasty, used to treat neoplastic destruction of the posterior wall of vertebra, may be aided by CT imaging. While CT offers some potential advantages for a limited number of situations, it is generally less available, more expensive, and slower than fluoroscopic imaging. Finally, the user of CT relinquishes the capability for real-time visualization of contrast or cement injection. These restrictions keep the use of CT limited to a small number of cases and situations.

Pharmacological Agents for Spine Intervention

Corticosteroids

Corticosteroids have a long history in the treatment of pain related to spine disease and have been used since the 1960s. At that time, they were injected both epidurally and intrathecally for pain management. By the 1980s there were reports of complications that included arachnoiditis, meningitis, and paraparesis/paraplegia.^{1,2} Controversy was sufficient in Australia to prompt explicit government warnings about the use of corticosteroids for epidural pain management.³ Review of the scientific literature regarding these findings suggests that many of the complications resulted from or were associated with the intrathecal use of corticosteroids.^{1–5} We know that some definite side effects can result from these drugs; physicians should be aware of these and should discuss potential complications with their patients.

When used in spine injections, corticosteroids are believed to help produce chemical stabilization of the local environment. This is accomplished by reducing the local amount of phospholipase A2 and arachidonic acid, as well as by decreasing the cell-mediated inflammatory and immunological responses.

The most common corticosteroid used for spine injections has been a long-acting form of methylprednisolone acetate (Depo-Medrol; Pharmacia-Upjohn). This material is available in doses of both 40 and 80 mg/mL. The acetate formulation is quite insoluable in water and has a long half-life in tissues. Its relative strength is approximately five times that of hydrocortisone. It often contains the preservative polyethylene glycol, which is thought to be potentially neurotoxic. Indeed, this material may be the source of arachnoiditis created with intrathecal injection of Depo-Medrol. Depo-Medrol is particulate and therefore can cause stroke if injected intra-arterially (i.e., into the vertebral artery during an attempted cervical foraminal injection). Adding anesthetic solutions exacerbates the problem because the combination increases precipitation within the syringe.

A more recent option for an injectable corticosteroid is the combination of betamethasone sodium phosphate and betamethasone acetate (Celestone Soluspan; Schering). This mixes a short- and a long-acting form of betamethasone in the same injectable solution. It contains no preservative and comes in doses of 6 mg/mL. Betamethasone is approximately 30 times as strong as hydrocortisone. It seems to have a less particulate nature and a decreased tendency to precipitate when mixed with anesthetics. All these properties make it less apt to create arachnoiditis when injected intrathecally and less prone to create stroke if given intra-arterially. Recently both Depo-Medrol and Celestone have gone through periods of decreased availability. This has caused some labs to use a long-acting form of triamcinolone (Aristocort; Fujisawa USA).⁶ This material is particulate (similar to Depo-Medrol) and also contains the preservative polyethylene glycol. It is available in doses of 25 mg/mL and is approximately five times as strong as hydrocortisone. It seems to offer no advantage over Depo-Medrol.

Anesthetic Agents

Local anesthetic agents are commonly added as part of the injectate used for numerous spinal and pain management injection procedures. Local anesthetics block the sodium channel, completely halting electrical impulse conduction in peripheral nerves, spinal roots, and autonomic ganglia.⁷ To block nerve conduction, the local anesthetic must cover at least three consecutive sodium channels (nodes of Ranvier). Differential blocking occurs because fibers carrying different types of information (pain, sensory, motor) are of different size. The smallest of these are the nociceptive (pain) fibers. These fibers attain calcium channel blockade with the smallest amount of anesthetic. Progressively larger fibers require a larger volume of anesthetic to block enough adjacent channels to stop conduction. Pain fibers are the most sensitive, followed by sensory, and finally motor fibers. This differential blocking allows pain relief without obligatory motor blockade.

Local anesthetics are organic amines with an intermediary ester or amide linkage separating the lipophilic ringed head from the hydrophilic hydrocarbon tail. The amino ester group of anesthetics includes procaine, tetracaine, and benzocaine. These anesthetics have been used for a long time and are known to have a higher allergic potential than the amide-linked group of anesthetics (lidocaine, bupivacaine, and ropivacaine) now in common usage. The amino ester group is thought to have their allergic potential because of their metabolite *p*-aminobenzoic acid (PABA). The members of the amide group, which do not have this metabolite, are known to have a very low allergic potential and little cross-reactivity. However, the amide group may contain the preservative methylparaben, which is metabolized to PABA and can produce cross-reactivity for potential allergic reactions with the ester group. Preservative-free amide anesthetics are therefore recommended for all injection procedures.

Lidocaine is a common first-generation member of the amide anesthetic group. It was found safe except in large quantities that generally exceeded 500 mg. It has a relatively short duration of action, usually lasting only several hours. Bupivacaine is a second-generation amide anesthetic that has a prolonged duration of action. It is, however, associated with more cardiac and neurotoxic reactions and has a maximum recommended safe dose of 150 mg. Because of the poorer cardiac profile of bupivacaine, third-generation amide anesthetics were developed. Ropivacaine is a member of this group that produces long-

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term local anesthesia like bupivacaine but with a better cardiac profile. Injections of local anesthetic are small enough that one should generally never approach the maximum allowable dosages.

Bupivacaine and ropivacaine come in different concentrations (0.25, 0.5, and 0.75 % and 0.2 and 0.5 %, respectively). The lower dosages are useful for pain relief in epidural and nerve blockage injections. The more concentrated dosages will produce motor blockade, which is not wanted with these procedures.

Antibiotics

Antibiotics are needed for only selected procedures in spine intervention. These include discography, intradiscal electrothermal therapy, percutaneous discectomy, vertebroplasty and kyphoplasty, and the implantation of pumps and stimulators. Most injection procedures do not require antibiotics. The purpose of antibiotic coverage in most of these procedures is to decrease the chance of seeding bacteria in poorly vascularized sites such as the disc or around foreign bodies (implantables). Since penicillin allergy is not uncommon, a broad-spectrum antibiotic with minimal or no penicillin cross-reactivity is generally chosen. Though some penicillin cross-reactivity with the cephalosporins exists, it is minimal and therefore a reasonable choice is cefazolin (Ancef). This is the most common antibiotic used for this purpose and is given in a 1 g dosage intravenously or intramuscularly (IV or IM) 30 minutes prior to the procedure. Additionally, it can be put into the contract for discographic procedures (usually 20-100 mg, with the upper range used when no IV antibiotics are given). It must be borne in mind that this antibiotic will cause grand mal seizure activity if given intrathecally. No antibiotic should be injected if a transdural approach is employed.

In some patients, allergy or lack of access to an IV hookup may make alternate choices better. Another commonly utilized antibiotic in the interventional lab is ciprofloxacin (Cipro). This is a fluoroquinolone with a broad spectrum of coverage and without cross-reactivity to penicillin. It is usually given orally in dosages of 500 mg twice a day. It can be given intravenously (400 mg) but must be given slowly over a 60minute period to avoid pain and IV site reaction. This generally limits its use in the lab to oral administration.

Another good alternative is levofloxacin (Levaquin), a fluorinated carboxyquinolone. It may be given orally or intravenously and has similar plasma and time profiles for both, making it a good choice for either route (again slow administration is required for IV use). The general dosage is 500 mg every 24 hours.

Analgesics

Conscious sedation, sometimes needed with a few procedures in the realm of image-guided spine pain management (e.g., percutaneous vertebroplasty), works fine while the patient is on the table. However, some procedures are frankly painful (e.g., discography), and others (e.g., epidural steroid injection) may be associated with a postprocedural pain flare-up. If persistent pain occurs, one may need to prescribe analgesics appropriate for the patient's pain level and suspected duration. This will not usually take the form of long-term or chronic analgesic administration. The two mainstays for postprocedural pain management are opioids, nonsteroidal anti-inflammatory (NSAID) drugs, or combination agents that contain drugs of both types.

Mild to intermediate pain may be handled by the use of NSAIDs alone or in combination with a weak opioid (codeine, hydrocodone, dihydrocodeine, oxycondone). Controlled trials show little difference in efficacy of the NSAID category, and therefore finding one that works will usually be sufficient. There is potential toxicity from the NSAIDs to the gastrointestinal, genitourinary, central nervous, and hematological systems. Consider avoiding NSAIDs in patients predisposed to developing gastropathy or bleeding diathesis. Ketoralac (Toridol) is very effective for short-term use in intermediate pain relief.⁸ It is recommended only for short-term use and should be administered with an initial IV or IM loading dose given prior to oral dosing. Multidose (IV or IM) administration recommended for patients less than 65 years is 30 mg every 6 hours, not to exceed 120 mg per day. For patients over 65, renally impaired patients, and those weighing less than 50 kg, the dosage is 15 mg every 6 hours, not to exceed 60 mg per day. If there is breakthrough pain, one should not increase the NSAID dosage but add additional analgesic coverage. Regular, rather than intermittent, therapy promotes both anti-inflammatory and analgesic effects.

Intermediate pain is often managed with the weaker opioids such as codeine, hydrocodone, dihydrocodeine, or oxycodone. These drugs are usually formulated as combination products and are weak only insofar as the inclusion of aspirin, acetaminophen, or ibuprofen results in a ceiling dose above which the incidence of toxicity increases. Prescribed alone, some of these drugs can manage even severe pain. Codeine is emetic and is prescribed much less than in the past. Hydrocodone preparations (Vicodin, LorTab) are now more commonly used. The potency is between that of codeine and oxycodone. Hydrocodone is not available as a single entity preparation. Oxycodone, now available as a combination product (e.g., Percocet, Percodan), as well as a single-entity preparation (e.g., Roxicodone, Percodone), is very effective. It also is now available in a slow-release formulation (Oxycontin) that is very potent.

The most potent opioids are reserved for severe pain (e.g., the intractable pain associated with cancer). The members of this group include morphine, controlled-release morphine (MS Contin), hydromorphone (Dilaudid), meperidine (Demerol), and methadone (Dolophine). Oxycodone also falls somewhat within this category when used as a single-entity preparation.

Adjuvant Analgesics

Classic pain is usually well handled by one of the NSAIDs, an opioid, or a combination product. These analgesics effectively deal with pain resulting from classic nociceptor response to intense, potentially tissue-damaging stimuli. However, neuropathic pain results from spontaneous discharge of injured nerves. It may be enhanced by sympathetic afferent activity as well. This type of pain is not as easy to control with standard analgesics; successful treatment has been achieved by means of adjuvant drugs such as antidepressants and anticonvulsants.

When neuropathic pain is described as burning and constant, the tricyclic antidepressants become the first line of therapy. Syndromes such as postherpetic neuralgia and phantom limb pain are examples. Amitriptilyne (Elavil) is the most widely studied drug used for this type of dyesthetic pain. The operative mechanism for antidepressantmediated analgesia is believed to be the increase in circulating pools of norepinephrine and serotonin created by reductions in the postsynaptic uptake of these neurotransmitters. The quantities of drug administered are well below what is needed to relieve depression and suggest a separate mechanism of action.

When neuropathic pain is described as intermittent but sharp and lancinating, anticonvulsant drugs have been used with success and should be tried before the antidepressants. It is believed that they relieve pain by damping ectopic foci of electrical activity and spontaneous discharge from injured nerves. Though carbamazepine and phenytoin have been useful as adjuvant analgesics, gabapentin (Neurontin) is a new anticonvulsant that has been found to be effective for neuropathic pain relief while avoiding most of the side effects found with the other anticonvulsants.

These and other adjuvant analgesics should be used when neuropathic pain contributes to a patient's discomfort.

Radiographic Contrast Agents

Always an area of potential controversy for the image-guided physician, the choice of an appropriate contrast agent is challenging. The main concern is related to allergic potential and use within the thecal sac. There is no method that completely avoids the potential for allergy. Premedication is indicated in all patients with known allergy or prior reaction. If that reaction was severe, then all methods should be used to avoid the use of iodinated contrast. Substitution of another type of material may be useful (e.g., gadolinium). Pretreatment should include oral corticosteroids (prednisone, 50 mg, 13, 7, and 1 hours before the procedure), and oral H1 and H2 blockers 1 hour before the procedure (diphenhydramine, 50 mg; tagamet, 300 mg).⁹

Although allergic reaction to nonionic contrasts exists, it may be lower than the incidence found with the ionic media. Routine use of nonionic contrast (Isovue, Omnipaque, Optivist, Optiray) is effective and safe for facet and sacroiliac joint injections. However, when there is a chance of injection into the thecal sac (e.g., epidural steroid injections), an agent that is approved for intrathecal use is recommended (Isovue M-200, Isovue M-300).

Neurolytic (Cytotoxic) Agents

Chemical and thermal agents intended for neurolysis have been used for decades.¹⁰ Commonly used agents or procedures include absolute alcohol, phenol, cryoanalgesia, and radiofrequency lesions. These materials or methods are intended to create long-term or permanent damage. This must be taken into account when one is planning therapy and discussing the procedure with the patient.

Absolute alcohol is commercially available as a 95% concentration. Its use at this concentration is very painful, and therefore substantial sedation or anesthesia is necessary during injection. Being hypobaric to cerebrospinal fluid (CSF), alcohol rises if injected into the thecal sac. When injected near the sympathetic chain, alcohol destroys the ganglion cells and blocks postganglionic fibers.¹¹ Postinjection neuralgia, hypesthesia, or anesthesia can be side effects of alcohol use.

Phenol (carbolic acid), like alcohol, has been used extensively and for a long time.¹² It is not available commercially as an injectable preparation but can be made by the hospital pharmacy. It has the advantage of causing much less local pain during injection than does absolute alcohol. Phenol is usually prepared in concentrations of between 4 and 10% and is hyperbaric to CSF. It is not stable at room temperature. Phenol produces a shorter and less intense blockade than does alcohol. Moller et al. estimated that 5% phenol was equivalent to 40% alcohol.¹³ In intractable pain, the analgesic effects of phenol and alcohol have been found to be equal.¹⁴

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Patient Evaluation and Criteria for Procedure Selection

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When did the pain start? Where does it hurt? What sort of pain is it? How much does it hurt? The answers to these questions provide important clues to why a person is in pain. Unfortunately, we must rely on the patient's information about the when, where, what, and how of pain to shed light on the biological basis of most pain conditions. On the other hand, we understand the interaction of various aspects of pain sufficiently to reveal when a patient may be malingering for financial or emotional gain or to decide which tests may allow us to diagnose an underlying pain-generating condition or disease.

A multidisciplinary diagnostic effort by a trained team best serves patients suffering from chronic pain. After reaching a diagnosis, the team can determine the best strategy to treat the underlying disease and the pain.

Determining the source of spinal pain can be extremely challenging because of the vast number of structures that can generate pain. Pain can arise from bones, muscles, ligaments, nerve structures, and/or alterations in vascular supply. In addition, pain has numerous etiologies, ranging from structural malalignment to somatoform disorders.

The first step in determining the source of pain is to perform a thorough history and physical exam, to be supplemented with appropriate diagnostic tests to make an accurate diagnosis. Only then can we take the second step—determining which tool to use to help the patient with pain.

General contractors can build houses because they understand the jobs of the many specialists involved (e.g., electricians and plumbers). Pain physicians must also understand the tools in their toolbox and know when to apply them. These tools include medical management, physical medicine techniques, radiation and chemotherapeutic options, neuromodulation techniques (electrical stimulation and intraspinal infusion therapy), therapeutic neural blockade, anatomical procedures to fix structural abnormalities, and, of course, ablative techniques (Figure 3.1).

If physicians offer only interventional techniques, patients will not receive the most comprehensive care. On the other hand, if physicians



fail to offer interventional options, they are neglecting the most highly effective options. To minimize risk and discover the least invasive/ most successful treatment for a patient, we generally begin with the most conservative approaches (medical management, rehabilitation strategies, lifestyle changes, psychological approaches, and alternative strategies) and work our way up the continuum of complexity and risk to interventions like spinal cord stimulation and intrathecal drug de-livery with an implanted pump. Conservative therapies can offer pain control without the risks associated with invasive techniques. Conservative therapies, however, do not always work and are not permanent. When conservative therapies fail or the side effects of these therapies become intolerable, a physician should consider use of an interventional technique (Figures 3.2 to 3.4).

This text concentrates on the importance of interventional techniques in the management of pain. Although each chapter highlights indications, techniques, outcomes, and complications, it is important to recognize that interventional therapies are not the only options for patients with pain. Before considering interventional techniques, an accurate diagnosis must be made, and conservative therapies should be considered, if not exhausted.

This chapter begins by reviewing the diagnostic tools that are invaluable in evaluating patients and identifying appropriate candidates for various therapeutic and palliative procedures: review of the patient's medical history, a thorough physical examination, imaging studies, electrodiagnostic tests, laboratory tests, and diagnostic nerve blocks. Finally, we discuss the appropriate role of interventional therapies.

History and Physical Examination

Reviewing a patient's medical history and conducting a thorough physical examination provide healthcare practitioners with vital informa-



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tion for making diagnostic and treatment decisions. We glean most of our information about a patient's medical history simply by asking the patient and/or the patient's family members pertinent questions. The asking part is easy. Knowing what to ask is harder and, of course, crucial. We can augment or confirm some aspects of the patient's medical history by asking the patient to bring a completed questionnaire to the initial appointment.

Recording and reviewing the patient's medical history highlights what we should expect and check for during the physical examination. This activity also helps establish a productive patient–physician relationship by assuring the patient of the physician's interest, which helps the physician gain the patient's trust and confidence. By providing a clear picture of the patient's functional status prior to the onset of pain, the history will also help define the treatment goal.

History Gathering

To obtain a patient's medical history, the physician must be a good listener and must direct the questioning appropriately to reveal and/or confirm vital information. Asking patients in pain the right questions will provide a clear picture of the onset and progression of the pain as well as the effect of the pain on each patient's daily life. These questions must elicit the chronology of events leading up to the consultation and must cover psychosocial and behavioral factors that affect the pain and interfere with the achievement of treatment goals. Thus, it is important to find out whether the patient likes his or her job, especially if the person is on disability leave and/or is receiving worker's compensation. It is also important to note the existence of pending litigation or other sources of secondary gain related to a patient's condition.

Questions about the biological aspects of the pain should reveal:

Its location Its quality Its intensity (measured on a scale) Its time course and whether it is constant What exacerbates it What alleviates it Its effect, if any, on functional status

The clinician should review the results of any diagnostic tests or treatments for the pain (especially the efficacy, dose, frequency, and any side effect of pain medications and any psychological interventions) and gather information about the patient's general state of health, current medications, allergies (distinguishing between true drug allergies and transient adverse effects), sleep patterns (as a sign of possible emotional depression), and consumption of tobacco, alcoholic beverages, illegal drugs, drugs prescribed to another person, and over-the-counter medications. The history should also include information on any of the patient's childhood illnesses, physical and psychiatric adult illnesses, surgical procedures, major injuries, and hospitalizations that could affect the current pain problem.

Physical Examination

The patient's history and presenting complaint will indicate what needs to be assessed during the physical examination. In patients with unilateral limb pain, physicians should first examine the unaffected contralateral limb for comparison. The physician should inspect all areas where the patient feels pain for the presence of erythema, discoloration, abnormal nail growth, masses, induration, or scars. Light palpation of the painful area will reveal the presence of hyperalgesia. If the patient has symptoms of neuropathic pain, a thermal stimulus applied to the painful area will uncover thermal hyperalgesia.

If the patient has a lesion, palpation will indicate the presence of a mass and palpation-induced pain. Testing for sensory and motor function and deep tendon reflexes will uncover any involvement of peripheral nerves or nerve roots. In patients with neck or low back pain, it is important to examine the spine and determine range of motion. We may be able to determine where the pain originates (e.g., in such areas as the hip, sacroiliac joint, or lumbar spine) by performing appropriate procedures and maneuvers. Physicians can test for the presence of three or more of Waddell's signs (tenderness, simulation, distraction, regional disturbances, and overreaction) to determine whether low back pain is psychological in origin. The physical examination also provides an important opportunity to gauge the patient's mood, affect, and degree of pain behavior.

Imaging Studies

Imaging studies are crucial for identifying anatomical abnormalities that corroborate physical findings.

Conventional Radiographs

Because they can indicate whether a bone is healing and aligning properly or whether a patient has osteomyelitis or osteoporosis and can even reveal the coexistence of a pathological fracture and a destructive bond lesion, as well as size and shape of primary bone tumors, conventional radiographs are particularly helpful in diagnosing the cause of musculoskeletal pain in the back, neck pain, and pain in the limbs and/or joints.

Radiography is an extremely precise way to diagnose various arthritic disorders. Rheumatoid arthritis of the hands usually involves the metacarpophalangeal joints, and a radiograph can reveal an incriminating narrowing of the joint space as well as articular surface erosions. Radiographs also reveal arthritic osteophytes (bony outgrowths) and sclerosis (scarring). Additional reasons for spine pain exposed by radiography include spondylolisthesis (when one vertebra has slipped over another), narrowing of disc space, kyphosis ("widow's hump"), scoliosis (abnormal curvature of the spine), osteoporosis, hypertrophic spurs, failed spinal fusions, spondylosis (degeneration of one or more vertebrae), pars interarticularis defects (a break in the posterior elements of

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the spine), and zygapophyseal (facet) joint abnormalities. We can also use oblique x-rays to expose the neural foramina and flexion/extension views to assess spinal stability. Because this diagnostic tool is noninvasive, most people with chronic pain accept it readily.

Myelography

Myelography may be used to confirm a diagnosis of a surgically correctable lesion, such as a herniated disk, and to pinpoint its exact location. It is less commonly used today but still helpful when primary screening with magnetic resonance imaging fails or cannot be used (as is the case when a pacemaker is present).

Computed Tomography Scanning (CT)

We use CT scans to evaluate the bony structures and soft tissues of the spine. Laterally placed fragments of herniated disc, for example, may be visible on a CT scan but missed on a myelogram. A CT scan provides important additional information when a herniated disc causes radicular pain by compressing a nerve root exiting through its neural foramen. Images of facet joints obtained by CT will reveal the degenerative and/or hypertrophic origin of chronic spinal pain, and axial CT scans provide three-dimensional images of spinal ligaments and discs.

Magnetic Resonance Imaging (MRI)

Presently, the single most important imaging tool for spine pathology, MRI provides a detailed image of the spinal cord, cerebrospinal fluid, extradural structures (intervertebral discs), and the patency of neural foramina. An MRI reveals disc degeneration, herniated discs, facet joint arthropathy, vertebra or disc infection, subluxation, stenosis, fracture, neoplasm, and vascular abnormalities.

Ultrasound

Although virtually useless for evaluating musculoskeletal pain, ultrasound is the best way to evaluate suspected gallbladder disease in patients with abdominal pain.

Bone Scanning

Bone scanning permits detection of the early stages and the course of bone metastasis, osteomyelitis, bone trauma, arthritis, hairline fractures, and all other diseases that involve bone turnover and can easily be missed by conventional radiography. Because bone scanning is nonspecific, however, diagnoses based on bone scans must generally be supported by appropriate clinical information and other imaging studies.

Thermography

Thermography may help diagnose neuromuscular and soft tissue disorders, especially in patients whose abnormalities elude detection

during a physical examination. Some clinicians use thermography to evaluate:

Neuropathic syndromes (e.g., complex regional pain syndrome, radicular syndromes, peripheral neuropathies, carpal tunnel syndrome and other nerve entrapments, postherpetic neuralgia, thoracic outlet syndrome, and trigeminal neuralgia)

Myofascial syndromes (e.g., fibromyalgia and lumbosacral strain)

Circulatory disorders (e.g., peripheral vascular occlusive disease, vasospastic disease, and venous insufficiency)

Skeletal disorders (e.g., osteomyelitis, lumbar facet syndrome, rheumatoid arthritis, scoliosis, and postfracture extremity pain)

Clinicians have not yet agreed upon the clinical applicability of thermography, and its use remains controversial and limited.

Electrodiagnostics

Electrodiagnostic studies provide information on how well nerve roots, peripheral nerves, and muscles are functioning. These diagnostic tools thus provide important information in suspected cases of nerve entrapment, radiculopathy, and peripheral neuropathy, to name a few. Specially trained physicians generally perform and interpret electrodiagnostic studies.

Electromyography (EMG)

Electrical potentials become abnormal in the presence of a diseased muscle or nerve serving a muscle. To discern the presence of abnormal potentials, one can record changes in intermuscular voltage on an electromyelograph. An oscilloscope displays activity measured by a monopolar needle electrode inserted in the muscle and by a surface electrode. A loudspeaker simultaneously amplifies the distinctive sounds of the muscle activity. We check for abnormal potentials during needle insertion and when the muscle is resting and contracting.

In a resting muscle, abnormal potentials can appear as fibrillation in a single muscle fiber with a disrupted nerve supply, positive sharp waves (a sudden move to the positive potential followed by a slow move to the negative), and/or fasciculation (spontaneous depolarization in a group of muscle fibers innervated by a single nerve fiber). Fibrillation potentials and positive sharp waves often occur simultaneously in the presence of radiculopathy and peripheral neuropathies, such as a diseased nerve plexus or degeneration of nerve axons, which cause muscle fibers to lose their normal innervation and undergo spontaneous depolarization. Because it can occur in healthy individuals, fasciculation must accompany fibrillation potentials and positive sharp waves to contribute to a diagnosis of neuropathic disease.

A normally active muscle, contracted minimally, will involve a single motor unit potential with four phases. A polyphasic potential, with five or more phases, may indicate neuropathic disease or myopathy. In the early stages of neural injury, however, neural conduction velocity testing is more sensitive than EMG because EMG changes occur slowly over a period of weeks.

Nerve Conduction Studies (NCSs)

Nerve conduction studies, which use surface electrodes to stimulate a peripheral nerve and evaluate how well it is functioning, expose the abnormal nerve conduction that occurs during neuropathy as well as the location of a nerve lesion and/or nerve entrapment.

To perform motor NCSs, we stimulate a nerve to record a target distal muscle's evoked response (impulse velocity, amplitude, and latency—the interval after the stimulus and before the muscle contracts) and display these data on a monitor. To determine the velocity of a particular segment of a nerve, we stimulate the nerve at each end point of the segment and measure the latency from each point in an appropriate muscle. If we are examining the median nerve segment between elbow and wrist, for example, we can calculate conduction velocity by subtracting the distal latency (wrist to hand muscle) from the proximal latency (elbow to hand muscle) and then dividing the result into the distance between elbow and wrist.

To perform sensory NCSs, we place both a stimulating and a recording electrode over the target sensory nerve. We measure antidromic conduction (movement of impulses in the opposite direction to normal) by placing the stimulating electrode proximal to the recording electrode. We measure orthodromic conduction (movement of an impulse in the normal direction) by placing the stimulating electrode distal to the recording electrode. To calculate conduction velocity, we divide the distance between the electrodes by the latency time. Sensory NCSs may reveal peripheral neuropathies before a patient experiences significant sensory loss.

We can perform sensory and motor studies on the median, ulnar, radial, and tibial nerves. Additional sensory studies involve the lateral femoral cutaneous, sural, and superficial peroneal nerves, and we can conduct motor studies on the peroneal, sciatic, and other nerves.

Laboratory Tests

Laboratory tests can uncover abnormalities associated with many of the neurological diseases that present with pain. Obvious uses of laboratory tests include screening for diabetes, malnutrition, toxins, dysproteinemia, cancer, and the thyroid disorders that can cause compression neuropathies. We can also detect abnormal inflammatory states or autoimmune dysfunction by checking a patient's erythrocyte sedimentation rate or levels of antinuclear antibodies.

Diagnostic Nerve Blocks

To perform a diagnostic nerve block, we inject a local anesthetic around a nerve proximal to a presumed pain-generating lesion. Our diagnosis depends upon whether this leads to pain relief. There are many variables to consider in the interpretation of the results of nerve blocks. False positive results, for example, can be due to a placebo response or to the effect of systemically administered analgesics or a systemic uptake of local anesthetics. Other nonspecific effects may result from the needle placement or the effect of saline during a placebo test. It is also inappropriate to decide that just because a patient has responded to a placebo injection, the person's pain is psychogenic.

Peripheral Nerve Blocks

To determine whether peripheral nerves are the source of the pain, we inject local anesthetics around a nerve and assess the response. A report of a marked reduction in pain indicates that the pain is coming from a location distal to that nerve. (We must be mindful that the test can produce false positive results.) To block a sympathic nerve, we inject the local anesthetic onto the sympathetic chain at various sites. The primary sympathetic ganglia involved in pain include the stellate ganglion, the celiac plexus, the lumbar sympathetic ganglion, the superior hypogastric plexus, and the ganglion impar.

We use the stellate ganglion block to diagnose sympathetically mediated pain of the upper thorax, arm, head, or face and to treat postherpetic neuralgia, sympathetically maintained pain, or vasoocclusive disease.

Celiac plexus blocks indicate whether pain is arising from the abdominal viscera and relieve pain caused by upper abdominal malignancies, including pancreatic cancer. A positive response to a celiac plexus diagnostic block is prognostic of several months of pain relief from celiac plexus neurolysis.

Lumbar sympathetic ganglion blocks allow us to diagnose sympathetically mediated pain of the lower extremities. Superior hypogastric plexus blocks uncover any visceral cause of pelvic pain, and ganglion impar blocks shed light on the cause of perineal (rectal, anal, vaginal) pain.

The patient's response to a nerve block helps us diagnose cervical or lumbar facet joint syndrome. Pain arising from the C2-C3 facet joints generally radiates to the occiput and that arising from C5-C6 radiates to the shoulder. We can reproduce this pain with ipsilateral rotation and extension of the cervical spine. Lumbar facet joint syndrome causes constant pain in the lumbar region that may radiate to the hips or even below the knee and can be elicited by hyperextending the spine ipsilaterally.

Facet joint syndrome is difficult to diagnose because it arises from the same types of degenerative change that show up in x-ray images of asymptomatic joints. The diagnosis is further obfuscated because similar symptoms can arise from discopathy, nerve root impingement, and/or myofascial disease. We can differentiate facet joint syndrome by the response to radiographically guided injections of local anesthetics into the zygapophyseal joints or around the dorsal medial branches of the posterior primary rami.

Central Nerve Blocks

To determine whether a sensory nerve root is generating pain, we block central nerves by injecting local anesthetic under fluoroscopic guidance

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into the epidural space or onto selected dorsal roots. The use of a contrast medium helps ensure proper needle placement and spread of the local anesthetic. If the block results in pain relief, we presume that the pain generator is distal to the anesthetized site. If the block results in numbness but no pain relief, we presume the pain generator is proximal or collateral to the anesthetized site.

Differential epidural blocks can reveal whether pain is arising from the somatic nerves, the sympathetic nervous system, or the central nervous system. The first injection in a differential epidural is a placebo (saline). If this leads to pain relief, the clinicians halt the injections. If the placebo relief is long lasting, it is possible that the pain is centrally maintained or psychogenic. If the placebo provides no pain relief, we administer three injections of successively higher concentrations of local anesthetic. If the lowest concentration of anesthetic provides pain relief, we consider the pain to be sympathetically maintained. If the next level of anesthetic provides relief, we presume that the pain is somatosensory. If the pain persists, we inject the highest concentration, which usually causes a temporary loss of motor function. If this fails to provide relief, we presume the pain is centrally maintained or psychogenic.

Psychological Evaluation

Pain is, by definition, a sensory and emotional experience of actual or perceived tissue damage.¹ The biologically oriented clinician may not recognize the impact of depression, anxiety, or other negative affective states on the experience of pain. The experience of pain always involves emotional dysfunction (Figure 3.5). The challenge for the pain practitioner is to differentiate between the component that is biologically driven and the component that is magnified by emotions.² Patients with severe depression or anxiety should be evaluated to determine the impact of these comorbid psychological states on their pain. This evaluation is an important part of a medical approach to their pain and is essential before they receive interventional therapies.



FIGURE 3.5. Pain treatment strategy.

Patients with major depressed mood, anxiety, or other negative affective states report more pain with noxious stimuli than do controls with positive affective states. We believe that emotionally depressed patients can be appropriate candidates for interventional therapies; it is simply necessary to be especially careful when offering them therapies that carry significant risks. While it may be obvious that patients with severe pain caused by a peripheral pain generator will also experience depression or anxiety, it is less obvious that the same negative affective states actually increase the experience of pain itself. Depressed affective states can also maintain pain and cause it to take on a life of its own by dramatically amplifying what would otherwise be a relatively minor pain generator.

Frequently, a physician can determine the severity of emotional dysfunction during an initial encounter. If the patient reports anhedonia, depressed or increased appetite, a history of major depression, or difficulty sleeping, a physician should be alert to the possibility that depressed mood is an exacerbating component of the pain. When a major depression is suspected, it should be treated prior to initiating interventional techniques, directly or by referral to a competent physician who can help with this aspect of pain.

Pain Management

To reiterate: in order to determine the most appropriate therapeutic strategy, it is vital to begin by making an accurate and comprehensive pain diagnosis. The treatment of neuropathic pain might be very different from that of nociceptive pain. Likewise, the treatment of myofascial pain is very different from that of discogenic pain, and so forth. Frequently, the tools just discussed are sufficient to establish the diagnosis, the severity of symptoms, and the prognosis of the patient with pain. Once the diagnosis has been established, it is important to design the most appropriate strategy. This involves choosing the best strategy for the patient and selecting the appropriate patient for a given procedure. In other words, certain conditions may call for certain therapies, but for a specific patient suffering from one such condition, the usual therapies may be inappropriate. In addition, some therapies may fail in some patients and succeed in others with the same condition. Thus, most pain physicians offer a spectrum of options for patients with pain.

It is, thus, important that the physician involved in interventional pain medicine be familiar with the full spectrum of diagnostic and therapeutic care and with ways to determine appropriate patient selection for any given procedure.

Medical Therapies

Several classes of analgesics are effective in chronic pain. They should be considered as tools in a toolbox, however, not as a list of medications that must be tried prior to initiating interventional therapies.

Nonsteroidal Agents

Nonsteroidals function by altering the peripheral and central sensitization of the products of inflammation. When applied to peripheral pain fibers, prostaglandins (PGE₂ in particular) amplify the experience of pain. Nonsteroidals block the cyclooxygenase (COX) enzymes that oversee production of PGE₂ and, thus decrease the amount of prostaglandin. These pharmaceuticals are commonly used to treat pain syndromes characterized by inflammation or by mild pain. Nonsteroidals are also used to decrease the dosage of opioids required to control pain.

Unfortunately, traditional nonselective prostaglandin inhibitors also block the production of the constitutive enzymes required to protect gastrointestinal mucosa and platelet function. For this reason, pharmaceutical companies developed newer classes of nonsteroidals that selectively block the COX-2 enzyme. These agents appear to have a similar efficacy to the traditional nonsteroidals and to offer a marked improvement in the safety profile.

Antiepileptic or Membrane-Stabilizing Agents

The class of agents most commonly used to treat neuropathic pain, antiepileptics and membrane stabilizers, has become the mainstay of therapy for neuropathic pain (see Table 3.1). Membrane-stabilizing agents have multiple mechanisms of action and should be tried consecutively if a single agent fails. Gabapentin is the most commonly prescribed drug for neuropathic pain, even though it is indicated only for postherpetic neuralgia.

Tricyclic Antidepressants

Tricyclic antidepressants have multiple mechanisms of action and have been most thoroughly studied in the treatment of neuropathic pain. They function by decreasing depression and, thereby decreasing the amplification of pain. They also decrease the inhibitory neurotransmitters norepinephrine and serotonin, thereby amplifying the impact of the body's own mechanisms to inhibit pain transmission.

The anticholinergic effects of tricyclic antidepressant can cause problems in patients with glaucoma, cardiac conduction abnormalities, or prostatic hypertrophy; thus, these pharmaceuticals must be used cautiously in elderly patients or in patients with these comorbid diseases.

Local Anesthetics

Also used in the treatment of neuropathic pain have been intravenous lidocaine and oral mexiletine. While these drugs clearly have central effects, they also have peripheral effects because they decrease the spontaneous activity of peripheral pain generators. Years ago, studies indicated that there may be an increase in the incidence of cardiac arrhythmia in patients who received these agents immediately after experiencing a myocardial infarction. Thus, local anesthetics must be used cautiously in patients with comorbid cardiac disease.

	GABA	Glutamate and		Esteria	
Agent	receptor	excitatory amino acids	Channels	Ectopic impulses	Miscellaneous
Gabapentin	Augments transmission, increases rate of synthesis	Inhibits release	Blocks Na ⁺ and Ca ⁺		Stimulates 5-HT release; Inhibits branch chain AA transferase
Topiramate	Enhances at GABA-α receptor	Antagonizes AMPA and kainate receptors	Blocks Na ⁺	Suppresses	Carbonic anhydrase inhibition
Lamotrigine		Decreases release of glutamate and aspartate	Blocks voltage- dependent Ca ²⁺	Suppresses	Suppresses acetylcholine
Carbamazepine		Decreases transmission	Slows recovery of voltage-activated Na ⁺ , modulates L-type Ca ²⁺	Reduces	TCA effects; Antagonizes adenosine receptors
Phenytoin	Enhances activity		Inhibition of Na ⁺ and Ca ²⁺		May inhibit somatostatin release
Zonisamide			Blocks Na ⁺ and T-type Ca ²⁺		Facilitates dopaminergic and serotonergic neurotransmission
Valproate	Decreases degradation, increases synthesis	Reduces cerebral EAAs			Structurally unrelated to any other anticonvulsant
Clonazepam	Increases potentiation of transmission				Structurally related to benzodiazepines; may have antianxiety and antispasmodic effects

TABLE 3.1. Mechanism of action of pharmaceuticals indicated for other conditions and used to treat pain

Abbreviations: GABA, γ -aminobutyric acid; EAA, excitatory amino acids; 5-HT, 5-hydroxytryptamine (serotonin); AMPA, α -amino-3-hydroxy-5-methyl-4-isoxazolepropionate; TCA, tricyclic antidepressant.

Opioids

Opioids, which have demonstrated efficacy in both nonneuropathic and neuropathic pain, remain one of the more controversial agents used in the management of pain. There is no ceiling effect for opioids used to treat pain, and patients rarely become addicted to the medications when appropriately prescribed. Whenever possible, opioids should be given according to a time-contingent rather than a pain-contingent regimen. Physicians who adopt modern behavioral approaches believe that this minimizes the risk of psychological dependence.

Topical Agents

The number of agents used topically for the control of pain is growing. At this point, however, the Lidoderm patch is the only topical agent approved by the U.S. Food and Drug Administration (FDA), and that approval is for the treatment of postherpetic neuralgia. Lidocaine seeps into the skin and anesthetizes peripheral pain generators.

A second topical agent with widespread acceptance is capsaicin, which, in concentrations of 0.025 to 0.075% is effective in the management of pain arising from a variety of conditions. Applied multiple times a day, capsaicin slowly destroys the C-fibers thought to be important in pain transmission. A single application of 5 to 10% capsaicin under regional anesthesia provides pain relief for weeks or months. This approach is currently under investigation. (The second author holds a patent on this technique.)

Anxiolytic Medications

Anxiolytics seem to have a limited role in the treatment of pain. No randomized controlled trials support their use in the treatment of pain. They are commonly prescribed, however, for patients with comorbid anxiety disorders. Anxiolytics must be used cautiously because patients experience significant withdrawal symptoms upon removal, and certain anxiolytics can cause psychological dependence.

Alternative Medications

It is important to remember that all biologically active agents carry a slight risk, and alternative medications have not been systematically studied or approved by the FDA. This does not mean that they are ineffective; instead it means that we lack information to support or refute the validity of therapeutic claims. Indeed, many of the standard agents that have been subjected to the scientific method and determined to be effective had their basis in herbal remedies (e.g., morphine and aspirin). Kava is an alternative medication that is widely accepted as effective in the treatment of anxiety and may be useful in patients with anxiety-amplified pain. Other agents, such as soy and glucosamine sulfate, are under investigation.

Botulinum Toxins

Botulinum toxins A and B are considered for patients who have pain from a primary or secondary muscle spasm. If the muscle in spasm can

be identified and relieved with a temporary block, this level of relief can be prolonged by injecting botulinum toxin accurately into the problematic muscle.

Physical Medicine and Rehabilitation

The importance of making an accurate diagnosis cannot be overstated. Frequently, comorbid myofascial dysfunction can become a primary pain source. Patients with back pain can develop severe muscle spasms that then become the primary pain problem. When this occurs, underlying pain generators as well as the myofascial dysfunction need to be treated. Myofascial disease can be corrected with injections (myoneural blocks), stretching exercises, strengthening exercises, application of heat and cold, and correction of gait abnormalities. Other therapies, including the application of electrical stimulation and ultrasound, are commonly used to release muscle spasms.

Interventions

Neural Blockade

As indicated, there are diagnostic and therapeutic nerve blocking techniques. Therapeutic blocks involve application of local anesthetics plus steroids around the nerves. On occasion, physicians resort to longer lasting neurodestruction.

One of the most common ways used in America to block nerves is by injecting a steroid epidurally. These blocks are effective in patients who suffer from disc herniation with radiculopathy. A specific type of epidural block that employs transforaminal techniques is used to decrease inflammation around nerves. Overall, epidurals are thought to be safe and effective and should be considered in patients with known disc herniation or lesion.

Neurodestructive Techniques

We rarely deliberately destroy primary motor or mixed motor/sensory nerves. We often use radiofrequency lesioning techniques of the spine, however, to treat known facet disease. Patients who are found to have facet arthropathy on imaging and/or physical exam (patients with exacerbation of pain on extension and facet arthropathy on imaging studies) are frequently treated with facet rhizolysis. This technique has an extremely high success rate and very low complications. We generally delay use of other neurodestructive techniques in the spine until all conservative therapies have failed. This is particularly true for patients who have long life expectancies.

Spinal Cord Stimulation

Electrical stimulation should be considered after conservative therapies have failed. In this technique, used most commonly for people who have a radiculopathy as a major component of their pain, electrodes

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are implanted in the spine. In the United States, spinal cord stimulation is most often used to treat patients with failed back surgery syndrome with radiculopathy. Techniques using multiple leads and contact arrays have been developed to treat patients with low back pain.

Intrathecal Infusion Techniques

The use of techniques that involve intrathecal infusion, the implanting of a pump that delivers medication directly to the spine, minimizes the total dose delivered to control pain and, thus, can reduce side effects.

Follow-Up

It is important to assess and reassess patients. With medications, it is important to assess the level of pain relief as well as side effects. If side effects become too difficult for a patient to bear, the drug-sparing techniques described in this book are indicated. With interventional therapies, however, a positive outcome can be short-lived. A physician should not assume that a patient had an excellent outcome simply because the person does not return for follow-up.

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4

The Surgeon's Perspective: Image-Guided Therapy and Its Relationship to Conventional Surgical Management

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Introduction

The indications for surgical management of compressive syndromes such as herniated nucleus pulposus with radiculopathy and lumbar spinal stenosis with neuroclaudication are clear. Predictable outcomes from decompression to alleviate referred extremity pain may be obtained in a high percentage of patients. For example, in the case of a herniated nucleus pulposus with unilateral radiculopathy, assuming strict concordance between the patient's clinical presentation and imaging findings, a 90 to 100% successful outcome is expected following laminotomy discectomy.¹ Likewise, the addition of arthrodesis to treat degenerative spondylolisthesis in the setting of stenosis with neuroclaudication has been shown to be the treatment of choice, based on randomized prospective data.² Outcome data for surgical treatment of back pain per se, in the absence of neural compression and referred extremity pain, is, however, less promising.^{3,4} Lumbar discography, for example, has been cited as a reasonable diagnostic technique to identify painful segments and treat them by arthrodesis.³ Not only have the sensitivity and specificity of the diagnostic technique been criticized,^{5–7} however, but the treatment itself—arthrodesis—has been studied in only one randomized, prospective study to date.⁸

From a surgical perspective, precise, reliable, sensitive, and specific diagnostic techniques are required to identify a lesion amenable to surgical decompression, and/or reconstruction. Controversy surrounding each step of a treatment algorithm such as that just described (e.g., persistent axial pain \rightarrow discography \rightarrow arthrodesis) and conflicting or variable reports of sensitivity, specificity, and efficacy further hinder the clinician in making rational decisions based on acceptable standards of care or scholarly consensus. Invariably, individual surgical

philosophy plays a role in patient selection, with some physicians more likely to recommend surgery for indications that would not be accepted by others.^{4,9} Furthermore, a surgical diagnosis may not represent a true surgical lesion. It is the unfortunate experience of many surgeons to have patients referred to them with a lumbar disc prolapse, apparent radiculopathy, and the expectation of a surgical recommendation, to discover that the prolapse demonstrated on magnetic resonance imaging or computed tomographic myography is minimal, or is not precisely correlated with the patient's symptoms.

The surgical treatment of lumbar spinal stenosis serves as another example. In one report, patients with a higher degree of midsagittal stenosis including complete myelographic block had lower functional disability scores at follow-up of 4.5 years. Patients who had a mid-sagittal stenosis exceeding 12 mm had a poor outcome.¹⁰ While one surgeon may wish to treat a patient conservatively until such a critical threshold is reached, to maximize surgical outcome, another may offer an earlier decompression based on individual patient characteristics, experience, and expectations. This difference in philosophy may be further compounded by discrepancies in education between patient and physician and, thus, in their respective expectations.

Another level of variance is added by pain-based diagnostics, which contains an unavoidable element of subjectivity. Obviously, patient expectations factor into this as well, with most surgeons more likely to offer surgical care to those who appear to have reasonable expectations. Unfortunately, there are no reproducible standards whereby patient expectations can be quantified,^{11–14} thus adding another layer of individual idiosyncrasy.

The goals of this chapter are to review from a surgeon's perspective provocative diagnostic maneuvers, including discography, facet blockade, selective nerve root blockade, epidural infusion, and sacroiliac joint injection. Specifically, the results of these diagnostic maneuvers will be scrutinized for their predictive value with regard to current concepts in surgical treatment. Additionally, vertebroplasty and kyphoplasty will be reviewed, as well as intradiscal therapy, focusing specifically on intradiscal electrothermal therapy (IDET).

Discography

While the use of discography to diagnose spinal pain syndromes has increased, the practice is not free from controversy. Despite reports of its utility in clinical decision making,³ as well as reports of high sensitivity and specificity,¹⁵ including one report of 100% sensitivity and specificity in distinguishing symptomatic from asymptomatic patients with back pain,¹⁶ discography is innately subjective and thus can never be completely controlled. This aspect of the therapy relates to the use of pain provocation, which must be concordant with presenting symptoms. As Saal¹⁷ notes, most pain-provocative or ablative tests used in the diagnosis of spinal conditions are closely related to the physical examination. In the case of "nonspecific" low back pain created by degenerative lumbar disc disease, the findings from a physical examination are

not as clearly defined as those involved in radicular syndromes. While numerous authors have noted the association of certain physical signs with discogenic pain,^{18–27} only one study in the literature correlates specific physical findings with the results of discography per se: Donelson et al. noted an increased incidence of positive concordant discography in patients who failed to centralize²⁸ according to the criteria of McKenzie.²⁹ In a specific subset, discography was more likely to be clinically positive (concordant) in patients with annular incompetence. The clinical correlate of this was failure to centralize.

While this is certainly encouraging, it is by no means definitive. One of the key issues in determining the sensitivity and specificity of a particular test is comparison to a recognized and accepted standard of accuracy, a "gold standard." This further complicates the situation for discography, and for invasive spinal diagnostics in general: since a painful joint or disc may have a variable or wide range of anatomical and clinical features that overlap with an asymptomatic structure, a "gold standard" is difficult to define.¹⁷ Furthermore, since there is no reliable surgical confirmation of the symptomatic status of a noncompressive degenerative lumbar disc (painful vs painless), surgical confirmation is not a viable option. This inherent level of uncertainty is further compounded by the innately subjective nature of discography as noted earlier.

In an attempt to address false positive findings of lumbar discography, Carragee et al.⁶ studied eight subjects, with a total of 24 discograms. None of the patients had a history of low back pain. Patients were scheduled to undergo posterior iliac crest grafting for nonthoracolumbar procedures; 2 to 4 months after the bone graft, patients underwent lumbar discography by a blinded protocol. Fourteen of 24 discs were painful, with two (14.3%) reproducing the pain "exactly." In this case, the pain was referred to the iliac crest bone graft. Based on these results, Carragee et al. concluded that the ability of a patient to separate spinal from nonspinal sources of pain may be questionable. This study is important for several reasons. First, it suggests that discography done under blinded conditions, in accordance with accepted protocol, may in fact not be specific to spinal pathology. Second, it suggests that in patients who were free from other potentially confounding influences (all patients passed a standardized psychometric screening battery prior to the test), significant pain can be produced in a clinically irrelevant setting. Since to be graded positive, pain must be concordant, by definition all those patients in whom no spinal pain source was being evaluated, would have had discordant spinal pain. However, many patients undergoing spine procedures have had iliac crest bone graft harvest. This serves to underscore the possibility that in patients with previous surgery, the findings from discography may be complicated by a confounding variable: a potential pain generator in close anatomical if not physiological proximity.

The technique of discography is of interest as well. While the doubleneedle technique and multiple blinded injections have become the standard of care, the utility of pressure-controlled discography remains unclear. In a multicenter retrospective study of long-term surgical and nonsurgical outcomes, Derby et al.³⁰ reviewed 96 patients who underwent first discography and then fusion, or continued nonoperative care. These investigators noted no long-term differences in surgical outcome across the entire sample, with the surgical group as a whole doing better than the patients who did not have surgery. In a specific subset, the data suggested that patients with highly pressure-sensitive discs appeared to achieve better long-term outcomes with interbody or circumferential fusion than with intertransverse fusion. For this reason, the authors suggested that there may be a biochemical component to discogenic pain. These results, however, have not been corroborated in prospective studies.

Another requirement for successful discography is the study of a large enough number of discs to permit inclusion of a rostral and, possibly, caudal control. Given that many surgeons have empirically limited arthrodesis to two- or three-level disease in the lumbar spine, the presence of appropriate control levels is critical.

A final note of concern must also be added regarding surgical treatment for discogenic pain. The newer intradiscal therapies are promising but certainly not definitive, and substantial variability exists in surgical outcomes for discogenic pain. Whitecloud and Seago³¹ reported a 70% rate of clinical success for cervical arthrodesis on the basis of discography. While Wood et al.³² have noted that thoracic discography may differentiate between symptomatic and asymptomatic degenerated discs (as characterized by the presence of Schmorl's nodes), the optimal surgical treatment of thoracic discogenic pain remains to be identified. In the lumbar spine, a wide variety of success rates have been reported. In one study, an overall success rate of 46% was identified, with a clinical success rate of 96% in the subset that fused solidly.³ Clearly, based on data collected to date, there is no role whatsoever for decompressive surgery in the treatment of discogenic (axial) pain syndromes.

What then are the criteria for "definitive" discography and its use as an indication for reconstructive surgery? Patient selection should be guided by the rigorous criteria.^{3,20} Strict adherence to technique, including double-needle, multiple blinded injections and identification of rostral and caudal controls, is essential, as is insistence on strict concordance with presenting complaints for a study to be considered "positive." Although the optimal technique of surgical reconstruction has not been definitively identified, the bulk of current literature would probably favor an interbody approach.

Finally, and most important, patient selection is of the greatest importance. Ideally, the patient should be free of confounding organic and psychological pathologies, should have disease limited to one or two levels, and should have reasonable expectations. Perhaps it is in this final area that the thought processes of the diagnostician and surgeon must be most closely aligned.

Facet Blockade

Numerous studies have demonstrated that the zygapophyseal joints, particularly in the lumbar spine, are a source of low back pain with or without referred sclerotomal pain.^{21–23} Several studies also suggest that

so-called facet pain may have a higher prevalence than previously suspected, with rates reported as high as 40% in older patients.^{36–38} While few would dispute the existence of posterior mechanical column pain in the presence of a sagittal deformity (e.g., spondylolisthesis), some investigators have disputed its existence without either such a deformity or coexisting degenerative changes in the motion segment.³⁹

The potential clinical utility of a diagnostic response from anesthetic blockade of a suspected pain generator is highest when there is a significant gap between objective data and subjective complaints.¹⁹ Obviously, the ability of the block depends on the pharmacology of the agent used, the anatomical accuracy of the needle placement, and, perhaps most significantly, the ability of the patient to accurately report changes in symptoms. Kaplan et al.⁴⁰ characterized the ability of lumbar medial branch blocks to anesthetize the facet joint. In this study, 18 asymptomatic individuals were assigned to L4-5 or L5, S1 facet blocks with radiographic contrast until capsular distention elicited pain. No extracapsular contrast extravasations were noted. One week later 15 of the 18 underwent one of two randomized injections with saline or lidocaine. Thirty minutes after medial branch injections, the same individuals underwent repeat capsular distention of the joints that had been distended the preceding week. All five control individuals who received saline injections experienced pain with repeat capsular distention. Only one of the nine patients who received the active block experienced pain on capsular distention. Thus, with strict attention to technique, including the avoidance of inadvertent venous uptake with medial branch injection, facet blockade was successfully accomplished in 89% of the active treatment group.

There are difficulties similar to those discussed for discogenic pain when one is attempting to identify patients who will be candidates for facet block on the basis of physical findings. Several studies to date^{38,41} have failed to identify predictive value for any clinical findings or feature that would suggest a positive response to facet blockade. Revel et al.⁴¹ did note an increased likelihood of response to facet blockade in older patients who were relieved of pain in recumbency and did not have an increase in pain with coughing or use of the Valsalva maneuver. Specificity and sensitivity were increased when range of motion and functional tolerance were included: final sensitivity and specificity were, however, limited at 78 and 80%, respectively.

As is the case with discography, there is no "gold standard" from a surgical point of view that can help to refine the diagnostic accuracy of facet blockade. In the lumbar spine, North et al.⁴² found that 42% of patients who had greater than 50% relief after facet anesthetic block had clinical improvement 2 years after facet rhizotomy. However, 17% of block responders who did not have facet rhizotomy were improved as well. In the cervical spine, some evidence exists that intervention for a facet-mediated pain problem may be warranted. Several studies^{43–46} have investigated the reliability of facet blockade in the cervical spine, as well as the utility of radiofrequency (RF) neurotomy.⁴⁷ There has been one published report investigating the correlation of facet blocks with lumbar fusion,⁴ but few meaningful conclusions can be drawn
from this study, which was retrospective and did not use facet blockade as the definitive diagnostic procedure for surgical decision making.

Thus, at the present time the identification of facet-mediated pain by diagnostic blockade has little meaningful impact on surgical decision making. Based on the literature to date, RF facet rhizotomy may be viable. There are however, no convincing studies in the peer-reviewed literature suggesting that conventional surgical treatment (e.g., arthrodesis) is effective in treating facet-mediated pain syndromes, in the absence of sagittal deformity.

Sacroiliac Joint (SI) Injections

The difficulties identified in terms of sensitivity and specificity, particularly in comparing diagnostic blockade to a known, or reproducible, standard also apply to SI joint blockade. It is generally accepted that the SI joint can be a source of pain owing to posterior ligamentous disruption, secondary to trauma, infection, or tumor. The characteristics of so-called SI joint pain without these obvious anatomical correlates, are, however, controversial. To date, no physical finding has proven to be specific enough to reliably diagnose sacroiliac joint pain.⁴⁸ Additionally, the sacroiliac joint appears to be relatively immobile and position has not been shown to be altered by manipulation.⁴⁹ Technically, the SI joint may be more difficult to access than others, although access is possible with strict attention to fluoroscopic technique.^{50–52} Several studies have noted that the pain provoked by joint distention may be ablated by anesthetic block.^{50,51} The clinical significance of this finding is unclear. Unfortunately, many of the appropriate afferent pathways are poorly understood. Additionally, in the presence of capsular incompetence, contrast extravasations may anesthetize nearby neural structures, further compounding the diagnostic difficulties with this particular injection.

From a surgical point of view, perhaps the most telling limitation is the lack of any reproducible surgical procedure to treat sacroiliac joint pain. While joint reconstruction or arthrodesis has been demonstrated to restore pelvic stability in traumatic situations, there are no published reports in the peer-reviewed literature of significant pain relief following SI joint fusion for clinical syndromes diagnosed by SI joint blockade. Cavillo et al.⁵³ reported two instances of successful treatment of presumptive SI joint pain by neurostimulation. The precise mechanism is unclear and certainly cannot be extrapolated.

Thus, from a surgeon's point of view, sacroiliac joint injections are therapeutic only because no firm recommendations can be made on surgical treatment for these presumed disorders.

Selective Nerve Root Blockade

Selective nerve root blockade has received attention as a diagnostic and therapeutic tool in the management of referred pain, presumably of radicular origin. From the surgical point of view, the potential utility of this test lies in diagnostic specificity: not in its ability to identify a radicular etiology as the source of referred pain, but to localize a symptomatic level. In certain instances with clinical evidence of radiculopathy and no underlying structural cause, nerve root blockade has been used to guide surgical intervention such as laminectomy or fusion.⁵⁴ This is particularly distressing, since selective nerve root blockade has been found, in randomized prospective studies, to be neither sensitive nor specific.^{55,56} Based on these data, it would appear that these blocks may have a therapeutic role, but the role as a definitive diagnostic maneuver is minimal.

A particularly unfortunate clinical situation occurs when a patient who has been diagnosed with radiculopathy is informed that surgery is required for neural compression even though, from a strictly anatomical point of view, no surgical lesion exists. Again, the potential dichotomy between the diagnostician and the surgeon bears scrutiny: although the patient may in fact have a radiculopathy that is helped by selective nerve root blockade, this may not be amenable to surgical treatment.

Selective nerve root blockade has been used in the diagnosis of radicular syndromes.55-58 However, recent reports have called attention to temporary pain relief by reversible anesthetic blocks that failed to yield reliable long-term predictions about interventional results. There have been disappointing results from neuroablation procedures including dorsal rhizotomy⁵⁹ as well as ganglionectomy⁶⁰ when these procedures were selected on the basis of response to selective nerve root blockade. Wetzel et al.⁵⁹ reported a 19% success rate on patients who underwent selective lumbar sensory rhizotomy, with levels being selected on the basis of response to selective nerve root blockade. In this study, the decision to perform rhizotomy was based on the response to selective neural blockade that required reproduction of familiar pain, the disappearance of root tension signs after infiltration of anesthetic, and correlation between clinical and radiographic findings. These criteria were met in 90% of the cases, but satisfactory relief was not reliably obtained by selective sensory rhizotomy of the appropriate root. In addition, results of selective blockade may be confounded by systemic effects of lidocaine. When this is viewed in conjunction with the results of anesthesia of cutaneous nerves in the area of referred pain (i.e., pain relief), a notable lack of anatomical specificity becomes quite evident.60,61

North et al.⁵⁶ performed diagnostic nerve blocks in a randomized prospective manner. In this study, 33 patients underwent a battery of local anesthetic blocks in an attempt to evaluate sciatica. The specificity of sciatic nerve block was 24% immediately and 36% at 1 hour. The sensitivity of selective nerve root blockade was 91% immediately and 88% at 1 hour. When analyzed in the context of blocks (from proximal to distal), the root block alone yielded significant pain relief in 9% immediately and 21% at 1 hour. The root block yielded greater relief of pain than any other block in 30% of patients immediately and 42% at 1 hour. In all other cases the sciatic block or facet block yielded equal or better results.

To date, there has been no convincing study demonstrating the ability of conventional surgery (i.e., lateral recess decompression or foraminotomy) to reliably treat referred pain diagnosed on the basis of response to selective nerve root blockade. It is possible that selective blockade may be of therapeutic value in the ongoing treatment of chronic radicular pain. However, reliance on this technique as the sole or determining diagnostic maneuver from which surgery is planned is only to be condemned.

Epidural Steroid Injections

Epidural steroid injections should theoretically diminish inflammation in the epidural space and lead to improvement in symptoms resulting from neural compression. Epidural injections are commonly used in the setting of spinal stenosis with neurogenic claudication, and unilateral or bilateral radiculopathy from disc prolapse. A recent study by Wang et al.⁶² suggests that epidural steroid therapy benefits patients with lumbar disc prolapse and radiculopathy. In this retrospective review, 69 patients were studied. At an average follow-up of 1.5 years, 77% had resolutions of symptoms significant enough to cause them to decline surgical intervention. Riew et al.⁶³ studied the effect of selective nerve root injections on patients with radiculopathy from disc prolapse or foraminal stenosis. These authors found that 53% of patients were able to obtain sufficient pain relief to be able to forgo a surgical solution. However, Carette et al.,⁶⁴ in a randomized prospective double-blind study, examined the effects of epidural steroid injection on sciatica due to lumbar disc prolapse. The authors found no functional benefit in the group who underwent epidural injections. Short-term improvements in leg pain and sensory deficit were noted in the treatment group, but these benefits did not last beyond 3 months. Many patients in the study went on to discectomy within a year.

Thus, from a surgical prospective, the diagnostic utility of epidural steroid injection is quite limited. Certainly, there are no convincing data suggesting that a response or lack of response to epidural injection correlates positively or negatively with the outcome of decompressive surgery. From a practical point of view, the use of epidural steroid therapy would appear to be reasonable in the symptomatic management of patients with compressive syndromes. Additionally, from a costeffective point of view, it may be plausible to consider epidural therapy as a first-line intervention.

Minimally Invasive Intradiscal Therapy

From a therapeutic point of view, the treatment of discogenic pain appears to be rather limited. On the one hand, appropriate conservative care (e.g., active physical therapy, pharmacological management) should be expected to yield success in the vast majority of cases. However, failing this, the only other available treatment has been arthrodesis. Clearly, this is a very limited treatment continuum. From a philosophical point

of view, a minimally invasive intradiscal treatment technique is quite attractive in an attempt to extend that continuum. Recent attention has been focused on the use of thermal energy to treat discogenic pain (intradiscal electrothermal therapy, or IDET). Whether the mechanism of action is deafferentative, biomechanical, or both remains to be elucidated,^{65,66} although clinical data suggesting a delayed therapeutic effect after the procedure would suggest the latter. Numerous studies suggest a therapeutic effect.^{67–70} Although most studies have been prospective cohort controlled, or retrospective, within the limitations of this study design a therapeutic effect comparable to that of arthrodesis has been suggested. One randomized prospective, double-blinded study has been reported to date (at the 2002 annual meeting of the International Spinal Injection Society): Pauza et al. noted a significant effect of treatment at 6 months in the active versus the placebo group.⁷¹

In a multicenter study, Wetzel et al.⁷² reported significant improvement in many functional scales, and a decrease in Visual Analog Scales (VAS). In this particular study, all investigators were surgeons, and all patients who were treated with IDET were considered to be potential surgical candidates. Of the original group, 14 went on to spinal fusion. When this group is compared with those who underwent IDET only (N = 43), similar rates of improvement in terms of functional scores and pain relief were noted. However, when patients were asked specifically whether they felt that the procedure was worthwhile and would consider it again, 61% of the IDET-only group responded positively versus only 27% of the surgical group.

Controversy remains, however, regarding the mechanism of action of intradiscal thermal treatment. Studies investigating the use of thermocouple technology (e.g., IDET) have reported conflicting results. Kleinstueck et al.⁶⁵ noted variability in outer annular heating, and little or no biomechanical effect acutely, as measured in vitro. The in vitro limitations of this study are apparent, inasmuch as such a study design fails to take into account the ongoing processes of healing. By contrast, Shah et al.⁶⁶ did demonstrate annular shrinkage, coalescence of collagen, and denaturation in a study of cadaver discs following IDET lesions. Light microscopy demonstrated significant coalescence of collagen, with no evidence of endplate damage. Temperature mapping in this study did suggest that an intradiscal thermocouple raised the temperature significantly across the entire posterior annulus, thereby inducing the observed changes.

From a surgical perspective, the efficacy of intradiscal therapy remains to be proven, although its prospects are encouraging. Clearly, the randomized prospective study methodology such as that of Pauza et al.⁷¹ with long-term follow-up will be required to answer this question.

Vertebroplasty and Kyphoplasty

Osteoporotic vertebral compression fractures are the leading cause of disability and morbidity in the elderly.^{73–75} The consequences of these fractures may include pain, and in many cases vertebral collapse and

kyphosis. Traditionally, these fractures have been treated nonsurgically, except in cases of fractures associated with neurological compromise. Obviously, surgical reconstruction in the patient with osteoporosis is challenging. From a surgical point of view, orthopedic fracture care emphasizes the restoration of anatomy, correction of deformity, and subsequent preservation of function. These goals have not been met in the conservative care of patients with vertebral compression fractures. The ideal treatment should address both the fracturerelated pain and the mechanical compromise related to kyphosis.

Percutaneous vertebroplasty was described in 1987.⁷⁶ In this procedure, whereby polymethylmethacrylate is injected into a compressed segment, immediate stability is obtained, but deformity is not corrected. Suggested indications included stabilization of painful osteoporotic fractures, painful fractures due to myeloma, and painful hemangiomata. Reports on clinical outcome for vertebroplasty have been encouraging, with most patients experiencing partial or complete pain relief within 72 hours.^{77–82} Complication rates have been low, with the most significant complications resulting from extravertebral cement leakage causing spinal cord or nerve root compression, or pulmonary embolism.^{77,78,80,82–84} Additionally, a higher rate of extravasation has been noted in patients with metastatic disease versus patients with osteoporosis.^{85,86}

Overall, vertebroplasty appears to be a reasonable method by which to treat a symptomatic vertebral compression fracture that has failed to respond to time-limited conservative care. Certainly, in a patient with multiple levels and significant debility, this may be the procedure of choice. However, a potential theoretical limitation of vertebroplasty is its inability to address the aspect of persistent deformity, which is accompanied by a theoretical increased risk of adjacent segment degeneration, or possible fracture, as well as chronic pain related not to the fracture per se but, rather, to the postural concerns raised by deformity.

Kyphoplasty claims to reduce a fracture via an inflatable bone tamp placed percutaneously into the vertebral body.86-90 Indications for kyphoplasty include painful osteoporotic compression fractures with induced kyphotic deformity. Kyphoplasty has not been investigated in the treatment of nonosteoporotic spinal metastatic disease. Initial reports of pain relief with kyphoplasty are comparable to those for vertebroplasty. In a study by Garfin et al.,⁹¹ 90% of patients reported significant pain relief in the first 2 weeks of the procedure. In the initial series of these investigators, there were four major complications in 340 patients. Overall, serious adverse events occurred in 1.2% of patients.⁸⁸ Wong et al.⁸⁶ reported one presumed cement embolus to the lung, although this was attributed predominantly to technical issues associated with the use of a less viscous cement. Lieberman et al.⁸⁹ had one major and two minor complications while achieving an average of only 2.9 mm height restoration. In addition, Phillips et al.⁹⁰ reported improvement in local kyphosis by a mean of 14°. Kyphosis reduction may also be seen with vertebroplasty simply as a result of pain relief, so the effect with kyphoplasty may be less significant as an indicator of a procedural advantage.

The obvious theoretical advantage of kyphoplasty—namely, an attempt to restore normal anatomy—requires further follow-up and investigation. Certainly, if fracture reduction can be demonstrated to result in a decreased risk of adjacent segment failure, either by a painful degenerative change or subsequent fracture, then the advantages of kyphoplasty would be apparent. However, height restoration, to date, has been meager (89), and the cost and complication rates remain a disadvantage when the bone tamp procedure is compared with vertebroplasty.

Conclusion

From the point of view of planning surgical intervention, a diagnostic test must be sensitive, specific, and reproducible. The patient's clinical findings must be precisely supported by the results of the diagnostic intervention. A well-studied surgical procedure to treat the specific pathology must be identified. Clearly, in many of the diagnostic regimens reviewed, the very nature of the tests (especially those involving pain provocation or ablation) may preclude the achievement of full sensitivity. Thus, the practical utility of a particular study in the matrix of clinical evaluation and subsequent surgical planning is of crucial importance. Appropriate patient selection and education about expected outcomes are vital to identify patients who will have a successful surgical outcome. Ideally, the indications and expectations should be identical in the minds of the diagnostician and the surgeon.

Finally, in many instances, more rigorous study of both diagnostic and surgical procedures is required. It is perhaps the greatest temptation of the clinician scientist to utilize promising techniques or procedures in an effort to alleviate patients' suffering for apparent problems before the techniques have been completely evaluated. Thus the exercise of compassionate restraint may be the greatest challenge facing clinicians today.

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Image-Guided Percutaneous Spine Biopsy

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Prior to the development of imaged-guided percutaneous spine biopsy techniques, an open biopsy procedure was required for definitive diagnosis. The advantage of the open biopsy procedure is twofold. First, under direct visualization multiple, and larger, tissue samples can be obtained and made available for frozen histopathological analysis. Second, the open biopsy can be performed as part of a surgical decompression and/or stabilization procedure of the spine. The first report of percutaneous spine biopsy was in 1935 by Robertson and Ball.¹ Their procedures, however, did not utilize imaging guidance. Siffert and Arkin utilized a posterolateral approach for spine biopsy using radiographic guidance.² Fluoroscopy-guided spine biopsy was subsequently reported in 1969, and CT-guided spine biopsy was reported in 1981.^{3,4} Percutaneous spine biopsy has several advantages over an open biopsy procedure. The percutaneous image-guided procedure is faster and more cost-effective and has an overall lower risk of complications.⁵

Image-guided spine biopsy procedures are usually performed to diagnose suspected primary or secondary neoplastic processes or to evaluate for the presence of infectious spondylitis.⁶ These procedures are less frequently performed to assess for other noninfectious inflammatory conditions that can affect the spine. The decision to perform a spine biopsy procedure is made after close communication between the radiologist and the referring clinician. Both individuals must be convinced that the benefit to be gained from the biopsy results firmly outweighs the risks of the procedure. To this end, as a prerequisite, there must be a thorough medical history and physical examination combined with a complete review of all prior imaging and laboratory examinations. This consultation will avoid unnecessary spine biopsies (when they are not indicated or when a more accessible bone biopsy site, such as the iliac bone, is available), ensure patient safety, and identify the optimal location and level for performing the biopsy procedure.

Spine biopsy is often performed to evaluate destructive or spaceoccupying lesions within the spinal axis (Table 5.1). Abnormal foci of marrow replacement within the vertebral column that are detected

TABLE 5.1. Indications for spine biopsy

- 1. Suspected secondary spine tumor (i.e., metastasis) with either a known or an unknown primary tumor
- 2. Suspected secondary spine tumor, with a history of two or more preexisting primary tumors
- 3. Suspected primary spine or paraspinal tumor
- 4. Pathological compression fracture
- 5. Suspected infectious spondylitis
- 6. Suspected inflammatory condition that involves the spine

with noninvasive imaging modalities, such as computed tomography (CT) or magnetic resonance imaging (MRI), are also often referred for spine biopsy. In every instance, the decision to proceed with a biopsy procedure is based upon a thorough analysis of risks and benefits. The overall benefit of the information gained by the procedure should always favor its performance. The results of the biopsy will affect the subsequent clinical management of the patient and influence treatment decisions in such areas as surgery, chemotherapy, radiation therapy, and antibiotic therapy.

The immediate contraindication to percutaneous biopsy is coagulopathy. Yet even this condition, when properly anticipated and managed, can be corrected long enough to permit a surgeon to perform the procedure. When a vascular tumor such as a renal metastasis is suspected, a catheter angiogram should be considered in the diagnostic workup. These vascular lesions, however, can be carefully sampled with smaller gauge core needle biopsy systems and with fine-needle aspiration techniques (Figure 5.1).

Informed consent must be obtained prior to the procedure after the patient has received an explanation of the benefits and risks of imageguided percutaneous spine biopsy. The procedure offers the benefit of supplying diagnostic information that will guide subsequent treatment decisions. The alternative procedure is an open spine biopsy.

The general risks of percutaneous spine biopsy include bleeding at or deep to the puncture site manifested as active hemorrhage or hematoma formation (Table 5.2). Infection is another potential complication associated with spine biopsy, hence the requirement for strict aseptic technique when the procedure is performed. The spread of disease by the biopsy procedure, an extremely rare complication that has been described,⁷ is related to tumor implantation or spread of infection along the biopsy tract.⁵ The development of coaxial biopsy techniques and transcortical approaches with shorter needle trajectories has decreased the incidence of these complications. Site-specific biopsy complications that have been reported are related to the spine level (cervical, thoracic, or lumbar spine) that was sampled and the proximity to critical structures. Pneumothorax can occur not only during thoracic spine biopsy but also during the attempted biopsy of thoracolumbar or cervicothoracic lesions. Neural injury, particularly to the spinal cord, is a devastating complication that has been reported. Nevertheless, the incidence of reported complications in percutaneous skeletal biopsy is low, estimated at less than 0.2%.⁵ The combination



FIGURE 5.1. Axial CT image shows a lytic lesion (arrows) that is centered primarily within the posterior elements of the thoracic vertebra. Since the patient had a history of kidney resection, this lesion was sampled by fine-needle aspiration with a 22-gauge spinal needle. A single pass showed positive cytology for metastatic renal cell carcinoma.

of image guidance, small-gauge biopsy needle systems, and operator experience should result in an overall major complication rate that is much less than 1%.

Patient Preparation

Percutaneous spine biopsy can be performed either on an inpatient or outpatient basis. The patient must not eat or drink for a minimum of 8 hours prior to the procedure. The following laboratory parameters are assessed at our institution: hematocrit, hemoglobin, platelet count, prothrombin time (PT), partial thromboplastin time (PTT), international normalized ratio (INR), blood urea nitrogen (BUN), and creatinine. Patient allergies are recorded, with particular attention to anesthetic agents and imaging contrast agents. Prior to performing the

- TABLE 5.2. Complications associated with spine biopsy
- 1. Active hemorrhage
- 2. Hematoma
- 3. Vascular injury
- 4. Neural injury (spinal cord or nerve) resulting in transient or permanent paralysis
- 5. Pneumothorax
- 6. Infection, including meningitis

biopsy procedure, the operator should carefully scrutinize all pertinent imaging studies. This will help identify the optimal lesion(s) for biopsy and the safest approach to access the lesion(s). Furthermore, this preprocedure evaluation can assist in the selection of the appropriate needles and imaging modality.

Percutaneous spine biopsy can be performed with local anesthesia, with local anesthesia and conscious sedation, or under general anesthesia. The procedure is often performed with a combination of local anesthesia and intravenous conscious sedation using a short-acting benzodiazepine (Versed) and an analgesic such as fentanyl or morphine. While general endotracheal anesthesia is often not utilized owing to the requirement for prone positioning of the patient, general intravenous anesthesia can be performed with propofol. To minimize the possibility of infection, the study should be performed with strict aseptic technique.

Patient positioning depends upon the spine level (cervical, thoracic, or lumbosacral) of the lesion and its location (vertebral body vs posterior elements). The prone position is optimal for accessing lesions in the thoracic or lumbosacral spine or, rarely, within the posterior aspect of the cervical spine. The supine position is usually required to access the cervical spine. In certain instances—for example, when a patient cannot lie completely prone—the lateral decubitus or prone oblique position can be helpful (Figure 5.2). Patient monitoring is performed with the help of a pulse oximeter, continuous electrocardiography, and



FIGURE 5.2. Axial CT image obtained during a thoracic spine biopsy performed with the patient, who could not tolerate the prone position, in a prone oblique position. A transcostovertebral approach (arrow) was used, and the lesion was subsequently shown to be an osteoporotic compression fracture.

an automated blood pressure cuff. Appropriate placement of the monitoring equipment is required so that it does not obscure the field of view during the procedure and does not contaminate the sterile field. An intravenous catheter should also be in place prior to the procedure to facilitate the intravenous administration of medications, contrast agents, or hydration. The antecubital fossa should be avoided in situations that require prone positioning of the patient: the patient's elbows are often flexed in this position, and the intravenous catheter function can be compromised.

Equipment Requirements

Image guidance can be accomplished with several different modalities. These include fluoroscopy, computed tomography, computed tomography combined with a multidirectional fluoroscope, computed tomographic fluoroscopy, and magnetic resonance imaging.⁸ The choice of equipment is determined by its availability, operator preference, and by the location and size of the suspected lesion. A CT-guided spine biopsy can be performed without or with the use of a stereotactic apparatus to guide the insertion of the biopsy needle.^{9–11} The use of MRI requires the simultaneous use of MR-compatible equipment, both for patient monitoring and for performing the biopsy procedure.

The modality selected depends upon its availability and the training and experience of the operator. The cross-sectional modalities afford the advantage not only of precise lesion localization but also of "critical" structure (e.g., lung, aorta, carotid artery) identification. In experienced hands, however, fluoroscopy-guided biopsies tend to be performed more quickly and with good patient safety. For cervical spine biopsy, CT, fluoroscopy, or CT with fluoroscopy facilitates the selection of an optimal biopsy trajectory that yields access to the lesion but avoids critical neck structures. Numerous factors influence the total procedure time, but the average time using local anesthesia is approximately 30 minutes. This assumes that the patient is cooperative and that the radiologist and the radiology technologist are experienced in biopsy procedures.¹²

Several biopsy needle systems are commercially available (Table 5.3). The system that is utilized depends upon the lesion type (soft tissue or osseous), the lesion location (vertebra, disc space, paraspinal soft tissues), and the method of specimen acquisition (aspiration biopsy vs core biopsy). Aspiration biopsy can be performed with a 22- or 20-gauge stylet-bearing needle. Core biopsy can be performed with a trephine or beveled tip (usually 11-, 12-, or 14-gauge) bone biopsy needle or a soft tissue–cutting needle (usually 18 gauge) (Figure 5.3). These core biopsy needles can be used as part of either a tandem needle system or a coaxial system. In the tandem tachnique, the needle that is used in the initial application of local anesthesia both localizes the lesion and serves as a visual guide. In a simultaneous tandem system, the biopsy needle is placed alongside a thin needle that was previously placed to anesthetize the biopsy tract. In a sequential tandem system,

System	Manufacturer or city
Aspiration	
3.5–6 in. 18- to 22-gauge spinal needles	Becton-Dickinson, Rutherford, NJ
10–20 cm 22-gauge Chiba needles	Cook Co., Bloomington, IN
Cutting Tru-cut	
Trephine Craig Ackermann Elson Franseen Geremia Jamshidi Parallax	

TABLE 5.3. Some commercially available biopsy systems

the biopsy needle is advanced along a tract previously created by the smaller anesthetizing needle.

Coaxial needle systems have increased in popularity.¹³ The biopsy needle is advanced over the anesthetizing and localizing needle (22 gauge). The localizing needle has a removable hub and serves as a mechanical guide for the biopsy needle. A guiding cannula, through which multiple biopsy needle passes can be made, is left in place. Coaxial biopsy needle systems are particularly helpful for cervical spine biop-



FIGURE 5.3. An 18-gauge soft tissue–cutting needle (arrow) is used to obtain a core of soft tissue from this large paraspinal mass that erodes the lateral margin of the vertebral body.

sies. The major advantages of the coaxial system, therefore, are a decreased procedure time, resulting from better accuracy, and decreased procedure complications. Only a single biopsy tract is used with the coaxial system, thus avoiding the risk of additional soft tissue structure injury associated with a second pass. Additionally, the guiding cannula can serve as a guide for fine-needle aspiration prior to core biopsy, or for obtaining multiple core biopsy samples with a soft tissue–cutting needle. An 18-gauge spring-loaded biopsy needle is used to obtain soft tissue cores. Accessory guidance systems have been developed to facilitate needle localization. These vary in complexity and are infrequently used in routine practice.

Biopsy Techniques

An important decision that is made before and during spine biopsy is the choice of approach. The determinants for the approach are lesion location and lesion size (Table 5.4).¹⁴ A posterior approach is used for thoracic, lumbosacral, and posterior cervical lesions. An anterior approach is used for most cervical spine biopsies. The location of "critical" normal anatomical structures will also modify the approach. Unless the lesion is clearly localized to the left side of the spine, for example, a right-sided approach is preferable to a left-sided approach for accessing thoracic spine tumors without damaging the aorta. In the cervical spine, the critical structures include the great vessels of the neck, the pharynx and hypopharynx, the trachea, the esophagus, the thyroid gland, the lung apices, and the spinal cord. In the thoracic spine, the critical structures are the lungs and the aorta. In the lumbar spine, the critical structures are the aorta, inferior vena cava, kidneys, large and small bowel, conus, and exiting spinal nerves. The objective is to choose a trajectory that enables access to the lesion without compromising normal, critical structures (Figure 5.4).

The specific location of the lesion within the spine will also influence the approach that is selected. A vertebral body lesion and a posterior element lesion (Figure 5.5) will be approached differently. The type of posterior approach (posterolateral, transpedicular, or transcostovertebral)

Location	Approach	Spine level
Bone	Paraspinal oblique	
	Transpedicular	Thoracic or lumbar
	Transcostovertebral	Thoracic
	Posterolateral	Lumbar > thoracic >> cervical
	Anterolateral	Cervical
Disc	Paraspinal oblique Posterolateral Anterolateral	Thoracic or lumbar Cervical
Paraspinal	Paraspinal oblique	
Soft tissues	Posterolateral Anterolateral	Thoracic or lumbar Cervical

TABLE 5.4. Biopsy approaches



FIGURE 5.4. Axial CT image shows a localizing needle adjacent to the right pedicle (long arrow) of a lumbar vertebra. A transpedicular approach was chosen to access the most proximal (small arrow) of three sclerotic lesions in a patient with a history of breast cancer.



FIGURE 5.5. Axial CT image shows an expansile lytic lesion within the right transverse process and posterior vertebral body of this thoracic vertebra. Fine-needle aspiration of the right transverse process (arrow) was therefore performed with a 22-gauge Chiba needle.





can be tailored to the specific location of the lesion (Figure 5.6). The posterolateral approach can be used to access lesions located within the vertebral body, disc, or paraspinal soft tissues of the lumbar spine (Figures 5.7 and 5.8). The transpedicular approach can be used to safely access lesions within the thoracic or lumbar vertebrae. A transcostovertebral approach can be used for thoracic disc space lesions, thoracic paraspinal soft tissue masses, or vertebral body lesions (Figure 5.9).

The selected imaging modality is used to identify the lesion level (Figure 5.10). Once a safe path to the target lesion has been chosen,



FIGURE 5.7. Axial CT image obtained during a disc and vertebral endplate biopsy (arrow) shows a bone biopsy needle inserted via a left posterolateral approach.

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FIGURE 5.8. Axial CT image shows a left parapedicular approach (arrow) used to sample this destructive vertebral body lesion.



FIGURE 5.9. Axial CT image shows a right transcostovertebral approach (arrow) used to sample this destructive vertebral body lesion (fungal osteomyelitis).



В

FIGURE 5.10. Steps in a CT-guided biopsy. (A) To use a right transpedicular approach (long black arrow), the skin entry site must be located near the second skin marker (white arrow). (B) The guide needle is advanced to the posterior margin of the pedicle (arrow).



FIGURE 5.10. *Continued*. (C) The bone biopsy needle is advanced through the pedicle to sample the right-sided lytic lesion (arrow).

the entry site on the skin surface is marked with an indelible ink marker. The region of interest is then prepped and draped in sterile fashion. A 1 cm wheal is raised at the skin entry site by using a 25gauge needle and a local anesthetic agent (e.g., 1% lidocaine, 0.25% bupivacaine). A #11 scalpel blade is used to make a dermatotomy incision at the skin entry site. A stylet-bearing thin needle is then advanced by means of image guidance, and the local anesthetic is then administered into the deeper soft tissues. If a vertebra is to be entered, infiltration of the anesthetic agent into the periosteum is extremely helpful in minimizing patient discomfort. With coaxial technique, the position of the needle tip relative to the lesion is adjusted and confirmed by means of image guidance. When the needle tip is in satisfactory position, the needle hub is removed and the needle then essentially serves as a stiff guidewire. A guiding cannula is inserted over the hubless needle and advanced to the desired level under image guidance. Aspiration or core needles can be passed through this guiding cannula to obtain specimens.

The needle tip must always be accounted for with respect to the target lesion and to all pertinent critical structures (Figure 5.11). This rule applies especially to cutting needles whose biopsy chamber requires additional exposure and excursion within the lesion matrix to enable the cutting portion of the needle mechanism to slide over the biopsy chamber and retrieve the specimen. Moreover, specimen retrieval by



FIGURE 5.11. Axial CT image obtained during a bone biopsy shows a guide needle that reaches the anterior vertebral body cortex (large arrow). Note the proximity of this needle to the aorta (arrowhead). The guide needle had been advanced far beyond the target lesion (small arrow).

means of fine-needle aspiration requires an in and out motion within the lesion matrix. Failure to completely account for the position of the needle tip may result in an unsuccessful biopsy, and may also injure a critical structure. To access bone marrow or a lytic lesion with an aspiration or cutting needle, a preexisting bone window must be present within the vertebral cortex, as occurs with a lytic focus, or a cortical window must first be cut with a bone needle. Neither aspiration nor cutting needles will penetrate normal or near normal bone cortex.

Cervical spine biopsy often requires an anterolateral approach.¹⁴ The neck can be separated into suprahyoid and infrahyoid compartments (Figure 5.12). The location of the carotid space contents within these compartments and the location of the spinal lesion will determine the skin entry site for the biopsy (Figure 5.13). Other important structures that are to be avoided include oropharynx, hypopharynx, and visceral space contents (esophagus, trachea, thyroid gland). In approaching lower cervical spine lesions, care must be taken to avoid the pulmonary apex. In addition to being constantly aware of the location of the location of the vertebral artery. When in doubt about the location or identity of a potentially important vascular structure, administer an intravenous contrast agent to clarify the situation.

The trajectory can be anterior or posterior to the carotid space, depending on the location of the great vessels. A 22-gauge needle can be used to go safely beside these structures with CT guidance. Alterna-



FIGURE 5.12. Location of the prevertebral and paravertebral spaces within the suprahyoid (A) and infrahyoid neck (B). Note the anterolateral position of the carotid space (arrows) relative to the prevertebral space.



В

FIGURE 5.13. Steps in a CT-guided biopsy of the cervical spine. (A) Skin markers (a set of four taped 18-gauge 1 in. needles) are placed for an anterolateral approach with the patient in the supine position. The soft tissue window algorithm is used to identify the carotid artery (arrow) and internal jugular vein (arrowhead). (B) Coaxial technique is used to advance a needle with a removable hub, through a short 18-gauge needle, past the carotid artery (white arrow) and adjacent to the abnormal cervical vertebra (black arrow).



FIGURE 5.13. *Continued.* (C) A bone cannula is safely advanced over the wire. A trephine needle (arrow) is advanced into the substance of the vertebral body to obtain a core of bone.

tively, some operators prefer to use palpation and carotid displacement during the initial needle placement, to bypass the carotid artery. This maneuver is often performed with fluoroscopy-guided biopsy procedures. Once the needle tip has passed beyond the carotid space and is near the target, a coaxial technique can be used to safely obtain multiple biopsy specimens. A posterior approach is occasionally required for accessing posterior element lesions. Given the relatively small size of the posterior elements and the proximity to the spinal cord, it is advisable to utilize CT for safely approaching and sampling lesions in this location.^{14a}

For thoracic or lumbar spine lesions, a transpedicular approach is optimal for accessing centrally located vertebral body lesions (Figure 5.14). The pedicle provides a safe passageway to the vertebral body. Special care must be taken to avoid fracturing the pedicular cortex. This complication can cause either direct injury to the spinal cord or exiting nerve root, or can indirectly injure these structures by leading to hematoma formation. The margins of the pedicle should be visualized at all times while the biopsy needle courses through the pedicle. A potential pitfall of the transpedicular approach, which occurs when the pedicle is not involved by tumor, is the possibility of obtaining a false negative biopsy result. The solution in such cases is to take deeper and multiple samples.

The transcostovertebral approach is useful in accessing laterally located thoracic vertebral lesions or in sampling the thoracic disc.¹² The



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FIGURE 5.14. Steps in a CT-guided biopsy of the thoracic spine. (A) The patient is in the prone position and skin markers (arrow) are placed to determine the optimal skin entry site. (B) A 1.5 in. 22-gauge needle is used to administer local anesthetic along the biopsy tract to the periosteal surface (arrow). (C) The sequential tandem technique is used to replace the 22-gauge needle with a 12-gauge bone needle, which is gradually advanced through the pedicle (arrow) and into the vertebral body under imaging guidance.



FIGURE 5.14. *Continued.* (C) The sequential tandem technique is used to replace the 22-gauge needle with a 12-gauge bone needle, which is gradually advanced through the pedicle (arrow) and into the vertebral body under imaging guidance.

posterolateral approach is ideal for accessing laterally located vertebral body lesions or their paraspinal soft tissue components or the intervening disc space within the lumbar spine. Two, preferably three, core specimens are obtained and placed in 10% formalin. When bone biopsy cores are obtained, they must undergo a period (approximately 48 hours) of decalcification in 7% formic acid, whereupon the specimens are embedded in paraffin for subsequent histological sectioning and staining. The reported diagnostic accuracy of core biopsy ranges from 77 to 97%.¹⁵ If the clinical concern is infection, the specimens are placed in sterile containers and immediately brought to the microbiology laboratory for appropriate processing.

When aspiration biopsy is anticipated, it should be performed prior to obtaining any core specimens, since the core biopsy can create a hemorrhagic tract that prevents successful aspiration of the desired abnormal tissue.¹⁵ Otherwise, a different tract to the lesion must be utilized. Successful aspiration biopsy requires a secure fit between the aspirating syringe and the needle hub to facilitate forceful suction. Full negative pressure is generated by using a 20 mL syringe while the needle is being advanced and retracted within the lesion.¹⁶ The distance of the needle excursions depends upon the lesion size; large lesions permit safer, longer excursions, and short excursions are required for small lesions adjacent to critical structures (Figure 5.15). Needle excursions extending more than 3 to 4 mm are required to obtain a specimen.¹⁷ Slight adjustments in angulation, when possible, are made with each needle pass to increase the yield of pathological tissue.¹⁷



FIGURE 5.15. Axial CT image shows a large right paraspinal mass (arrows) that erodes into the lumbar vertebra. The size of this mass permits long excursions of the biopsy needle during fine-needle aspiration.

A flash of hemorrhagic fluid within the needle hub usually signals the end point of aspiration. In the ideal situation, the needle and syringe are withdrawn from the spinal lesion and this ensemble is immediately handed to a cytotechnologist, who prepares slide smears of the specimen. The technologist or a pathologist looks at the slides under a microscope and determines whether abnormal cells are present within the specimen. Alternatively, the biopsy specimen can be placed in 95% ethanol before being sent for cytological analysis. The published accuracy of aspiration biopsy is series dependent and ranges from 23 to 97%.¹⁵ When infection is the working clinical diagnosis, the aspirates are not placed in ethanol but instead are submitted in sterile containers to the microbiology laboratory. If fluid cannot be aspirated, a few milliliters of sterile, nonbacteriostatic normal saline can be injected through the biopsy needle and reaspirated for subsequent microbiological analysis. Aspirates obtained following core biopsies can also be sent for microbiological analysis: there is always bleeding at the core biopsy site, so that blood can be aspirated and placed in a sterile container.

Alternatively, the aspiration biopsy can be performed prior to the core biopsy procedure. These two techniques have been shown to be complementary and to increase the diagnostic accuracy of the percutaneous biopsy procedure.¹⁵ The histological features of cell structure and microarchitecture may provide a specific cytological diagnosis. A positive fine-needle aspirate can obviate a more aggressive biopsy procedure, thereby reducing the likelihood of a procedure-related complication (Figure 5.16). Furthermore, the core biopsy can also be used

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to produce a touch preparation for immediate cytological analysis.¹⁸ These procedures in combination can minimize the possibility of obtaining a specimen too small for analysis. A spine biopsy procedure may be discontinued when a positive aspirate is identified by the cytopathologist, or when a set of three fine-needle aspirations and three



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FIGURE 5.16. Intraspinal biopsy. Fine-needle aspiration technique was used to sample (A) a cystic astrocytoma (arrow) of the spinal cord and (B) a solid astrocytoma drop metastasis within the lumbar spinal canal (arrow).

bone and/or soft tissue cores has been obtained. Other factors, such as small lesion size, limited lesion access, or the occurrence of a complication may require discontinuation of the biopsy procedure at the discretion of the operator.

Specific instances do occur in which percutaneous biopsy may be unsuccessful, yielding either no specimen or one that proves to be nondiagnostic. The bony elements of the vertebrae consist of round, hard surfaces. Securing purchase on their normal hard cortex can be difficult when the target lesion lies deep to normal bone. Sclerotic or osteoblastic lesions can be quite difficult to sample (Figure 5.17).⁷ At the other end of the lesion spectrum are heterogeneous lesions that are predominantly either cystic or necrotic. Despite multiple attempts, it may not be possible to harvest a satisfactory specimen from these lesions. Lesions with variable histology from one area to another, such as cartilaginous tumors, can also cause a diagnostic dilemma. Fortunately, these diagnostic challenges are infrequent. More often, one is unable to retain a specimen within the bone biopsy needle chamber after successful entry into the substance of an osseous lesion. Several maneuvers can be attempted to obtain a specimen. Slight, gentle rocking of the needle may allow separation of the specimen from the parent bone. If the lesion is large enough and there is a margin of safety, then advancing the biopsy needle slightly may enable retention of the bone core within the chamber of the biopsy needle. Applying suction to the biopsy needle with a 20 mL syringe may also facilitate a successful biopsy. Some single-pass bone biopsy needles come with an inner cannula that is partially truncated near its tip to trap the bone core within the parent needle chamber. Alternatively, if the sample size remains unsatisfactory for diagnostic purposes, a larger gauge needle system such as the Craig system can be used to obtain a specimen (Figure 5.18).

Other reasons for a nondiagnostic result include biopsies that are limited either by small lesion size or because too few passes were made with the biopsy needle. Hypervascular lesions can be difficult to sample, since the brisk bleeding that can potentially occur with the initial access to the lesion can terminate the procedure. The intraosseous blood that is often aspirated during bone biopsy is sometimes erroneously discarded. This osseous blood should be considered to be a biopsy specimen and submitted for pathological analysis, since it is possible to diagnose malignancy from this tissue.¹⁹ Occasionally, a discrepancy in accounting for vertebral levels between different modalities causes the wrong vertebral levels to be sampled. Many spine lesions are identified on MRI, yet the percutaneous biopsy procedure is performed either with fluoroscopy or with CT. In certain situations, lesion conspicuity may be so much decreased with the latter modalities that optimal sampling is compromised. With respect to infectious spondylitis, the common reason for a nondiagnostic biopsy result is that patients are already being treated with antibiotics at the time of the procedure. Other reasons for a nondiagnostic biopsy result in spine infection include a failure to perform the correct microbiological testing, such as not performing an acid-fast bacillus stain or culture, dismissing as contaminants unusual microbes that may in fact be the

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FIGURE 5.17. (A) Axial CT image obtained during a cervical spine biopsy of a sclerotic vertebral body lesion (arrow) shows a guide needle in place. (B) The bone needle deflected across the hard surface of this sclerotic lesion and was advanced into the opposite side of the vertebral body. The needle tip is located just medial to the foramen transversarium (arrow) and anterior to the right neural foramen. The patient did not experience any adverse sequelae despite this suboptimal needle placement.



FIGURE 5.18. Axial CT image demonstrates a Craig bone biopsy needle with its tip located in the substance of a lytic endplate lesion (arrow). Smaller gauge needles were unable to provide satisfactory amounts of tissue.

causative agents, improper specimen handling or transport (e.g., not using anaerobic culture media when these organisms are suspected), or failing to follow specific cultures (e.g., *Mycobacterium tuberculosis*) for an extended period of observation.

To optimize the success of the biopsy procedure, the radiologist must communicate his or her clinical concerns to either the pathologist or the microbiologist. In the case of a suspected neoplasm, the clinical information and the radiological differential diagnosis should be communicated to the interpreting pathologist. The more useful the data shared with the pathologist and/or the microbiologist, the greater the likelihood of arriving at the correct diagnosis. (This is the equivalent of a radiologist's request for the appropriate clinical history from the referring clinician whenever imaging studies are to be performed or interpreted.) For instance, if a patient is undergoing a biopsy to test for possible metastatic breast cancer, it is helpful to inform the pathologist that the woman had a mastectomy last year at the same institution. Similarly, it is important to inform the microbiologist whether the patient is already on intravenous antibiotics or that a specific organism, such as *Mycobacterium tuberculosis*, is causing concern.

Postoperative Care

Immediately following the procedure, a sterile dressing is placed over the skin entry site(s). The patient is observed in recovery for 2–4 hours, depending on the type of anesthesia that was used. Monitoring of the patient including vital signs is continued during the recovery period. The puncture site is periodically observed for signs of active bleeding or for expanding hematoma. Strict bed rest is maintained throughout the recovery period. When the patient is judged to be stable, either by the radiologist who performed the procedure or by the anesthesiologist who sedated the patient, he or she is discharged from the recovery area: an outpatient goes home, an inpatient to a hospital room. An instruction sheet with attention to wound care and observation should be given to all outpatients. All patients should be informed that the test results might not be available for several days owing to specimen processing requirements. More important, patients should also be made aware of the small, but real possibility that the test results may be nondiagnostic, whereupon a repeat percutaneous biopsy or an open biopsy may be required. Adequate follow-up on all biopsy procedures is essential, and the final results should be communicated to the referring clinician(s).

Conclusion

Image-guided percutaneous spine biopsy is a procedure that can be performed safely and efficiently by radiologists. The procedure is performed to determine accurately the composition of abnormal tissue. The information obtained from the biopsy procedure can be used to guide patient management. The radiologist is part of a team that includes the patient, the referring clinician, and a pathologist. Optimal communication among the team members will increase the likelihood of a successful procedural outcome.

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6

Discography

Kurt P. Schellhas

Technological improvements in spinal imaging and interventional techniques have led to increased understanding of the origins of spinal pain. Magnetic resonance (MR) imaging provides us with variable sensitivity in detecting extramedullary spinal pathology, depending upon the anatomical region under study (cervical, thoracic, or lumbar).^{1–23} Degenerative changes involving multiple spinal structures (discs, facet joints, ligaments, vertebral bodies, and musculature) at multiple spinal segments (multisegmental disease) are commonly observed with high-quality MR imaging. The existence of visible (imaging studies) multistructural and/or multisegmental degeneration has led to increasing demand for more definitive spinal injections to elucidate the significance of imaging observations relative to clinical complaints and/or physical findings. Discography in particular has been the focus of increased clinical utilization and scientific investigation.^{1,3–5,7,9,11–21,25–31,32–42}

The concept of spinal disc internal derangement⁹ with or without discogenic pain has gained widespread international recognition as a result of research that has correlated disc pathology observed on MR imaging with discography in both lifelong asymptomatic subjects and nonlitigious chronic pain sufferers.^{5,17,22,40} These investigations have revealed the limitations of MR imaging in the evaluation of spinal origin pain. Sensitivity to MR procedures has been proven to be low in the detection of symptomatic internal disc disruption and annular tears in the thoracic region²² and even worse in the cervical spine.^{18,19}

When one is evaluating pain and/or disability of suspected spinal origin, it is of critical importance to accurately diagnose the precise origin(s) of pain and structural derangement.^{43–45} It is equally important to evaluate the significance of pathological findings on imaging studies and whether they correlate with symptoms. Discography is used in the lumbar,^{1,5,9,16,30,35–37,40,41,43} thoracic,^{15,22,23} and cervical^{10,17,18,28} regions to assess pain that is suspected to be of discogenic origin. Formal investigations have shown that discography performed by skilled, knowledgeable, and experienced proceduralists can substantially im-

prove both surgical and nonsurgical treatment outcomes.²⁶ Clinical questions to be answered by^{12,13} discography include the following.

- 1. Whether disc or vertebral body endplate pathology observed on imaging studies of clinical significance?
- 2. To determine if therapeutic intervention is indicated, and if so, what type of therapy (surgical or nonsurgical)?
- 3. If surgical intervention is a consideration, what spinal segments and structures may need to be dealt with? Also, the choice of operative procedure will be influenced by the results of discography. Is a satisfactory surgical outcome possible?
- 4. What is the ultimate prognosis?

Technical Considerations

Discography must be performed safely and accurately, and the results must be reproducible. To achieve these objectives, discographers must be thoroughly knowledgeable in spinal anatomy and pathology, fluoroscopic imagery, radiological equipment, and radiological/fluoroscopic projection. Most interventionists and procedurally oriented neuroradiologists can easily adapt to the requirements of this procedure. Discography should ideally be performed with a high-resolution, multidirectional, C-arm fluoroscopic device with magnification and a tilting fluoroscopic table with a movable top. For discography in the cervical and thoracic regions, the multidirectional C-arm and movable table are requirements.^{15,17,18,22,28}

Discitis is a serious potential complication of discography,^{29,31,44} which, in the author's opinion, merits the use of antibiotics unless contraindicated owing to allergy. In the past 8 years, and in our last 8000 and counting discograms, in the absence of an allergy to either cephalosporins or penicillins (and no knowledge of prior cephalosporin use), we have routinely used an intradiscal antibiotic (Cefazolin) that covers *Staphylococcus aureus*.^{12,18} Clinical experience (not formally investigated) suggests that the risk of disc infection is reduced with the use of intradiscal antibiotics. We mix 1 g of Cefazolin in 10 mL of sterile saline with approximately 45 to 50 mL of nonionic, low osmolar contrast agent. This can also be mixed at the time of each individial case, as a mixture of 9 to 10 mL of Iohexol with 2 mL (200 mg) of Cefazolin. Antibiotic should not be put in the contrast if there is a chance of a dural puncture as Cefazolin will cause seizure.

Sedation

Our experience has been that conscious sedation and/or anesthesia are needed only rarely for this procedure.¹² In the hands of a skilled proceduralist and experienced technical staff, discography is performed routinely on fully alert, unsedated ambulatory outpatients in a short period of time (10–45 minutes, depending upon the number of discs studied). Since the patient's perceptions and response(s) are the main

focus of this test, the patient should be alert and able to communicate during the procedure. In isolated circumstances, however, conscious sedation may be advisable for selected patients who are agitated, have physical limitations, and/or who are in such extreme pain that any added stress might limit their ability to cooperate.³⁹

Lumbar Discography

Various techniques have been described for lumbar discography. In our practice and experience,^{12,13} patients are placed prone on a tilting fluoroscopic table having a multidirectional movable top and rotational tilt. Either foam pillows or pads are placed beneath the upper abdomen and lower chest both to reduce lumbar lordosis and to elevate the side of the patient into which we will be introducing the needle(s). We advise needle introduction from the side opposite the area under investigation if the patient's pain is clearly lateralized. In cases of midline and/or bilateral pain, the side of needle placement can be based upon individual preference and circumstances.

When the patient has been positioned, fluoroscopy is performed with the C-arm to identify the route of optimal access for needle placement into each disc. We usually mark the lumbosacral disc access route first (assuming that it is to be studied), since this disc proves to be the most challenging level in most individuals. Typically, the C-arm is rotated approximately 30 to 45° away from the midline and 10 to 45° cephalad to visualize this optimal route directly into the lumbosacral disc. Upper lumbar discs (above L3-4) generally require caudal angulation of the fluoroscopic access route. Dorsolateral fusions and/or instrumentation can be very challenging with a dorsolateral approach. Some with fusions may require a midline or paramidline transdural approach, all to be determined fluoroscopically prior to sterile preparation, draping, and needle introduction.

After a route to the disc has been identified, the patient's skin is indented with a device that will leave a small, lasting skin imprint that will be recognizable after skin cleansing and the application of drapes. Many C-arms, including some of the ones we operate, have an optional laser light to assist with needle guidance. We still indent the skin prior to needle introduction, since patients often move slightly as the procedure begins.

It is vital to thoroughly cleanse a wide area of the patient's skin with either iodine solution or an iodine-free soap (if allergy to iodinated compounds exists), to make sure that the disinfectant enters small cracks and pores. Most documented cases of postdiscography discitis are due to the introduction of skin and/or dermal appendage bacterial contaminants (*Staphylococcus aureus/epidermitis* primarily). If iodine solution is utilized, it needs to be left on the skin for at least 2 minutes prior to alcohol rinse to exert optimal bactericidal affect.

After disinfectant solutions have been applied to the skin, contrast and other injectable media are drawn up. We employ the low osmolar, nonionic contrast solutions (e.g., Iohexol, 240 mg/mL), unless contrast allergy exists. We draw up 10 to 12 mL (mixed with Cefazolin unless allergic) into a 10 to 12 mL syringe for a lumbar discogram. If more than three levels are to be studied, and/or if degeneration of multiple segments is noted on imaging studies, we may draw up a second syringe in advance. If there is allergy to iodinated compounds, we use either sterile saline (with or without Cefazolin) or intradiscal Gadolinium mixed with sterile saline in a mixture of 0.15 cc Gadolinium into 30 cc sterile saline. We perform MR immediately after these cases where we inject intradiscal Gadolinium and saline. After we have drawn up our injectable solutions, the skin cleansing solution is rinsed from the patient's skin with alcohol, a sterile, fenestrated drape is placed over the prepared site, and the procedure is begun.

Both single-needle and coaxial, two-needle techniques have been described. Having tried both techniques, we now use a single, 3.5 to 8 in. (depending upon patient size) 22-gauge spinal needle for dorsolateral placement on all our patients. If we are forced to perform a transdural approach, we will use either a single, 26-gauge or 25-gauge needle of 3.5 to 5 in. We have found the coaxial technique to be unnecessary. It makes for a slower procedure, and may (not proven however) increase the risk of infection. We believe that procedural speed is vitally important at each disc level studied. Our needles are usually inserted for only 1 to 3 minutes each. As soon as each disc has been injected, filmed, and later anesthetized (if necessary), the needle is removed.

When approaching a lumbar disc obliquely, we most often use a 22gauge, 5 in. spinal needle; however, 6, 7, and 8 in. needles are also used, depending upon patient dimensions. Following skin puncture, the needle is incrementally advanced along the fluoroscopic access to the inferior margin of the disc to be punctured. Live fluoroscopy during needle advancement is unnecessary. Instead, the needle is advanced incrementally, with intermittent fluoroscopic checks lasting milliseconds, performed with our hands removed from the field, while we stand behind a shield. Directional control of the needle is achieved by bevel rotation prior to and/or during each advancement.

When the needle tip reaches the disc annulus (generally perceived as a firmness), it is firmly advanced 1.5 to 2 cm into the center of the disc nucleus. Fluoroscopy is then rotated typically to either a lateral or anteroposterior (AP) projection (based upon proceduralist preference), to confirm the depth and location of the needle tip within the disc center. Optimally, the needle tip is located as near to the center of the disc as is possible in all dimensions. During advancement of the needle to the external annular margin, it is relatively common to either hit or irritate a traversing lumbar nerve root, especially at L5-S1, where the route of access is small. If a nerve is inadvertently hit or irritated, the needle should be withdrawn slightly and repositioned, if possible, in an attempt to avoid the nerve. By inserting the spinal needle from the site opposite the clinical pain under investigation, one can avoid unintended provocation of pain closely resembling the pain under investigation, which could cause confusion in the interpretation of the response at this level.

Following needle placement, contrast agent is injected under live fluoroscopic observation. In cases of contrast allergy, exposures of the disc should be obtained in both AP and lateral projection prior to the introduction of sterile saline (with or without Gadolinium). When contrast is used, films need not be obtained until contrast injection has taken place. While the discographer observes the disc on the fluoroscopy monitor, the assisting technologist(s) carefully observe(s) the patient for any signs of pain perception. The disc is injected either to capacity or until extradiscal leakage of contrast is observed (Figures 6.1–6.6). If sterile saline is being used, injection continues until one of the following occurs.

- 1. An end point is reached, preventing further injection.
- 2. Pain manifestations are observed.
- 3. At least 4 mL of saline has been injected, indicating leakage.

Frequently observed sites of contrast leakage include the epidural space (Figure 6.2C), vertebral body medullary space, paraspinous veins (Figures 6.2B and 6.5A), paraspinous tissues (Figure 6.2B), and the epidural veins (Figure 6.5B). It is crucial to adequately inject each disc in terms of volume. A typical intact lumbar disc (Figure 6.1A,B) will accept approximately 1.5 to 3.5 mL of fluid, depending upon the size of the individual and state of the disc. If no leakage is observed, the disc should be injected to at least 4 to 5 atm of pressure (120-150 mmHg if a manometer is being employed), provided that this distention is not painful. Adequate distention of an intact, or nonleaking disc is required, since only with annular distention is a reliable sensation provoked in most circumstances (mechanically sensitive discs). In normal discs, either no sensation or "pressure" is the perception most often described during injection. If the patient describes or manifests obvious pain or distress, the injection is voluntarily terminated. The total volume of injected material is recorded (along with injection pressure if manometry is employed), injection end-point characteristics are recorded (leakage, gradual, or firm), and if leakage is observed, the sites of leakage are recorded by filming. We have observed venous opacification to be present during injection of most discs (lumbar, thoracic, and cervical) harboring fullthickness annular tears. We recommend the filming of each disc during active injection in at least two perpendicular projections, most often AP and lateral. These views will in most cases optimally demonstrate both nuclear morphology and annular pathology that might exist.

Immediately after filming, the patient is questioned about the experience during injection. Patients are asked to describe in detail their perceptions, whether pain, pressure, or no sensation at all. On occasion, patients are asked to draw with a felt-tipped marker on the front and back on a human figure where they perceived the sensation(s). They are asked whether the sensation(s) perceived was/were familiar or unfamiliar (concordant vs nonconcordant) relative to their clinical complaints. Patients are thereafter requested to rate the maximum intensity of the experience on a scale of 0 (no sensation whatsoever) to 10 (extreme pain/pressure). This intensity rating (given as, e.g., 1/10, 8/10), and the concordance versus nonconcordance of the experience FIGURE 6.1. Painless (1/10 nonconcordant pressure) injection into an L1-2 disc exhibiting minimal fissuring; images obtained during distention of the disc with contrast agent. (A) AP projection reveals minimal grade I fissuring (arrows) toward both sides. (B) Disc appears completely normal on lateral projection.



А





FIGURE 6.2. Painfully deranged lumbar discs. (A) AP image obtained during disc injection reveals a grade III-IV tear (arrow) posterolaterally, opposite needle placement. Patient reported 9/10 concordant ipsilateral back, buttock, hip and dorsolateral leg pain. (B) AP and (C) lateral films of the L4-5 disc during injection. Note fullthickness lateral tear (arrow in B) opposite side of needle placement.

A





FIGURE 6.2. *Continued.* On lateral view (C), there is epidural leakage of contrast (curved arrow). Patient reported 8.5/10 concordant central and left-sided back, buttock, hip and leg pain, slightly different from the pain provoked at L5-S1 (A).

during injection, are recorded at this point. It is common for patients to initially describe an extremely painful experience as "nonconcordant" when in fact the pain they experienced was otherwise in a typical location. One must be aware that discography may, and in fact often does, provoke pain that is more intense than the clinical pain under investigation. The discographer must carefully question each patient to determine why an experience is concordant or nonconcordant, since otherwise a true positive (concordant intensity rating of \geq 7/10, with annular tear) disc may be incorrectly recorded as "nonconcordant." Pain that is, in fact, familiar in location but worse than usual should be recorded as "concordant."

If the injection was painful, and the disc exhibited annular pathology and was given a high intensity rating, we often thereafter inject local anesthetic (2–4% lidocaine or 0.5% bupivacaine, 1 to 3 mL in total volume) into the disc prior to needle removal. This injection generally relieves pain within minutes. We have found that injecting a local anesthetic into painful discs decreases the likelihood of producing false positive results later in studies of adjacent discs. The transmission of pain to an already sensitive, adjacent, torn disc can and does



FIGURE 6.3. Painfully deranged L4-5 disc exhibiting a focal grade III posterior tear (straight arrow). Lateral view of L4. Patient reported 7.5/10 concordant central and bilateral back pain. L5/S1 disc fusion with metal cage (curved arrow) in place.

occur and can be decreased or eliminated by administration of intradiscal anesthetic. In some cases, if the painful disc is filled to capacity and no more contrast can be injected, anesthetic injection will be impossible. In isolated cases of this type, subsequent levels may possibly need to be studied (restudied if the results are suspect) at a later date, when the distended disc has completely decompressed, and is no longer painful. We have found that even if the local anesthetic leaks out of the disc and into the epidural space, adjacent levels can be validly studied if this is done within minutes of anesthetic administration. After the initial lumbar disc level has been studied and the results recorded, the needle is removed and the procedure repeated at subsequent levels using the same technique just described.

In our practice, the most frequently requested lumbar discography procedure involves the study of three or four segments, most often L5-S1 upward to and including either L3-4 or L2-3. Experienced surgeons like to define at least one, or in some cases, two pain-free and anatomically normal or minimally deranged levels adjacent to (above and/or below) painfully deranged segments. Postdiscography computed tomography (CT)^{35,45} may be employed upon individual discs; however,



FIGURE 6.4. Painfully deranged L4-5 disc due to endplate infraction (Schmorl's node and arrow). Lateral view obtained during injection of disc. Patient reported 8/10 concordant central low back and sacral pain.

this is not a routine in our practice. Because of the high quality of prior MR imaging studies and of the films we obtained during discography, we have found postdiscography CT to be generally unnecessary. MR imaging follows all cases where intradiscal Gadolinium is employed.

Prior research demonstrates that annular tears, either full thickness or extending from the nuclear space into the outermost portions of the disc annulus, are generally observed in discographically painful discs (Figures 6.2, 6.3, 6.5, 6.6).^{16,45} A morphological scale describing the types and extent of lumbar disc annular tears is presented in Table 6.1. Morphologically normal discs and discs with only internal grade I fissures should not be painful to discographic injection.17,22,40 It is reasonably common to note the provocation of pain from an immediately adjacent, painfully deranged and not anesthetized disc when a normal disc is distended to capacity. It is this important fact that underlies our advocacy of studying suspect discs (abnormal appearance on MR imaging studies), initially followed by the use of intradiscal local anesthetic into painfully deranged discs before control levels are studied. When the abnormal levels first are studied, local anesthetic may be injected into the disc, rendering it pain free for the later study of adjacent segments. We frequently observe a higher intensity response at



FIGURE 6.5. Painfully deranged L4-5 disc with nuclear space–epidural and paraspinous–venous communication. (A) AP and (B) lateral images obtained during active injection reveal opacification of paraspinous (arrows in A) and epidural (arrow in B) veins. Patient reported 10/10 concordant back, buttock, hip and leg pain, ipsilateral to the left-sided tear (opposite the side of needle placement). FIGURE 6.6. Diagnostic (A) and therapeutic (B) discograms in painfully deranged disc with classic high-intensity zone (HIZ) lesion noted on MR (not shown). (A) Lateral film obtained during disc injection reveals full-thickness tear posteriorly and inferiorly (arrow). (B) Lateral view revealing fluid-fluid level following therapeutic intradiscal injection of mixture of water-soluble steroid and local anesthetic. Arrow denotes fluid level between contrast (on left) and therapeutic substances (posteriorly and on right). Film obtained by using horizontal lateral projection with patient prone.







normal-appearing control levels immediately adjacent to painfully deranged discs in comparison to normal-appearing control discs at least one segment removed from the painful and deranged level(s).

Prior investigations^{1,16} have demonstrated a high correlation between lumbar disc annular tears exhibiting a "high-intensity zone" (HIZ) on T2-weighted, high-field MR images, and painful concordant discography. These discs are often "chemically sensitized"^{12,26} and are painful with low-pressure and low-volume injection (Figure 6.6A). Internal disc derangement(s) with endplate infraction(s) (Schmorl's nodes) (Figure 6.4)^{3,15,20–22} have been shown to be frequently painful (see later section, "Thoracic Discography"). It must be noted, however, that with the possible exception of lumbar disc HIZ lesions in back pain sufferers, lumbar discographic response is difficult to predict from MR imaging studies.

The study of control level discs warrants discussion. Based upon our experience,^{12,13} it is imperative to complete the procedure by studying at least one control level disc that appears to be either normal or less degenerated than the disc(s) under primary investigation. Control levels should be studied whenever a positive response is provoked at suspicious levels. Without the study of a control disc or discs, the validity of response at the painfully deranged level(s) may be questioned. Observing pain-free response to a normal-appearing control level adds validity to the painful response(s) in comparison to studying only the abnormal disc(s) without control(s). It is equally important in surgery planning²⁵ to discographically study control levels to make sure of internal disc integrity at segments that might become marginal discs, adjacent to a contemplated fusion. In cases of lumbar fusion, the best surgical results are obtained when normal and pain-free levels are present immediately above and/or below the level(s) to be fused. If a first control level proves equivocal, a second control level should be studied. If, on occasion, one encounters a patient response that is either equivocal or unexpectedly high at normal-appearing control levels, the entire study must be viewed with skepticism. In our practice, such patients generally are advised by their clinicians to not have surgery. Based upon formal, prospective investigations of clinical subjects and asymptomatic volunteers, clinically suspect discs that appear abnormal on imaging studies have been shown to be more likely to be painful and concordant and given an intensity rating that is high in comparison to less-diseased or normal-appearing control levels.^{5,40}

Lumbar disc injection pressure has been correlated with pain provocation and with outcomes after discectomy and fusion.²⁶ Discs that are intensely painful with both low pressure (≤ 1 atm, or 33 mmHg) and low-volume injection of either saline or contrast have been defined as "chemically sensitive" (Figures 6.2, 6.5, and 6.6), as opposed to mechanically sensitive discs that must be pressurized to provoke a response (Figures 6.1, 6.3, and 6.4). These pain responses appear to be mediated through chemoreceptors within sensory fibers that have grown into the annular tear itself. Often HIZ lesions (meeting strict radiological criteria) prove to be "chemically sensitized" when studied discographically in symptomatic patients.^{1,16} Although this concept of the "chemically sensitized disc" is valid, it is not a necessity for expe-

 TABLE 6.1. Classification of lumbar disc annular lesions

Grade 0	Normal, intact annulus
Grade I	Fissure/tear involving inner one third of annulus
Grade II	Fissure/tear involving inner two thirds of annulus
Grade III	Tear extending from the nuclear space either into or through the outer one third of the disc annulus, involving up to 30° of the disc circumference
Grade IV	Tear extending from the nuclear space either into or through the outer one third of the annulus, involving greater than 30° of the disc circumference

Source: Refs. 12, 16, 41, 45.

rienced discographers to routinely monitor injection pressures with manometry. It is, however, important to carefully monitor, record, and report when the pain response occurs; if it occurs immediately with injections of low pressure and volume, one can then confidently make the diagnosis of a chemically sensitized disc without having to use special manometric devices.

We have treated and observed patients who received substantial therapeutic benefit of varying duration (weeks to years, including no relapse) from the intradiscal injection of steroid and local anesthetic into painfully deranged lumbar discs.¹² Our experience has been that nonprotruding, chemically sensitive HIZ lesions associated with clinical pain and no neurological deficit are most likely to benefit from this therapeutic intervention (Figure 6.6). When this procedure is performed, we frequently combine it with a diagnostic discogram and initially inject a small amount of contrast medium for provocation, to assure intranuclear needle placement, and to rule out major venous communication with the nuclear space. If the discogram is positive, after filming we inject 1 to 4 mL of a mixture of equal parts betamethasone and lidocaine (2-4%) and/or bupivacaine (0.5%) through the same needle placed for the provocative test. We have performed this procedure in up to three discs at one setting. Our best results, however, have been in individually deranged discs, showing either normal external contour or minimal protrusion and the HIZ lesion. Non-HIZ discs also may respond, as long as a tear either into or completely through the outer annulus exists, permitting the therapeutic substances to directly contact the sensitive nerve endings and/or chemoreceptors, both within and/or immediately adjacent to the painful tear.^{46,47}

Spinal Deformity, Lumbar Fusion, Instrumentation, and Discography

Lumbar discography is being requested and utilized frequently in cases of spinal deformity¹⁴ and/or previous spinal fusion and instrumentation. We frequently perform discography upon patients who have undergone unsuccessful spinal fusion with or without instrumentation (too often without preoperative discography) to assess the presence or absence of discogenic pain at suspect levels and to study the internal integrity of adjacent segments.^{12,13} Spinal fusion with instrumentation is a major endeavor, and an increasing percentage of spine surgeons are required to know about disc integrity before operating on patients for whom fusion, with or without the use of instrumentation, is being considered.

A most unfortunate and potentially avoidable circumstance that we encounter is the patient who has had multiple spinal operations and fusion(s), with or without instrumentation, and still suffers pain and disability.^{12,48} Too often MR imaging may be either impossible to obtain or severely degraded by the hardware in such patients. Furthermore, even if MR images are successfully obtained, disc integrity cannot be adequately assessed in many cases. We have demonstrated hundreds of concordant, intensely painful discs that were left in place when others had undertaken a purely dorsal fusion at the segment.^{12–14} Experience and prior literature^{25,48} reveal that the odds of obtaining a desirable surgical outcome decline significantly with each successive surgical intervention. Discography, when performed upon the fused and instrumented spine, requires special skill and creativity. As in the unoperated back, it is important to study all suspect discs that are accessible and ideally one or two control levels.

We have investigated lumbar fusions performed with interbody metal cage grafts (Figure 6.3)⁴⁹ and found that CT scans cannot reliably determine fusion integrity. Observation of what is commonly referred to as "viable bone" within such grafts does not reliably indicate the presence of solid fusion at that segment, as has been believed. We have often found such "bone" to be soft, permitting us to pass 22-26 gauge needles into and through it with ease. Furthermore, we have injected over 50 of these grafts within symptomatic patients to date, both fused and ununited at the segment(s) under study, and many of these were reported to be intensely and concordantly painful. When these painful cages have been surgically retrieved, the pain has been eliminated.

Thoracic Discography

Discography in the thoracic spine requires a high-resolution, multidirectional C-arm device with filming capability and a tilting table with a movable top.^{12,15,22} Review of previous thoracic MR imaging studies is required prior to the procedure, to rule out the presence of either spinal cord compression or cord deformity at or adjacent to any level to be studied. The discographer must have knowledge of spinal canal dimensions prior to undertaking the procedure. We avoid the study of any segment in which spinal cord compression and/or deformity exists, and we on occasion decline the procedure altogether when we are asked to inject discs deforming the cord and there is accompanying myelopathy. Each case of cord impingement with or without myelopathy must be considered individually.

To perform thoracic discography safely, one must avoid the lung, which is anterior and lateral to the needle route into the disc (Figure 6.7), and the spinal cord, which is dorsal and medial to the route employed.¹⁵

FIGURE 6.7. A. 20° oblique projection revealing the optimal route of thoracic disc access (arrow). Needle passes through the square space between rib head (dot) and thoracic facet joint on left.



The needle is generally directed between 15 and 30° oblique to the AP projection. Each disc access route is determined fluoroscopically prior to skin marking, sterile preparation, and needle introduction. Lower and midthoracic discs can be easily and safely studied in most individuals, while high (T5-6 and above) thoracic discs may be extremely difficult, in some cases impossible, to reach. As one ascends in the thoracic spine, the route of access disappears owing to the shorter disc height and more close approximation of the ribs and costovertebral joints. Such factors as disc height, spinal deformity, and costovertebral and vertebral body osteophytes will affect the accessibility of individual thoracic discs.

In most cases, we employ 25-gauge, 3.5 in. spinal needles for thoracic discography; for large patients, however, a 5 in., 22-gauge needle may be required and is entirely safe to use. Once needle placement has been accomplished, the injection and filming are performed, and the responses recorded, in identical fashion to that described for lumbar discography (Figures 6.8–6.10). In most cases, clinically suspect, abnormal-appearing thoracic discs (seen on MR studies) are studied,



FIGURE 6.8. Painfully deranged T11-12 disc exhibiting a mixture of venous opacification and epidural leakage of contrast material during injection. (A) AP film reveals lateral leakage of contrast (arrow) into paraspinous veins and tissues. (B) Lateral view demonstrates posterior leakage into epidural space and veins (heavy straight arrow). Note anterior tear (curved arrow). Note anterior tear (curved arrow). Patient, who reported 8/10 concordant back and abdominal pain, had been through extensive and unrevealing gastrointestinal evaluation for abdominal pain prior to discography.



along with at least one adjacent and/or nearby control level, as in the lumbar region. Postdiscography CT scans may be helpful in individual circumstances; however, as in the lumbar spine, this is not a routine in our practice. Clinical investigation involving chronic pain sufferers and asymptomatic volunteers has revealed that MR imaging is generally insensitive in the detection of painful thoracic disc annular tears.²²

Thoracic disc degeneration and annular tears are a frequent cause of clinical pain and disability (Figures 6.8 and 6.9).²² Thoracic annular tears, with or without frank disc protrusion and/or endplate disruption (Scheuermann's disease or Schmorl's nodes) (Figure 6.10)^{15,23} frequently result in clinical pain, disability, and painful discographic responses. Thoracic disc pathology often results in extraspinal presen-



FIGURE 6.9. Painfully deranged T6-7 disc with epidural leakage of contrast. (A) AP and (B) lateral images obtained during injection reveal contrast leakage into the epidural space (arrows). Patient reported 8.5/10 concordant back, bilateral rib cage, and intrathoracic pain produced with injection.



FIGURE 6.10. Painfully deranged T12-L1 disc due to endplate infractions (Schmorl's nodes). Lateral image obtained during injection reveals Schmorl's nodes (arrows) involving both adjacent endplates. Circumferentially, disc annulus was fully intact. Patient reported 7/10 concordant lower thoracic and upper lumbar pain provoked with injection.

tations of pain, with or without back pain (Figures 6.8 and 6.9). Thoracic disc lesions may produce complaints involving the chest wall, visceral thoracic and upper abdominal structures, and the lumbar and sacral region. Discography response cannot be predicted in the thoracic spine based upon imaging studies.²² We have observed that thoracic discography has become an indispensable procedure in the investigation of pain that may have originated in the thoracic spine.

Cervical Discography

Studies have proven that MR imaging is insensitive in the detection of painful cervical disc annular lesions and internal disc derangements.^{17,18,28} Positive (intense, concordant pain) cervical discography in symptomatic patients with either normal or mildly abnormal MR stud-

ies is common. Discography often reveals cervical disc annular lesions that are simply not visible on the highest resolution MR imaging studies. Prior research has demonstrated that discographically normal cervical discs should not be painful but are relatively uncommon in clinical practice, since coincidental (painless) annular lesions are the rule in the cervical spine. The presence or absence of annular disruption has little relevance in the cervical spine, although all intensely painful discs manifest tears either into or through the outer annulus (Figures 6.11 and 6.12). At C2-3¹⁸ there is no demonstrable correlation between MR, discographic morphology, and provoked response (Figure 6.11C, D).

Cervical discography requires a high-resolution, multidirectional C-arm device with magnification and filming capability, as well as a sophisticated table. Although variable techniques have been described, we have used exclusively single 25-gauge needles in over 2900 patients, most of whom have undergone multilevel studies, and have had no serious complications. As in the lumbar and thoracic region, intradiscal Cefazolin is employed unless there is allergy to either cephalosporins or penicillins. It is crucial to review prior imaging studies (ideally MR) of the cervical spine before performing the discography. Discography should not be performed at any level where frank spinal cord compression exists, with or without myelopathy. Any disc level manifesting spinal cord deformity should be either avoided or studied with extreme care, depending upon individual circumstances.^{12,17,18}

In preparation for cervical discography, the patient is placed on the fluoroscopic table, supine, with the shoulders slightly elevated and head extended and rotated away from the discographer. For a righthanded discographer, the needle is introduced from the right side, from approximately 30 to 45° oblique to and slightly below the target disc. A single 25-gauge needle is carefully advanced toward (ideally into) the disc, while the left index and middle fingers are used to palpate the cervical spine. The needle is directed between these fingers and passes directly through the skin and ideally into the disc, or as close to the disc as is possible. Neck palpation with the index and third fingers from the nondominant hand allows the proceduralist to push the carotid artery either laterally (most often) or medially and the esophagus (almost always medially) away from the intended needle tract. A 25-gauge needle, held in the right hand between the index finger and thumb, is carefully advanced through the skin and either into the disc or against the spine immediately adjacent to the disc. We perform the skin puncture and needle placement without live fluoroscopy. After needle insertion, we remove our hands from the field and perform fluoroscopy for a few milliseconds to assess needle position. After needle position has been determined, fluoroscopy is used to assist with fine adjustments until optimal needle position within the intended disc has been achieved. In most cases, if the needle tip is within millimeters of the inferior disc margin, it can be manipulated upward and into the disc without difficulty. If, however, the needle is noted to be above the desired disc, we recommend needle removal and reintroduction. The performance of lateral fluoroscopy during needle placement helps one eliminate the risk of unintended needle advancement through the disc



FIGURE 6.11. Painfully deranged cervical discs in patient with old, solid cervical fusion. (A) AP and (B) lateral films of the C3-4 disc obtained during injection reveal circumferential annular disruption and contrast leakage (arrows) (leakage best seen on lateral view, B). Note needle placement into center of nuclear space (A and B). 10/10 concordant bilateral upper and mid neck pain.





FIGURE 6.11. Continued. (C) AP and (D) lateral images obtained during injection of C2-3 disc reveal full-thickness tear posteriorly, with contrast leakage into both foramina and epidural space (arrow). Patient reported 9/10 concordant occipital head pain and upper neck pain.





FIGURE 6.12. Painfully deranged C4-5 disc. Lateral view obtained during injection reveals full-thickness posterior tear (curved arrow), with epidural leakage of contrast (straight arrow). Patient reported 9/10 concordant diffuse neck and bilateral trapezius muscle pain.

and into the spinal cord, which otherwise can easily occur (and has) in inexperienced hands.

Following successful needle placement into the disc, fluoroscopy is performed during the injection of either contrast or saline. Injection volume, end-point characteristics, patient response, concordance/non-concordance and intensity rating are recorded after the disc has been filmed. It is recommended^{17,18,28} that one study as many cervical discs as are accessible (C3-4 through C6-7 in most individuals), since pure imaging studies have been proven to be inaccurate in detecting painful annular lesions in the cervical spine. In special cases, especially when headache of suspected cervical origin is a prominent clinical complaint, discography at C2-3 may be indicated.^{18,28} In our experience, post-discography CT in the cervical region is generally noncontributory, although it has been studied, and is used by many.¹⁰ Whenever saline and Gadolinium are injected, postdiscography MR is performed.

Postdiscography Care

After completion of each discographic examination, patients are advised to expect some pain and discomfort, lasting up to 4 days, especially during the first 36 hours. Patients are routinely given printed instructions regarding what to expect. They are warned that if they experience symptoms such as worsening pain, fever, chills, malaise, and night sweats within one week of the procedure, a disc infection could be developing, and they should call us immediately. Patients are urged to contact the discographer and/or assisting technologist, one of whom is on call at all times, to deal with any procedure-related complaints or questions. We discourage patients from visiting emergency rooms, since too often inexperienced physicians overdiagnose disc infection that is not in fact present. In our experience to date, we have confirmed only six cases of postdiscography disc infection in more than 12,000 patients and more than 40,000 injected discs.

Patients are given a nonrenewable narcotic prescription intended to last 3 to 4 days. If they have experienced muscle spasms, a muscle relaxant is also provided. They are kept at our facility for at least 20 minutes after the procedure. All postdiscography patients are called 2 to 5 days later to check on their status.

Reporting of Discography Results

The formal reporting of discography should be performed within hours of the examination so that important details of each study can be recalled. In our practice, discography films and previous spine imaging studies of the same region are displayed for comparison at the time of formal interpretation. The following information must be communicated for each study.¹²

- 1. Injection volume, injection pressure, end-point characteristics (no end point, soft/firm, or voluntary termination of injection).
- 2. Intensity of response (0–10).
- 3. Concordance vs nonconcordance of the experience relative to clinical complaints.
- 4. Location(s) of pain/pressure perception.
- 5. Disc morphology (normal or abnormal, including details of anatomical derangement(s) encountered, such as annular tears, fissures, vertebral body endplate defects, and contrast leakage).
- 6. Upon completion of the report for each disc studied, we add a statement regarding the patient's general cooperation and pain tolerance observed during the procedure. We also state whether, in our opinion, results of the study are or are not valid.

Conclusion

Discography has become an indispensable assessment tool to evaluate pain of spinal origin; no longer is it reserved for those who are fusion candidates. With the continuous evolution of spinal interventions and the growing recognition of discogenic pain as a major clinical problem, the demand for this procedure is certain to increase. Our experience has been that when discography is performed with appropriate clinical indication(s) by skilled, knowledgeable, and experienced proceduralists, it leads to improved clinical outcomes. Discography is a procedure ideally suited for interventional neuroradiologists, especially those who also interpret spinal imaging studies.

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7

Intradiscal Electrothermal Annuloplasty

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Back pain is the most common pain complaint resulting in physician office visits. Most back pain resolves spontaneously with conservative treatment, although in some patients, pain persists, and the condition is termed chronic.¹ The intervertebral disc has long been thought to be one source of chronic back pain, and in recent years the concept of a discogenic pain source has become well accepted. Internal disc disruption is now thought to be causative in a large number, if not the majority, of instances of chronic low back pain.^{2–4} While some patients' symptoms and functional capacity will respond to aggressive conservative measures (rest, epidural steroids, physical therapy), these measures will fail in others. Surgical treatment for these patients, including interbody fusion techniques, has yielded mixed results in management of chronic pain and carries the risk of morbidity at surgery.^{5–10} In addition, interbody fusion changes the mechanics of the weight-bearing spinal segment, concentrating stress at the levels above and below the fusion. The phenomenon of subsequent degeneration of adjacent spinal levels after interbody fusion is also well recognized. Given the mixed results and significant morbidity associated with surgery, there has been increased interest in developing minimally invasive therapies for the treatment of the painful disc. Chymopapain infusion,¹¹ percutaneous disc decompression,¹² percutaneous laser disc decompression,¹³ nucleoplasty, and other techniques have been developed for percutaneous disc decompression with dissolution or removal of portions of the nucleus pulposus. Intradiscal electrothermal annuloplasty (IDEA), or intradiscal electrothermal therapy (IDET),³ is the first technique developed with the intent of directing minimally invasive therapy primarily to the posterior annulus of the disc to treat painful internal disc disruption.

Anatomy

The intervertebral disc is anatomically composed of a central nucleus pulposus with a peripheral and circumferential annulus fibrosus (Figure 7.1).² The nucleus is bordered superiorly and inferiorly by the car-



FIGURE 7.1. Sagittal diagram showing the anatomy of the lumbar intervertebral disc. The soft inner nucleus pulposus is encircled by the fibrous bands of the annulus which are thinner posteriorly.

tilaginous endplates on the articular surface of the adjacent vertebrae. The annulus itself is composed of two layers, an inner layer that attaches to the cartilaginous endplates, and an outer ligamentous layer that attaches directly to bone of the vertebral bodies. The annulus is loosely attached to the anterior longitudinal ligament but densely adherent to the posterior longitudinal ligament. Annular fibers are thicker anteriorly. The nucleus is a notochordal remnant that is relatively avascular in the adult and is not significantly innervated. The role of the nucleus in back pain is believed to be primarily a consequence of mechanical mass effect or chemical effects on local innervated structures. The annulus fibrosus, however, is innervated, most densely along the posterior aspect, and substance P and unmyelinated C fibers have been demonstrated in the annulus, supplied by way of the sinovertebral nerve (Figure 7.2).^{14–16} Sympathetic fibers are also evident adjacent to the outer portions of the annulus.

The function of the intervertebral disc is a combination of stress absorption (primarily nucleus), and motion restriction (annulus).² The an-



FIGURE 7.2. Axial cross section showing the innervation of the intervertebral disc. There is no significant innervation of the nucleus, while the annulus is innervated with unmyelinated fibers, primarily by way of the sinovertebral nerve. Pain fibers are present throughout the disc but most densely in the posterior annulus.

nulus serves to contain the nuclear material and to restrict longitudinal and rotational motion between spinal segments. Fibers in the annulus are arranged in variable directions in each fibrous layer (approximately 20 anteriorly, and approximately 12–15 posteriorly), providing support in multiple directions.

Intervertebral Discs in Spinal Pain

While incompletely understood, the concept of painful internal disc derangement (the *discogenic* or *discopathic* pain mechanism) has progressively gained acceptance as one source of chronic low back pain.^{2–4} Discogenic pain is typically characterized by axial mechanical midline low back pain, usually exacerbated by sitting or standing for prolonged periods of time. Hallmarks are reports of sitting intolerance with temporary relief when walking. The pain may be aching or stabbing, and there may be some discomfort radiating into the legs, although back pain is typically the more significant complaint. The diagnosis of discogenic pain is based on classic clinical history (including a pain diagram showing the patient's pain distribution) and pain-provocative discography with provocation of typical concordant pain symptoms on disc distention.

Theories for the exact pathophysiology of the pain mechanism abound, but most revolve around pathological tears of the posterior annulus of the disc and mechanical or chemical stimulation of nociceptive fibers located in and around the posterior annulus fibrosus and relayed through the sinuvertebral nerve. The present therapy for persistent axial back pain begins with conservative pain management regimens including elements such as rest, physical therapy, antiinflammatory agents and analgesics, epidural steroids, chiropractic, and acupuncture. Patients who report persistent and debilitating pain after a 6-month course of conservative measures would be considered to have chronic pain and would be candidates for more aggressive intervention.

The choice of surgical intervention may vary depending on local preferences and geographic location. These typically consist of fusion or discectomy and interbody fusion. Both these interventions have yielded mixed results in treating discogenic pain.^{5–10} Additionally, fusion may be costly; it carries some risk for significant morbidity, may require a long recovery period, and predisposes patients to functional changes in weight-bearing capacity that may concentrate stress above and below the fusion. All these factors have resulted in increased interest in developing other options to treat discogenic back pain.

Historical Perspective

Developed in the 1990s as a minimally invasive treatment for chronic discogenic low back pain refractory to conservative measures,³ the IDET technique involves intradiscal delivery of thermal energy to the internal structure of the disc annulus by way of a catheter placed within

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FIGURE 7.3. A commercially available annuloplasty catheter, the Oratec SpineCath wand. This flexible conductive catheter has an exposed resistive heating element on the terminal 2 inches. The catheter has a hockey stick curve to facilitate navigation along the inner aspect of the annulus.

the disc (Figure 7.3). Delivery of thermal energy is a common technique used in pain management, surgery, and tissue ablation.¹⁷ It has been shown in vivo to shrink and reorient collagen fibrils, coagulate nervous tissue, and cauterize fibrous tissue. Extensive in vivo studies have demonstrated the IDET method to be a safe technique for application of thermal energy to the disc annulus for the purpose of shrinking disc substance, promoting annular healing, and coagulating nervous tissue in the annulus in the course of treating discogenic pain.^{3,18–21} The first case was performed in 1997 with institutional review board approval; approval by the U.S. Food and Drug Administration was granted in 1998.

Indications and Technique

IDET is indicated in the treatment of chronic, activity-limiting discogenic low back pain that has been refractory to conservative measures and is generally characterized by:

- 1. Function-limiting low back pain of at least 6 months' duration
- 2. Back pain greater than leg pain with no true radicular symptoms
- 3. Failure to improve significantly with a comprehensive nonoperative back care program including

Progressive exercise (physical therapy) At least one fluoroscopic epidural injection A course of anti-inflammatory medication Activity modification

- 4. No extruded disc fragments and no neural impingement revealed by magnetic resonance imaging
- 5. Pain-provocative discogram with concordant pain reproduction on low-pressure injection at one or more disc levels

Images should be carefully reviewed to detect any annular tears and to exclude any free or extraligamentous herniation of nuclear material. The critical aspect of diagnosis and patient selection relies on a concordant pain response elicited on discography by an experienced discographer. Contraindications include nerve root compression (radicular pain distribution or motor findings on exam), extruded disc fragment, active infection and/or discitis, and bleeding disorder. Severe degenerative disc disease with greater than 50% decrease in disc height is a relative contraindication, since disc narrowing may preclude catheter navigation or placement of the catheter within the disc.

The procedure is generally performed in a fluoroscopy suite,²¹ using an intravenous conscious sedation protocol, typically with midazolam and fentanyl. The sedation level should be such that the patient is comfortable and sleepy but can be roused easily for questioning about radicular symptoms during needle placement and catheter heating. As with all spinal procedures, the indications for the procedure, risks, and appropriate expectations should be discussed with the patient prior to beginning, and informed consent should be obtained. If performed carefully by a skilled operator, IDET is very safe, and complications are very rare ($\leq 2\%$ in our experience).²⁰ The risks are generally those associated with any needle puncture, plus the additional potential risks of traversing nerve damage on disc access, disc herniation from catheter manipulation, and localized nerve damage from the application of thermal energy.

Having given informed consent, the patient is placed prone on a fluoroscopy table and midazolam sedation is initiated, while the low back is prepared and sterile drapes arranged. The prep area should be roughly equivalent to that used for discography. The disc to be treated is visualized fluoroscopically, and the fluoroscope is angled parallel to the disc, such that the endplates above and below are seen en face (Figure 7.4). The imaging orientation is typically craniocaudal angulation for L4-5 and L5-S1 and caudocranial for L1-2 and L2-3 (Figure 7.5). Then, to permit visualization and selection of the appropriate site for disc entry, the fluoroscope is obliqued laterally without changing the craniocaudal angulation. The site of entry is nearly the same as that used for discography and is chosen to allow access to the anterior aspect of the disc nucleus while minimizing the chance of encountering the traversing nerve root from the level above. From the level above the disc to be treated, the lumbar nerve root descends obliquely across the lateral aspect of the disc. Appropriate obliquity is generally achieved when the superior articular facet has traversed between one third and one half of the disc (Figure 7.6). In this projection, there is a triangular access window bordered medially by the superior articular process, inferiorly by the superior endplate, and superiorly and laterally by the traversing root (Figure 7.7).

Local anesthesia is achieved in the skin overlying the triangular access window and is carried down to the peridiscal soft tissues with a 22or 25-gauge spinal needle. The spinal needle is advanced slowly, and if any radicular symptoms are provoked on needle advancement, the position of the traversing nerve is noted and the spinal needle is withdrawn and reoriented to approach the disc medial to and below the position of the nerve root as close as possible to the superior articular process.

After local anesthesia, a skin dermatotomy is made with a scalpel blade and the 17-gauge introducer needle is then advanced along the



FIGURE 7.4. AP radiograph angled in craniocaudal fashion, parallel to the L4-5 intervertebral disc; the superior endplate of L5 and the inferior endplate of L4 are seen en face.

trajectory of the spinal needle and into the disc (Figure 7.8). The needle is advanced slowly to avoid encountering the traversing root, and if radicular symptoms are elicited, the needle is withdrawn and reoriented to avoid the root. A tactile resistance and gritty crunching is encountered when the needle first enters the annulus, and the fluoroscope is then repositioned in a posteroanterior (PA) projection. Care should be taken not to advance the needle beyond the disc margins, and if there is any confusion about the position of the needle tip during advancement, the position should be checked fluoroscopically in two orthogonal planes. The patient may report transient localized back pain as the needle penetrates the annulus. Radicular symptoms are not expected and may indicate needle position too close to the descending root. The needle position is checked in the PA projection confirming the tip position just inside the annulus. Under lateral fluoroscopy, the introducer needle is then advanced minimally to achieve positioning of the tip in the nucleus pulposus just in the anterior half of the disc. Optimal positioning is with the tip between a 12 and a 3 o'clock position (Figures 7.9 and 7.10). The needle is rotated to ensure that the opening in the needle tip points medially to facilitate catheter navigation. The stylet is removed from the introducer needle, and the catheter

FIGURE 7.5. Lateral diagram showing angulation (arrows) necessary for parallel approach to the lumbar discs. Caudocranial angulation is required for accessing the upper lumbar discs, and craniocaudal angulation is necessary for accessing the lower discs.





FIGURE 7.6. Oblique lateral radiograph demonstrating projection for safe disc access at discography or annuloplasty. Angulation is chosen parallel to the disc to be accessed, and obliquity is chosen to optimize access to the central disc and avoid the traversing nerve root. Optimum access is typically obtained when the superior articular process of the level below the disc has traversed between one third and one half of the disc under fluoroscopy.



FIGURE 7.7. Oblique lateral diagram depicting the access window for safe disc entry. In the oblique projection, the access window to the disc is defined by a roughly triangular window delineated by the superior articular process medially, the superior endplate below, and the traversing nerve root laterally and above. Staying close to the superior articular process keeps the needle as far as possible from the traversing nerve root.

is advanced slowly into the needle until the distal marker on the catheter enters the needle hub, indicating that the catheter tip is about to exit the tip of the needle. The catheter must be aligned such that the curve in the catheter tip points medially to allow the curve in the catheter tip to deflect off the inner margin of the disc annulus. Under lateral fluoroscopy, the catheter is slowly advanced into the disc. A



FIGURE 7.8. Oblique lateral radiograph demonstrating disc access with the introducer cannula. The needle enters the annulus in the access window parallel to the angulation of the disc.

FIGURE 7.9. Axial diagram depicting optimum positioning of the introducer needle in the disc. For IDET, optimum catheter positioning is just in the anterior half of the nucleus between 12 and 3 on the clock face. This approach facilitates guiding the catheter along the inner aspect of the anterior annulus.



small amount of resistance is expected when the catheter first enters the disc, but to avoid binding the catheter tip on annular tears, care should be taken to ensure that the catheter tip always advances when the proximal end is advanced. If significant resistance is met, positioning should be checked fluoroscopically to ensure that the catheter is not damaged, and the catheter should be removed and reoriented. The curve in the catheter is utilized to steer the catheter around the inner margin of the annulus. Lateral fluoroscopic monitoring allows the operator to visualize the catheter curving off the anterior and poste-



FIGURE 7.10. AP radiograph demonstrating the introducer cannula in the disc. The cannula is oriented parallel to the disc and positioned between 12 and 3 o'clock in the anterior half of the nucleus.
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rior margins of the annulus and to ensure that the catheter does not breach the anterior or posterior margins of the disc and enter either the retroperitoneum or the spinal canal (Figure 17.11). The catheter should be visualized gently curving off the anterior and posterior margins of the disc without extending significantly beyond the margins of the vertebral bodies above or below (Figure 7.12). Once the posterior curve has been visualized and the catheter tip is no longer pointing directly posterior, the fluoroscope is reoriented in the PA projection. If the catheter becomes inadvertently kinked during navigation, and is difficult to withdraw, the introducer needle should be partially withdrawn a few centimeters, whereupon further attempts at removing the catheter can be made. If the catheter is not easily removed from the introducer and becomes bound to the needle tip, the catheter and needle should be gripped firmly together and withdrawn as a unit to avoid shearing the catheter. To avoid damage to the catheter and the possibility of shearing, the catheter should never be advanced or withdrawn forcefully when resistance is encountered. A damaged catheter should never be heated and should be replaced.

Catheter navigation is generally not painful for the patient but may, rarely, provoke some minor back pain. If severe discomfort or radicular symptoms are encountered, manipulation should be stopped and positioning should be carefully checked fluoroscopically to confirm catheter location within the disc.



FIGURE 7.11. The course of the catheter along the inner aspect of the annulus and optimal positioning for treatment of the posterior annulus. (A) Axial cross section demonstrates a smooth curving course of the catheter along the inner annulus to terminate with the heating element (between the radiopaque markers) positioned along the posterior annulus. (B) Lateral projection is typically used for advancing the catheter under fluoroscopy. Lateral projection allows the operator to view the catheter making smooth curves along the anterior and posterior aspects of the annulus to avoid perforation into the retroperitoneum and spinal canal. (C) AP projection demonstrates optimal final positioning of the catheter with the heating element draped across the posterior annulus pedicle to pedicle.

FIGURE 7.12. Lateral radiograph demonstrating smooth curves of the catheter along the anterior and posterior margins of the annulus with no perforation of the disc.



The catheter is slowly advanced to achieve positioning with the heating element (distal 2 in. of catheter from tip to radiopaque 2 in. marker) draped across the entire posterior annulus of the disc (pedicle to pedicle on the PA projection). The catheter position is examined and photographed in two projections (Figure 7.13), documenting the position of the heating element across the posterior annulus and not contacting the introducer needle.

In extremely degenerated or desiccated discs, it may not be possible to navigate the entire posterior annulus without binding in annular fissures. Every attempt at optimum positioning should be made, maneuvering the curved catheter tip and introducer as just described. If the catheter tip cannot be advanced beyond the midline of the posterior annulus, an initial treatment is carried out at the best achievable position and the procedure repeated from the contralateral approach so that the entire posterior annulus is heated.

Once appropriate catheter positioning has been achieved, the catheter is attached to the generator box and the resistive element is heated. Resistance display on the generator box should be noted, since an excessively high reading (>250–300 ohms) may indicate that the catheter has been damaged, hence should not be used. Heating



FIGURE 7.13. Radiographs demonstrating final positioning of the catheter for treatment. (A) AP projection demonstrates the heating element positioned across the annulus pedicle to pedicle. Although the catheter overlaps the introducer on this projection, the heating element is not in contact with the needle at any point. (B) Lateral projection demonstrates the catheter to be contained entirely within the disc, with the heating element positioned along the posterior annulus.



protocols vary but are generally selected to maximize safe heat application to the annulus and minimize discomfort to the patient. A typical protocol uses gradual increase in temperature to achieve catheter heating of 90°C for 4 to 6 minutes. The patient may report provocation of typical back pain and some typical referred pain with energy delivery. This can be controlled with intravenous analgesics at the discretion of the treating physician. True radicular symptoms, however, are not expected, and if pain radiating to the leg is reported, energy delivery should be halted at once and the catheter repositioned.

After treatment, the catheter is withdrawn with a steady pull, taking care to avoid snagging the catheter on the introducer needle. Intradiscal antibiotics may be injected at the discretion of the treating physician as a prophylaxis against potential disc infection. The needle tract is anesthetized with local anesthetic as the introducer needle is withdrawn. If the catheter position was suboptimal and a second treatment from the contralateral approach is required, no antibiotics should be injected until the second treatment is complete.

Hemostasis is achieved with a few minutes of manual compression, and the entry site is dressed with a sterile bandage.

Postoperative Care

Following the procedure, outpatients are monitored for 20 to 30 minutes and discharged home with standard post–conscious sedation orders that include instructions to avoid driving for the remainder of the day. Postdischarge instructions should include back rest with no strenuous physical activity for 3 days to minimize risk of postprocedural disc herniation. Efficacy of the procedure is dependent not only on the technical aspects of the procedure but also on strict postprocedural guidelines that will allow healing within the disc and avoidance of reinjury. Many practitioners give a preprinted instruction sheet with "dos and don'ts" and exercise instructions to patients after treatment.

Patients should be counseled that they may experience an increase in typical symptoms for 1 to 7 days after the procedure, with transient local discomfort at the entry site(s). Pain can be managed with local ice at the injection site and nonsteroidal anti-inflammatory analgesics as needed. Patients with more severe pain or patients accustomed to narcotics may require narcotic analgesics as well. Most patients will return to their preprocedure pain level within the first week. A fitted lumbar corset may be prescribed at the discretion of the treating physician, to be worn during waking hours for the first few weeks after the procedure. The patient should be instructed to call if fever develops or if a flare-up occurs that does not resolve after the first week.

Symptomatic improvement usually begins in 1 to 2 weeks after treatment, and symptoms continue to improve gradually over time for as long as 6 to 9 months. Activity restrictions generally include the admonition to rest for 1 to 3 days after the procedure. Vertical sitting should be limited to 30 to 40 minutes for the first 2 weeks, then increased as tolerated; prolonged vertical sitting should be avoided. Lifting restrictions are generally imposed at 1 to 10 pounds for the first 2 weeks, then 25 to 50 pounds for the first 3 months.

Return to work varies for individual patients and their type of work. Most patients can return to sedentary work 2 to 5 days after the procedure, though they should be instructed not to sit in one position for more than 30 to 40 minutes at a time in the first few weeks. Patients should not return to heavy work or lifting before week 8 and should engage in some individualized and progressive work hardening before return. In week 2, patients should be encouraged to begin exercise with walking only and to begin stretching exercises. Walking and stretching are encouraged for the remainder of the recovery period to maintain flexibility and promote healing. Jarring axial loads (Stairmaster, running, rowing, aerobics) should be avoided. Patients who are slow to recover or need more detailed instruction may be referred for a formal physical therapy program for back stabilization at 6 weeks. Athletic pursuits can be resumed in month 4 depending on tolerance of increased activity. Golf and tennis may require special instruction.

In appropriately selected patients, results are fairly consistent. Published data in peer-reviewed journals are sparse, and no placebo or sham trial exists at present.^{22–29} Multiple citations report very similar results including several retrospective multicenter analyses, a few published prospective clinical trials, and a case-control study that compared IDEA outcome with that for nontreated patients denied insurance coverage for the procedure. All trials generally reported a roughly 65-70% response rate measured as a decrease in subjective pain (Visual Analog Scale) with a measurable decrease in analgesic use and measurable functional improvement (SF-36 scales) measured at 3, 6, 12, and 24 months after the procedure.

Conclusion

Discogenic pain syndromes are incompletely understood but are increasingly believed to be causative of a large number of cases of chronic low back pain. Treatment choices for patients in whom conservative measures fail are limited, and surgical options have considerable cost, morbidity, and only variable effectiveness in pain relief. IDET is a minimally invasive treatment proposed as an alternative to surgery in patients with chronic discogenic low back pain syndromes. Although objective evidence of effectiveness is still being collected, this newly developed procedure is an excellent starting point in the development of minimally invasive techniques in treating discogenic pain and adds another valuable tool to the armamentarium of the practicing spine interventionist.

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Automated Percutaneous Lumbar Discectomy in the Treatment of Herniated Discs

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It is approaching 20 years since we published the initial article introducing automated percutaneous lumbar discectomy (APLD).¹ At that time, there was tremendous resistance to the concept of a minimally invasive treatment for herniated lumbar discs. Chemonucleolysis had rushed onto the scene with great fanfare, only to be destroyed by the occurrence of devastating complications, such as transverse myelitis. At that time there was essentially no field of minimally invasive lumbar spine surgery.

The concept of minimally invasive lumbar spine surgery, exemplified by APLD, has stood the test of time. Based on the massive amount of data accumulated on APLD, percutaneous discectomy gained its own CPT code, emerging from the twilight zone of experimental procedures. Those most opposed to the concept of minimally invasive spine surgery, the neurosurgical community, have acknowledged its impact on the treatment of patients with herniated discs.²

Although perhaps not reaching its full potential in the volume of cases performed, APLD has had a significant impact on the evolution of disc therapy; it has been extremely successful in achieving its major goal, that of safety. The original intent of APLD was to have a highly safe, minimally invasive treatment for lumbar disc herniations, with a reasonable success rate. At least 170,000 APLD procedures (probably more, since outside the United States the disposable instrument has been routinely resterilized) have been performed with a mortality rate of zero: there has never been a report of death associated with the procedure. In over 50 published series, there has been no instance of permanent nerve injury or great vessel damage, the only reported complication being discitis at a rate of 0.2%, equivalent to that of discography.^{3,4} It can now be said unequivocally that APLD is the safest treatment available for herniated lumbar discs. Contrast this with open discectomy, or even microdiscectomy, as reported by Ramirez and

Thisted,⁵ who examined the complication rate associated with 28,000 open discectomies. In this study, there was a major complication in 1 of 64 patients, with a major neurological complication associated in 1 of 334 patients; amazingly, 1 of 1700 patients died from the procedure. Another prospective study reported by Stolke et al.⁶ examined the intraoperative complication rate associated with lumbar discectomies carried out by experienced neurosurgeons. In 481 procedures, a complication rate of 14% was reported, including one death, three nerve injuries, and a discitis rate of approximately 1%.

The use of the operating microscope and the decreased size of the resultant incision, constituting the so-called *microdiscectomy*, has not appreciably decreased the complication rate associated with lumbar spine surgery as indicated by the article published by Pappas et al.⁷ In 654 microdiscectomies, they reported two major vascular injuries, one of which resulted in death. A major bowel injury was also reported. It was basically in response to this situation of high-morbidity lumbar disc surgery that APLD was successfully developed.

Theoretically, APLD works by centrally decompressing the nucleus pulposus, with that decreased pressure transmitted through the rent in the annulus to the herniation. This results in decreased pressure on the affected nerve. The success rate of any percutaneous procedure based on the concept of central disc decompression is, therefore, highly dependent on selecting patients with pathology that is amenable to such an approach. The success rate of APLD has been reported anywhere from 43 to 85% depending on patient selection criteria. The major limitation, however, is that when only the strictest selection criteria are used, approximately 10% of the herniated disc population would be candidates for the procedure, which would still constitute approximately 40,000 cases a year.

It is the balancing of the very low morbidity associated with APLD that makes it competitive, in certain patient populations, with open discectomy, which reports higher success rates of over 90%. It is of interest, however, that when microdiscectomy is examined in a prospective fashion with the criterion of patient satisfaction included, the success rate falls to approximately 75%, very similar to the percutaneous methods.⁸

Other percutaneous disc removal methods are available, including laser disc decompression, biportal percutaneous disc decompression in which a scope is used to examine the disc during removal, and the so-called arthroscopic microdiscectomy by Kambin. Common to all methods is the problem of patient selection already alluded to, since none has been shown to consistently remove free fragments. Most important, however, these methods have all been associated with significantly greater morbidity than APLD. For example, laser discectomy has been reported to cause osteonecrosis of the vertebral body endplates due to adjacent heating.⁹ For radiologists considering entering this field, we suggest getting experience with APLD before considering the other variations of percutaneous disc decompression that are associated with a higher inherent morbidity.

Patient Selection

Classic Herniated Nucleus Pulposus (HNP)

APLD is efficacious only for patients whose herniations are still contained by the annulus or posterior longitudinal ligament, and this is the most important factor that has prevented the more widespread use of the procedure. Therefore effort must be expended to determine which patients are appropriate for this type of procedure. Magnetic resonance imaging (MRI) can be extremely helpful in excluding obviously migrated fragments and large disc extrusions. Herniations with smooth obtuse margins (Figure 8.1) are generally contained. Herniations with acute angulations or irregular shapes are more likely extruded. Although the intact annular fibers on an MR image are sometimes evidence of a contained herniation, there can be exceptions to this criterion.

An absolute contraindication of APLD is the migration of a disc fragment. When small degrees of migration are present (\leq 3 mm), the possibility of a good result from APLD is not precluded. In cases such as this, the epicenter of the herniation can still be at the disc level. Until recently, this criterion had always been assumed to be valid based on common sense although never proven by data. In a French study comparing chymopapain with APLD, 50% of the patients treated with APLD had fragments that had migrated more than 3 mm from the disc space. The success rate for APLD in this report was approximately 43%, proving the importance of this criterion.¹⁰

It is now clear that perhaps the most definitive procedure for selecting patients for APLD is the computed tomography (CT) discogram. This procedure demonstrates complete tears of the annulus and posterior longitudinal ligament (Figure 8.2), indicated by free flow of contrast medium into the epidural space, thus indicating the herniations that are extruded. A CT discogram also allows the assessment of the size of the rent in the annulus that is communicating with the herniation. Castro et al.¹¹ have shown this to be valuable information. When the rent is narrow, which gives a mushroom effect to the herniation, it is naturally more difficult to transmit a pressure difference through such an annular tear. The result of the procedure is then in doubt; a 50% success rate is reported in patients with this finding. When the neck of the herniation is wide (Figure 8.3), with room for transmission of the pressure difference or actual retraction of the herniation back through the rent in the annulus, an excellent success rate (>80%) was reported. At our own institution, by this criterion, we had an 88% success rate.

Besides the characterization of the herniation on imaging studies, a number of associated radiographic findings should be considered when one is evaluating patients for APLD. Patients with degenerative facet disease should be carefully evaluated prior to APLD. These patients often have associated back pain that is likely to persist after a successful APLD. A facet nerve block prior to a percutaneous discec-

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FIGURE 8.1. (A) Axial MR image showing contained HNP and a small central contained herniation with smooth obtuse margins. This patient would be a good candidate for a percutaneous discectomy. Such individuals often have back pain that can respond only to disc decompression. (B) Sagittal MR image showing contained HNP; L4-5 disc herniation is noted. The epicenter of the HNP is at the level of the disc space, and there is no evidence for an extruded fragment. (C) Axial CT scan showing contained HNP.

FIGURE 8.2. Axial view of a CT discogram showing contrast medium (arrow) that has extravasated into the epidural space. This patient had an extruded fragment and would not have responded to a percutaneous discectomy.



tomy can help disclose what portions of a patient's symptoms are related to a facet syndrome.

Clinically, patients who are candidates for APLD have the classic symptoms of a radiculopathy with sciatica (i.e., leg pain greater than back pain) and the classic neurological findings of wasting, weakness,



FIGURE 8.3. Axial view of a CT discogram showing a tear in the annulus with a wide neck (arrows) communicating with the HNP.

sensory and reflex changes, as well as a positive straight leg raising. APLD is not a procedure for patients with vague or equivocal symptoms and bulging discs. The percentage of patients who would be expected to fit into the high success category for APLD is approximately 5 to 10% of the overall herniated disc population that finally comes to surgery. With such low morbidity associated with APLD, however, what level of potential success (80%?, 60%?, 50%?) is acceptable to allow the procedure to be carried out on a more widespread basis? Now that APLD is no longer considered experimental, I usually give the patient the benefit of the doubt and the decision-making power to have the procedure even if a lower success rate might be expected. Such an instance occurs during discography when contrast material flows behind the posterior longitudinal ligament, indicating a complete tear of the annulus but not a complete extrusion. In our experience, these patients have approximately a 50% chance of success. When we encounter this situation we now give the patient the option to proceed with APLD even with the lower success rate. In fact, no patient has ever refused the 50:50 chance of avoiding an open discectomy.

Reherniation at the Level of Previous Surgery

With experience, it is now clear that in a number of clinical situations percutaneous discectomy is particularly useful. Perhaps APLD could have the greatest impact in a patient who has had a reherniation at the site and level of previous disc surgery. Patients who reherniate after open back surgery constitute approximately 5% of that patient population. Of great importance is that success rates are lower for patients who are reoperated on with an additional open discectomy at the same level as previous surgery; moreover, these patients are exposed to a much higher morbidity as a result of the lack of tissue planes due to epidural fibrosis.

We have found that APLD can be an excellent procedure for this patient population. Since the route of the instrumentation in APLD takes a posterolateral course that avoids the epidural space, the presence of epidural fibrosis does not complicate the procedure or add morbidity, as it does in an open discectomy. Interestingly, excellent success rates have been reported (as high as 90%) in this patient population.⁴ These results have been confirmed by other investigators. Mirovsky et al.¹² described the results with 10 patients with lumbar disc reherniation at the **same** level as an earlier open operation. With average follow-up of 2.5 years, 70% of their patients showed complete or significant pain relief while avoiding reoperation. Sixty percent showed diminution in motor deficit as well. Failures were in patients with spinal stenosis or segmental instability. In our own experience with 21 patients, 20 of whom had follow-up of 3 years or greater, 18 out of 20 were treated successfully.

The reason for the excellent success rate in this group of difficult-totreat patients may be secondary to the fact that epidural fibrosis decreases the chances for a free fragment occurring. In addition, because of the epidural fibrosis, relatively small changes in the disc pressure may provide greater symptomatic relief. Last, it must not be overlooked that this patient population has already experienced an open discectomy and may be more satisfied with only partial pain relief in exchange for avoiding a repeat open operation. It is in this patient population that we believe that APLD is still markedly underutilized. Certainly, when one weighs the risk versus benefit of APLD, with its lack of morbid-ity and excellent success rates in this difficult to treat group of pa-tients, APLD appears to be the procedure of first choice in this clinical situation.

Far Lateral Herniation

Another special patient population for which APLD should be the first procedure chosen consists of patients whose herniations occur in the far lateral location beyond the intervertebral foramen. Such patients are difficult to treat with a traditional interlaminar approach of microdiscetomy, which sometimes requires the removal of all or a large portion of the facet (Figure 8.4). Our excellent results with APLD in this patient population are understandable, since the percutaneous discectomy instrumentation essentially drives over the herniation itself.¹³ Special care is needed in performing the procedure in these patients, however, for if the nerve is pushed into a more posterior position, and placement of the instrumentation becomes more problematic.



FIGURE 8.4. Axial CT scan showing far lateral HNP on the right side (black arrow). The nerve (straight, white arrow) is displaced by the herniation posteriorly and laterally, possibly making placement of the instruments more difficult. The normal nerve on the left is noted (curved arrow).

Suspected Discitis

The last group of patients for whom APLD must be considered the procedure of choice are those suspected of having infectious discitis. Although percutaneous fine-needle aspiration biopsy sampling of a suspected disc space has strong advocates owing to its inherent safety, the samples obtained are so small that the accuracy of negative bacteriological results is in doubt. The small sample also, although perhaps adequate for culture and Gram's stain, prevents any meaningful histological evaluation, which can sometimes be important in making a rapid diagnosis in more unusual mycobacterial or fungal infections. The alternative to needle biopsy, open operative biopsy, has obvious disadvantages in this patient population. Automated aspiration biopsy of the suspected disc space is perhaps the best alternative for this clinical problem, combining the safety of skinny-needle biopsy with the ability to obtain large samples of pathological material, while therapeutically débriding the disc space. Our own experience confirms the impression that automated biopsy in this setting is advantageous.^{14,15} Of the 12 automated disc aspiration biopsies we have carried out for suspected discitis, we obtained eight positive cultures. What is of great importance is that five of the patients with positive cultures had had negative needle aspirations. It was this experience that convinced us that a negative needle biopsy result for a suspected disc space infection is of virtually no value, and a procedure that obtains a better sample must follow.

When an unusual infection is considered (i.e., tuberculosis or a fungus), the use of an automated biopsy becomes even more compelling. Yu et al.¹⁶ described two cases in which automated biopsy results were used to diagnose unusual infections. They described two patients, one of whom was diagnosed with *Candida* discitis and the other with tuberculosis. Their article emphasized the large sample obtained with the automated biopsy, allowing histological identification of both infections by microscopy, and the initiation of specific therapy without having to wait for cultures. These authors also stressed the usefulness of automated biopsy for the débridement and treatment of infected discs. Both patients received immediate symptomatic relief after removal of large amounts of infected disc material.

In these patients, the procedure is carried out in the same manner as APLD, the only technical caveat being the need for special attention to the depth of the instrumentation within the disc. The infected annulus has poor integrity, particularly anteriorly. This could put the great vessels in danger if the instrumentation is passed too far forward in the disc. Careful monitoring of the oblique view in which the full depth of the instrument placement can be appreciated prevents this from happening.

APLD Technique

The remarkable safety of the APLD technique is based on standardization of the APLD procedure with the recognition of important unchanging radiographic landmarks that can be used to ensure proper placement of the instrumentation. The procedure is carried out under local anesthesia, this being perhaps the greatest reason for the lack of reports of significant neural injury with APLD. Sedation can be given, but the patient's level of consciousness must be carefully monitored to ensure that the patient can still respond to pain. The only major injury in the literature associated with APLD occurred in Mexico and resulted in a cauda equina injury when the procedure was carried out under general anesthesia without attention to the important radiographic landmarks.¹⁷ The other major safety factor in the procedure is the design of the aspiration probe: 2 mm size minimizes the chance for nerve injury during placement of the instruments; and once inside the disc, its blunt end and internal cutting side port make injury to surrounding structures impossible.

Procedural Steps

- 1. *Choosing the entry point for the instruments.* The entry point for the instruments is usually chosen by measuring the distance from the midline on a CT scan that shows the whole abdomen through the disc space of interest. The path is calculated to the center of the disc passing just anterior to the facet joint. Using a CT scan in this manner excludes the possibility that the bowel will be in the path of the instruments and also eliminates the possibility of choosing an entry point too far medial or lateral.
- 2. *Patient positioning*. The patient is placed in the lateral decubitus position with a towel roll under the hip. Sterile preparation and draping are carried out. Since discitis is the only major complication to be worried about with APLD, we take special care with the skin prep. We carry out a 10-minute scrub with Betadine soap and then use three layers of Betadine followed by two layers of alcohol. We also give prophylactic antibiotics intravenously with coverage for *Streptococcus epidermidis* as well.
- 3. *Intradiscal steroid and local anesthetic injection*. Prior to placement of the disc aspiration probe, we make a disc injection of approximately 3 mL of a 50:50 mixture of 0.5% bupivacaine and betamethasone. This injection rehydrates the disc and improves the aspiration, and also helps decrease inflammation associated with the HNP. We have found that this can markedly hasten the recovery time after the procedure.
- 4. *Placement of the aspiration probe.* A lateral fluoroscopic view is used to place the 18-gauge trocar. When properly placed, the trocar should be at the posterior vertebral body line when the annulus is felt. At this point the AP view is obtained, and the tip of the trocar should be lateral to the medial border of the pedicles. This confirms that the trocar is not going through the thecal sac on the way to the center of the disc (Figure 8.5). Once confirmed to be outside the medial border of the disc and is confirmed on both views to be in the disc center. The cannula and dilator are placed over the trocar; then a trephine is used to in-



FIGURE 8.5. Correct placement of needle against the annulus. The top view shows the correct trajectory of the instrumentation to the center of the nucleus. When the tip of the trocar is against the annulus and in the proper trajectory, it should lie at a line that connects the posterior vertebral bodies (PVBL, posterior vertebral body line), and in the frontal view should be lateral to a line that connects the medial border of the pedicles. Only after these views have confirmed that the trocar is not passing through the thecal sac can the instrumentation be passed into the center of the disc.

cise the disc. The nucleotome is then placed into the disc, and final confirmation of its position is obtained in two views.

5. *Aspiration of the disc.* The disc is aspirated until no more material can be obtained. This usually takes about 20 minutes. The instrument can be moved back and forth and angled to obtain more disc material. We take advantage of the patient's being awake and in the lateral decubitus position by having the patient flex and extend during the procedure to facilitate disc removal.

Postoperative Care

After the procedure, the patient is held for approximately 2 hours and can be discharged. We have had no problem carrying out the procedure in an outpatient imaging center. Pain medication and antiinflammatories can be given for a short period after the procedure. If the patient has a very inflamed nerve root, consideration can be given to carrying out an image-guided selective nerve block to facilitate recovery. Postoperative physical therapy can be very helpful to facilitate recovery and prevent a reherniation. A procedure that does not result in substantial relief of pain should not be considered a failure until at least 6 weeks have passed postoperatively.

The only postoperative complication that need be looked for is discitis. It can occur months after the procedure and manifests as progressively worsening back pain. A normal sedimentation rate virtually excludes the diagnosis, but normal imaging studies do not exclude the diagnosis. In the face of an abnormal sedimentation rate, the disc should be reaspirated to exclude discitis.

Future Developments

Like other procedures that rely on central disc decompression for their mechanism of action, APLD is applicable in selected patients. At present, the patient with an extruded lumbar disc is still best treated by an open posterior approach, such as microdiscectomy or laminectomy. The brass ring of lumbar spine surgery will belong to those who are able to develop a procedure with the safety of APLD that can still deal with extruded and free fragments of disc. I have no doubt that, with the advent of sophisticated real-time guidance in the form of helical multislice CT and interventional MRI, this goal is attainable.

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9

Epidural Steroid Injections and Selective Nerve Blocks

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Interventional spine injection procedures for the diagnosis and treatment of low back and neck pain play an important role in the management of this common problem. Epidural injections for pain management have been employed since early in the past century.¹ Caudal epidural injections were first described in 1901 by Cathelin.² The midline epidural technique was introduced by Pages in 1921.³ Although the efficacy of these procedures continues to be the subject of debate, a number of studies and clinical experience support their use for the management of spinal origin pain.

Pathoanatomy

The vertebral column is richly innervated. The dorsal and ventral nerve plexus is derived from branches of the sympathetic trunk, sinuvertebral nerves, and the rami communicantes, as well as the perivascular nerve plexus of the segmental arteries.⁴ The double-layered peridural membrane forms the outer margin of the epidural space and lines the entire bony spinal canal. The epidural space is a circumferential compartment surrounding the thecal sac, but a median raphe may compartmentalize the dorsal epidural space. Also, because there is variable communication between the dorsolateral compartments and the ventral compartment of the epidural space, asymmetric filling of the epidural space is not uncommon upon injection of contrast media.⁵ However, the compartmentalization is usually incomplete, and the epidural space generally forms a contiguous compartment around the thecal sac from the skull base to the sacrum.

Low back and sciatic pain are likely a combination of mechanical compression and inflammatory changes resulting from degenerative disc disease. Histological studies demonstrate the presence of inflammatory cells and increased protein in the cerebrospinal fluid (CSF) of patients with degenerative spine disease.⁶ Recently, Rutkowski et al. demonstrated central nervous system neuroimmune activation and neuroinflammation following lumbar nerve root injury.⁷ The pharma-

cological basis for response to epidural steroid injections is based on mitigation of the inflammatory changes that cause pain symptoms.^{8,9} In a clinical study by Winnie et al., 80% of patients showed improved work status at 6 months following epidural injections.¹⁰ Benzon concluded that pain relief is produced by the "interruption of sustained neural activity that produced and perpetuated the paraspinal muscle spasm."⁸ It was formerly believed that peridural adhesions could be relieved by the volume effect of the injectate.¹¹ Although adhesional lysis is practiced by some proceduralists, it is unlikely to be the mechanism responsible for improvement following an epidural steroid injection.

Although numerous studies have argued the efficacy of epidural steroid injections,^{10,12–21} many of these trials are flawed in design. Unfortunately, double-blind controlled and randomized studies are difficult to perform in the clinical area. Despite this, there are a number of investigations that provide convincing evidence that epidural steroid injections are effective. Coomes and coworkers showed that epidural injections with anesthetic agents are more effective than bed rest for the treatment of low back pain.¹⁶ Burn and Langdon showed improvement in two thirds of the patients at 6 months (complete resolution of symptoms or significantly decreased pain).¹⁴ These investigators stratified patients based on age and duration of symptoms and found the best responses when symptoms were less than one year in duration and patient age was greater than 40 years. Heyse-Moore reported 120 consecutive patients who received epidural steroid injections with local anesthetic and found an overall success rate of 62% in their series.¹⁹ In this study as well, the best results were demonstrated in patients with a relatively short pain history: of patients who had had symptoms for 6 months or less, 81% improved; only 45% of more chronic sciatic pain sufferers showed improvement.¹⁹ Berman and coworkers also demonstrated better results in patients with subacute radicular pain (<3 months duration) versus those with more chronic pain symptoms.¹² Another variable that appears to affect outcome is spinal stenosis. Rivest and coworkers reported their findings in 212 patients and discovered that patients with herniated discs responded better to epidural steroid injections than those with lumbar spinal stenosis.²⁰ In addition, a number of reports have argued the efficacy of diagnostic nerve blocks for pain relief and for diagnostic benefits.^{22–27}

Yates compared the results of epidural injections of local anesthetic with and without the use of steroids.²¹ In this prospective double-blind study, patients with sciatica who received both the steroid and local anesthetics showed significant improvement at 1-month and 1-year follow-up, compared with those who received placebo.¹⁵ A double-blinded randomized control study by Ridley demonstrated short-term benefits in 39 outpatient sciatica pain sufferers. Patients receiving the injections showed significantly diminished rest and walking pain at 1 to 2 weeks following injection, compared with those who received placebo injections.²⁸ Dilke and colleagues published a double-blind

study comparing patients who received methylprednisolone versus others given a placebo injection. The treated patients showed decreased pain symptoms and fewer missed work days than the placebo group.¹⁷ When pain is addressed soon after the onset, many patients are able to return to work and remain active, thus preventing atrophy of stabilizing musculature and other undesirable sequelae of inactivity. Facilitating the return to work also minimizes the deleterious occupational and economic effects of missed workdays. For many, these short-term benefits justify the procedure. In our experience, a 6-month mean follow-up interval showed a 76% improvement in patients receiving epidural steroid injections.²⁹

Technique

Epidurography is generally performed to document the accurate delivery of therapeutic substances into the epidural space prior to the injection of epidural steroids and local anesthetic. The study also imparts important information regarding the anatomy of the epidural compartment. In addition, postinjection films provide visual feedback regarding the actual distribution of the therapeutic agents. An important role of the imaging study is to exclude intrathecal injection, which is a contraindication for the subsequent injection of therapeutic substances. The contrast agent utilized for epidurography is safe for myelography; thus an inadvertent dural puncture is harmless. However, the introduction of therapeutic substances into the thecal sac may lead to complications, especially with repeated injections. This is an important consideration, because without fluoroscopic guidance, incorrect needle placement occurs in up to half of cases, depending on the operator's experience.^{30,31} If accurate needle placement is not achieved, the therapeutic substances may be delivered into the paraspinous soft tissues, where they are ineffective, albeit harmless. On the other hand, if such drugs are injected into the thecal sac or a blood vessel, untoward sequelae may result. Unfortunately, negative aspiration for blood does not exclude an intravenous injection. In fact, intravascular injection may occur in up to 9% of cases, even with negative aspiration of blood.³⁰ Epidurography is thus useful for documenting the anatomy of the epidural space, ensuring accurate delivery and distribution of therapeutic substances, and preventing injection into the thecal sac or a vessel.

Interlaminar Lumbar Epidural Injection

Prior to the injection procedure, review of imaging studies is useful to evaluate pathological changes (e.g., stenosis) that may mitigate against a given injection site or favor a specific location (disc degeneration that correlates to the patient's symptoms). A pain diagram is completed by all patients so that a graphic depiction of pain distribution is available. After the patient has been placed in a prone position, fluoroscopic imaging is performed to optimize needle placement, based on the osseous

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anatomy. A multidirectional, high-resolution C-arm is preferred for fluoroscopic localization so that the image intensifier and x-ray tube can be manipulated to optimize the trajectory without the need to change the patient's position. The target anatomy is identified on the skin by using a radiopaque marker (or intrinsic light laser source), with the Carm unit oriented 20 to 30° caudal and lateral to the midline. After the skin entry site has been marked (usually with a small skin impression or marker), a wide area is prepped and draped in sterile fashion. Under intermittent fluoroscopic guidance, a 22-gauge spinal needle with a beveled tip is advanced to the epidural space by a dorsal, oblique, paramedian approach (Figure 9.1). The needle is advanced to the superior margin of the spinal lamina, immediately subjacent to the interlaminar gap. Fluoroscopy is performed intermittently to monitor the position of the needle as it is advanced.

After contact with the superior laminar margin, the needle is withdrawn slightly, and the bevel is oriented caudally. The needle tip is



FIGURE 9.1. Needle placement for interlaminar lumbar epidural injection. After contact with the lamina, the needle is guided superiorly into the intralaminar gap through the ligamentum flavum into the dorsal epidural space.

then guided over the lamina, through the ligamentum flavum, and into the dorsal epidural space at the midline. There is increased resistance as the needle traverses the ligamentum flavum. One should proceed cautiously upon encountering this structure, with incremental advancements of the needle interspersed with fluoroscopic visualization of needle position. When the negative resistance of the epidural compartment is encountered, the contrast agent will easily advance into the epidural space (Figure 9.2). A small air bubble in the tubing adjacent to the needle hub may facilitate this determination, but it is important not to inject a large volume of air into the epidural space, even though it is generally well tolerated in this compartment. If the needle tip is within an artery, there is potential for arterial gas embolism, a rare but serious complication.³² This should be avoidable by using realtime epidurography.

A variation of this technique uses a so-called epidural needle, with a tapered, rounded tip and a side hold. The epidural needle may be advanced directly toward the interlaminar gap. Although this technique does avoid contact with the periosteum (which occasionally may be painful), it does not provide the depth control that is gained from contact with the lamina. After needle placement and negative aspiration for CSF, 4 to 6 mL of nonionic contrast is injected, under direct fluoroscopic observation. Images are obtained to document epidural distribution of the injectable and to exclude subarachnoid injection due to inadvertent dural puncture, before injection of therapeutic substances.³³

Epidurography is performed with nonionic iodinated contrast that is approved for myelography. This renders an inadvertent thecal puncture essentially harmless. A volume of contrast medium is injected sufficient to achieve dispersal within the epidural space and to reveal the presence of adhesions, loculations, and even spinal canal stenosis. This provides important anatomical information and may explain a limited or compartmentalized block caused by limited distribution of the injectate.³⁴ Filming is performed in at least two planes, typically anteroposterior (AP) and lateral projections. Transforaminal epidurograms may be filmed by using an oblique projection. An oblique projection also is useful for cervical and occasionally thoracic epidurograms, where lateral projections are often suboptimal because of adjacent structures with markedly disparate densities.

After filming, the therapeutic substances are injected through the same needle without a change of position. Typically, a water-soluble steroid preparation (2–3 mL of betamethasone preparation or equivalent steroid dosage) is injected, followed by an injection of 3 to 5 mL of 1% lidocaine or 0.5% bupivacaine. Filming is repeated after the injection of therapeutic substances. The postinjection films document distribution of the injectate. These images may provide an explanation of a compartmentalized result. For this reason, the author does not perform a limited epidurogram (<4 mL of contrast). The contrast study is filmed and interpreted, with films documenting before and after the installation of therapeutic materials. These films are retained as part of the patient's medical records.



FIGURE 9.2. (A) AP radiograph following needle placement and injection of nonionic contrast media reveals opacification of the epidural space cephalad and caudal to the injection site. (B) Lateral radiograph demonstrates contrast within the dorsal and ventral epidural compartments during injection.

А



FIGURE 9.2. *Continued*. (C) Lateral radiograph following injection of therapeutic mixture reveals further dispersal of the previously injected contrast circumferentially within the epidural compartment.



С

Transforaminal Epidural Injection

For patients with unilateral and/or radicular symptoms, a transforaminal approach is often used. The patient is placed in a prone position on the fluoroscopy table, and the skin is marked with the C-arm oriented posterolaterally. The lateral angle is greater than that used for the interlaminar technique, generally 30 to 45° from the midline. Additionally, caudal angulation allows visualization of the undersurface of the pedicle above the target foramen. Using a slightly caudal angle to project the undersurface of the pedicle above the foramen will facilitate accurate needle placement. A spinal needle is then advanced to the undersurface of the pedicle, slightly medial to the center of the pedicle (Figure 9.3). Following negative aspiration for CSF, 4 to 5 mL of contrast is injected. This typically results in opacification of the proximal nerve sheath, with reflux of contrast into the adjacent epidural space (Figure 9.4). After fluoroscopic evaluation and filming, 2 to 3 mL of water-soluble steroid mixture, mixed with 3 to 5 mL of local anesthetic, is injected. Mixing the therapeutic agents provides early delivery of the local anesthetic to the (often sensitive) nerve and adjacent structures. Postinjection films are obtained to document dispersal of the injected materials. For a sacral foramen injection (typically S1), a



FIGURE 9.3. (A) Needle placement for a transforaminal injection. The needle tip is adjacent to the pedicle from a posterolateral approach. A more medial needle placement facilitates epidural reflux. Oblique (B) and AP (C) radiographs following needle placement subjacent to the pedicle.





FIGURE 9.3. Continued.

С

dorsal approach is used, with the tube angled slightly cephalad and laterally to profile the sacral foramen (Figure 9.5). Lateral fluoroscopy may be used to assess the depth of the needle and to prevent inadvertent advancement into the presacral space.

Caudal (Sacral Hiatus) Epidural Injections

The patient is placed in a prone position, and the sacral hiatus is palpated and marked with a blunt marker to indent the skin. Before sterile preparation of this site, gauze pads may be placed in the gluteal fold to prevent excess Betadine and alcohol from draining to the perineum and genitals. After sterile preparation is performed, a fenestrated drape is placed, and a 22-gauge spinal needle is advanced ventrally and rostrally from the midline overlying the sacral hiatus. The needle is advanced by using intermittent AP and lateral fluoroscopic imaging to document positioning of the tip within the caudal sacral canal. The needle should not be advanced above the S2-S3 level, to prevent inadvertent thecal puncture. Then 4 to 6 mL of nonionic, iodinated contrast is injected to exclude venous opacification and to document



FIGURE 9.4. (A) AP radiograph during injection of contrast media for a transforaminal injection at L5-S1. (B) After injection of 5 mL of contrast medium, contrast is seen along the L5 nerve root and within the epidural space from L2-3 to the L5-S1 level.



FIGURE 9.5. Radiographs taken during a transforaminal S1 injection: (A) AP and (B) oblique. A small amount of the mixture of contrast and therapeutic agents is used for a selective S1 nerve block. For a transforaminal S1 epidural injection, a larger volume is used to achieve epidural reflux and wider distribution of the therapeutic agents.



dispersal of injected materials within the caudal epidural space. Following filming, the therapeutic substances are administered, and a postinjection epidurogram is obtained to document dispersal of injectate. The volume of contrast and therapeutic agents is the same as that used for interlaminar injections.

Cervical and Thoracic Epidural Injections

An interlaminar approach may be used to perform cervical and thoracic epidural injections performed. The patient is placed in a prone position, and the skin is marked in a fashion similar to that used for lumbar injections. The author uses an epidural needle for these injections because of the small caliber of the epidural space and the proximity of the underlying cord, which is only a few millimeters from the intended injection site. Because the needle has a tapered tip, there is lower likelihood of causing inadvertent dural puncture. The needle is placed after initial skin puncture with an 18-gauge introducer needle and advanced in a rostral and medial fashion toward the midline interlaminar gap, under intermittent fluoroscopic observation (Figure 9.6). Again, contact with the lamina subjacent to the interlaminar gap provides depth control, which is extremely important given the underlying anatomy. After contact with the superior aspect of the lamina, the needle is retracted 3 to 4 mm and guided over the lamina toward the midline. Confirmation of needle positioning can be obtained with both oblique views, in addition to the AP view. The contralateral oblique view allows visualization of the needle as it passes over the lamina into the spinal canal (Figure 9.7). After needle placement, 4 to 5 mL of contrast is injected, followed by anterior and lateral (or steep oblique) filming to document dispersal within the epidural space (Figure 9.8). After this, 2 to 3 mL of steroid solution is injected.

We do not inject local anesthetic into the cervical or upper thoracic epidural spaces because it could result in the complication of high cervical anesthesia and potential respiratory suppression. Cervical epidural injections are safest at the C7-T1 level, where the dorsal epidural space is most capacious. The injected materials typically will migrate cephalad into the cervical epidural compartment, as demonstrated by the distribution of contrast media.

Selective Nerve Blocks

Selective lumbar nerve root injections are performed by using the technique described for transforaminal epidural injections. The undersurface of the pedicle is profiled from a posterior oblique angle (Figure 9.3). For a selective nerve root block, however, the goal is to avoid refluxing the therapeutic injectate into the epidural space. Rather, minimal epidural reflux is achieved by directing the needle slightly lateral to the 6 o'clock position relative to the pedicle. In this fashion, a limited amount of the mixture of contrast and therapeutic agents is injected to achieve primarily nerve sheath infiltration with minimal epidural reflux (Figure 9.9). Typically, 0.5 to 1.5 mL of nonionic iodinated contrast are injected (use only contrast agents that are approved for myelographic use). FIGURE 9.6. Posterior oblique approach or intralaminar cervical epidural injection. After contact with the lamina for depth control, the needle is guided over the superior margin of the lamina into the dorsal epidural space.



After needle positioning and negative aspiration, the contrast agent is injected. The films are obtained in the AP and oblique projections to document distribution of contrast media prior to the installation of local anesthetic and water-soluble steroid suspension. Usually, less than 2 mL of the therapeutic mixture is injected to avoid significant epidural reflux. If there is significant epidural reflux, selectivity is lost, and a positive response cannot reliably be attributed to blockade of the intended nerve. Therefore, if contrast injection reveals significant epidural reflux, the needle should be repositioned more laterally and additional contrast injected prior to filming and the injection of therapeutic substances.

An S1 nerve block is performed by using the technique described for a transforaminal S1 injection (Figure 9.5). A limited amount of the mixture of contrast and therapeutic agents is injected, however, to avoid significant epidural reflux. Typically, volumes less than 1.5 mL will not cause significant reflux into the epidural space.

Cervical nerve blocks should be performed only by proceduralists who have significant experience performing other spinal injection procedures. Precise needle positioning is critical because there are structures immediately adjacent to the nerve sheath that must be avoided.



FIGURE 9.7. (A) Oblique radiograph after needle tip is directed to the lamina. (B) AP radiograph demonstrating needle contact with the lamina.



FIGURE 9.7. *Continued*. (C) Right posterior oblique (contralateral to left paramedian approach) radiograph after needle had been directed over the lamina into the dorsal epidural space. Contrast gently directed to firm needle placement within the epidural space.



At the infralateral aspect of the neural foramen, the cervical nerve sheath can be safely injected. However, just medial to this, the vertebral artery traverses the spinal column. If a lateral approach to the foramen is utilized, it is not difficult to place the needle within the spinal canal, which may result in spinal cord damage. Thus we use an anterolateral approach, which does not allow direct access to the spinal canal through the foramen. As in the lumbar spine, bony landmarks are used as a visual aid and for tactile response provided by needle placement on the bone for depth control and anchoring prior to injection of contrast and therapeutic materials. If the vertebral artery is inadvertently encountered, the injection of a small amount of contrast will reveal the untoward placement. It is important to recognize this, since a subintimal injection could result in vertebral artery occlusion. Even worse, intra-arterial injection of the therapeutic mixture could result in seizures, stroke, or even death. Therefore, a radiculogram is essential for assuring accurate needle placement prior to the injection of therapeutic substances (Figure 9.10). Typically, less than 1 mL of contrast is necessary to confirm needle positioning and opacify the nerve sheath. After filming and confirmation of the needle position, 1 to 5 mL of a therapeutic mixture is injected. Patients are monitored for 20 to 30 minutes after the injection for initial response. The response is rated for therapeutic efficacy by asking the patient to provide a percentage improvement from 0 ("RO") to 100% ("R2"). Partial improvement (1-99%) is designated "R1."

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FIGURE 9.8. Radiographs following injection of contrast medium demonstrate opacification of cervical and upper thoracic epidural compartment bilaterally: (A) oblique and (B) AP views.

Complications

Generally, complications following fluoroscopically guided injections are minor and resolve without morbidity.^{35,36} Obviously, the complication rate associated with spinal injections is higher in inexperienced hands. Minor complications and failures occurred early in the author's experience and were seen in fewer than 1% of patients.³⁷ Burn and Langdon reported a 5.8% incidence of complications (none of which were serious) in their first year of experience.¹⁴ The use of imaging and



FIGURE 9.9. Radiographs demonstrate opacification of the right L4 nerve root with minimal epidural reflux: (A) oblique and (B) AP views. The unopacified nerve root is surrounded by contrast.

А




FIGURE 9.10. Radiographs following in-jection of 1 mL of nonionic contrast showing (A) oblique and (B) AP views. The left C7 nerve sheath is opacified without demonstrable epidural reflux. Following filming, 1.0 mL of a therapeu-tic mixture consisting of two parts lido-caine 2% to one part steroid suspension is injected is injected.

A



epidurography prior to injection of therapeutic substances significantly minimizes the risks of procedures.

Allergic reaction to contrast material is a known risk when iodinated contrast is used. Complications or side effects specific to epidural steroid injections include headache, which is most likely following thecal puncture. When a dural puncture occurs, it is easy to recognize after contrast administration, and neither steroid nor local anesthetic should be administered at that level. Instead, the needle is removed, and the epidural space is accessed at another level. The possibility of intrathecal injection is the reason for using a nonionic contrast medium that has been approved for myelography. If dural puncture occurs, the patient is given postmyelogram instructions (oral hydration and 12- to 24-hour bed rest). By diagnosing a thecal puncture and avoiding intrathecal steroid administration, significant side effects may be avoided.³³

There have been reports of arachnoiditis following intrathecal injection of therapeutic materials.³⁸ It is unlikely that a single subarachnoid injection of a water-soluble steroid preparation will result in permanent sequelae. In fact, intrathecal injections of steroids were once used to treat certain conditions such as multiple sclerosis. Nonetheless, the precautions described earlier for avoiding intrathecal steroid injections are important, since arachnoiditis may be a devastating clinical condition. More acutely, injection of local anesthetic into the thecal sac may result in profound hypotension and transient anesthesia. Transient anesthesia in the lumbar area will wear off in 1 to 3 hours and is usually only inconvenient. In the cervical region, this effect may result in respiratory arrest, necessitating intubation and respiratory support. This is generally avoided by not using anesthetics in cervical epidural injections.

Infection (epidural empyema/abscess or meningitis) is a potential and serious complication that may occur from contamination following skin puncture. Only a small inoculate can cause a significant infection. Such contamination is especially dangerous in the cervical spine. Meningitis may result, with the potential for rapid dissemination within the central nervous system. Obviously, the same meticulous attention to sterile technique that is used for myelography must be exercised for epidural injections.

High volumes of injectate into the epidural space may result in vitreal hemorrhage.^{39,40} Therefore, the total volume of injected materials (including contrast) should be limited to 10 to 13 mL. Transient paralysis also has been described following lumbar epidural injection, but this is extremely rare.⁴¹ This was postulated to be caused by either inadvertent thecal penetration or loculation of the injected fluid (causing transient nerve compression).⁴¹ Another reported side effect is water retention, which is generally short-lived.¹² Some trials reported no side effects in the patients studied.^{17,42,43}

Failure to use fluoroscopy may result in nerve injury and exacerbation of pain symptoms.^{44,45} A published report describing a complication in two patients highlights the importance of performing injections while the patient is awake and carefully monitoring the procedure fluoroscopically.⁴⁶ The patients in this report were sedated intravenously prior to fluoroscopically guided cervical epidural injection procedures. A heavily sedated patient will not display the expected pain response or experience paresthesias resulting from misguided needle placement into the spinal cord. The subsequent injection into the cord produced intrinsic spinal cord injury with permanent symptoms. Fluoroscopy and constant awareness of needle tip position, performing epidurography before steroid injection, and interaction with an awake patient will significantly decrease the chance of such misadventure. Of course, the use of fluoroscopy alone will not ensure against cord injury or thecal sac puncture.

Additional complications may result in anterior radicular arteries due to injection or injury of major feeding anterior radicular arteries to the spinal cord. This is likely the cause of profound complications, such as spinal cord infarction.⁴⁷ Failure to aspirate blood is not a sensitive means of excluding intravascular needle placement.⁴⁸

Conclusion

Selective nerve root and epidural steroid injections are safe outpatient procedures, best performed by using image guidance in conjunction with contrast agents. Use of the techniques described in this chapter will minimize rates of both minor and serious complication. The author has performed several thousand procedures in an outpatient setting without any serious complications.³⁷ Optimal safety and efficacy require an excellent working knowledge of the radiographic anatomy and the imaging equipment used to perform these procedures. Several studies have demonstrated the difficulty and uncertainty of obtaining an accurate injection without imaging guidance. Radiologists who are well trained in the performance of image-guided percutaneous injection procedures are thus best qualified to perform these procedures in a safe and efficacious manner. When properly performed, these procedures have a clinically established role in the management of neck and back pain.

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10

Diagnostic Epidurography and Therapeutic Epidurolysis

K. Dean Willis

Since its introduction in 1985, the Racz procedure (also known as epidurolysis, lysis of adhesions, adhesiolysis, epidural neurolysis, and epidural neuroplasty) has gained widespread acceptance in the pain management community. Early promotion of this technique for delivery of a percutaneous, epidurally administered, lesion-specific dose of steroid for the treatment of low back pain and radiculopathy met with reluctant acceptance at best. Soon published studies verifying the safety and effectiveness of this approach resulted in expanded use and a Current Procedural Terminology (CPT) code paving the way for insurance reimbursement.

The therapeutic benefit of a lesion-specific epidural steroid was demonstrated by Winnie et al. in 1972.¹ Prior to this, confusion existed over the inconsistent results of the blind epidural (nonradiologically directed) approach. All too often repeat epidural steroid injection (ESI) procedures performed without fluoroscopic guidance resulted in profoundly different outcomes. To address this issue, Mc-Carron proposed a pathological mechanism by which epidural fibrosis could be generated by disc disruption resulting in low back pain and radiculopathy.^{2,3} This epidural fibrosis responsible for the generation of pain,^{4,5} produces a space-occupying lesion (SOL) that can inhibit an undirected steroid injection from reaching the painful lesion. Racz and Holubec in 1989 demonstrated that the fluoroscopically directed technique of epidurolysis is superior to the blind technique because it guides the steroid injectate more specifically to the target lesion.⁶ Since that time many investigators at multiple centers have published studies demonstrating the advantages of this technique over its predecessor.7-15

Kuslich and others have independently demonstrated that ventral structures of the epidural space (posterior annulus, posterior longitudinal ligament) producing low back pain and traction of the lateral nerve roots secondary to adhesions within the neuroforamen are the primary sources of nociception in the epidural space.^{4,5,16–19} A review article by Anderson cites prospective studies demonstrating improved clinical outcomes and cost-effectiveness with this ventral epidural approach.²⁰ Therefore, a ventrolateral catheter placement is preferable to a midline or posterior catheter position.^{9,10,21}

The fluoroscopically directed epidurogram and epidurolysis treatment offers five distinct advantages over nonvisualized epidural steroid injection:

- 1. Epidurography provides diagnostic evidence of the suspect pain generator(s).
- 2. Catheter-guided, lesion-specific administration of epidural steroid has therapeutic advantages over the blind technique.
- 3. Documentation of the injection site (epidural vs subdural vs subarachnoid) provides important medicolegal information.
- 4. Having radiographic confirmation of injectate spread and having the needle entry distant from the site of pain pathology provide greater physiological safety.
- 5. Lysis of adhesions by both mechanical catheter placement and injection sequence treats the cause of pain (epidural adhesions) rather than merely providing symptomatic reduction of annular inflammation and/or radiculitis.

Epidurography

Epidurography is the diagnostic portion of the procedure without which epidurolysis or adhesiolysis cannot be accomplished. At this point a few pearls must be understood.

First, an area of abnormal contrast filling must be identified; this area must correlate with the patient's clinical presentation. For example, a patient who presents with symptoms of neurological dysfunction in a right L5 distribution should demonstrate a SOL involving the right L5 nerve root. A SOL involving an unaffected nerve root is not clinically significant. In other words, a space-occupying lesion warrants epidurolysis only when it is identified at the site predicted by the patient's symptomatology.

This does not mean that a steroid injection cannot or should not be performed at the predicted site in the absence of a contrast filling defect—only that in the absence of evidence of epidural adhesions (lack of a SOL), epidurolysis is not indicated. Ironically, it is in patients with no evidence of a SOL that a site-specific, epidurally administered steroid is likely to have its best clinical effect. This is often a circumstance when the pathology is simple radiculitis without adhesions of the nerve root within the neuroforamen. Long-term improvement is more likely if there is not adherence of the nerve root to surrounding tissue, which can reproduce a neuroinflammatory response after the steroid effect has worn off.

One must be well acquainted with the appearance of a typical epidurogram (Figure 10.1) to identify one that is abnormal or pathological (Figure 10.2).



FIGURE 10.1. Typical epidurogram: bilateral S1, L5, L4 with filling defect on left at the L3-4 disc level.

Pathological filling defects can be produced by the following structural abnormalities:

Epidural scarring or fibrosis Vascular congestion Disc material Tumor

Epidural fibrosis can be produced by a variety of mechanisms. The most common of these mechanisms is postsurgical scarring, producing the ill-defined and primarily descriptive diagnosis of "failed back surgery syndrome."²² One must recognize that postoperative fibrosis is not necessarily limited to the level or side of surgical intervention. Many "failed" back surgeries are due to an inaccurate diagnostic assumption of discogenic pain in a patient whose nociceptive stimulus may have been post–disc disruption epidural fibrosis. An abnormal-appearing disc is not necessarily painful, just as a normal-appearing disc is not necessarily nonpainful. McCarron used a dog model to demonstrate the intense inflammatory reaction that occurs in the epidural space in response to exposure to intradiscal nuclear material following disc disruption with or without discogenic pain.²

Vascular compromise secondary to venous compression and proximal distention can produce tissue edema and fibrosis, as well as an epidural filling defect with neuroforaminal compressive injury.



FIGURE 10.2. Epidurogram demonstrating an obvious filling defect of the left L5 nerve root.

Degenerative disease of the discs, vertebrae, or facets can produce an inflammatory epidural response. Likewise, disc disruption with bulging, herniation, or frank extrusion can produce a space-occupying lesion identifiable by epidurography with the cal sac impingement, nerve root compression, and/or painful distention of the posterior longitudinal ligament.⁵

Tumor of either primary or metastatic origin can be responsible for the appearance of a filling defect in the epidural space. The highly vascular nature of such tissue predisposes the patient to a higher risk of epidural hematoma with catheterization and mechanical disruption. A high level of suspicion must be maintained for such pathology when space-occupying lesions are identified.

Therapeutic Indications and Contraindications

The indications and contraindications for diagnostic epidurography with possible epidurolysis consist of one or more of the following:

- 1. Back or neck pain, with or without radicular pain of chronic duration
- 2. Unresponsiveness to conservative therapy
- 3. Lack of obvious source of pain pathology
- 4. Absence of focal neurological deficit

A good rule of thumb is to consider that the presence of a focal neurological deficit requires surgical decompression until another diagnosis is reached, while pain alone suggests a more conservative approach of injection therapy such as epidurolysis. This assumes that loss of function (focal neurological deficit) is most often due to compression while pain is most often inflammation. A compressed nerve root can be further compromised, perhaps permanently, with the potential barotrauma of an injection into a closed space (Figure 10.3A). Saberski et al. demonstrated that as little as 1 mL of injectate into a closed epidural space can produce 400 mmHg pressure.²³ Careful and judicious epidurography can determine the presence of a loculated space that can be decompressed to allow a more normal and safe epidural spread following epidurolysis (Figure 10.3B, C).

General Considerations

The original Racz procedure technique is well documented.^{6,8,15,20,24} As expected, modifications of this original procedure have emerged over the years.^{10,20,25} Changes in procedural technique, medications, and equipment may provide improved outcomes, safety, and cost effectiveness.^{9,12,23,26}

We suggest that practitioners proposing to add this therapy to their practice initially adopt a standard method well reported in the literature without modification. This establishes a dependable method during acquisition of basic knowledge and expertise in the therapy. Modifications can be considered with greater confidence when the entire scope of the therapy is better understood. We should always draw on previous experience (both our own and that of others) in modifying and improving an original idea. The desire to modify procedures carries with it the responsibility to study the effects any change might have on patient outcome. Only in this way can it be determined whether a given change is warranted.

The technical considerations proposed in this chapter have subtle variations from the original procedure that are identified with appropriate rationales. These variations have been discussed with Racz and others who have considerable expertise in the field and are acceptable although not adopted universally.

Technical Considerations

Epidurography and epidurolysis can be performed at any level of the spine from the sacral hiatus to the foramen magnum. The details provided here are generalized to all areas (sacral, lumbar, thoracic, and cervical) unless identified as specific to a particular area of the spine.

Informed Consent

Once it has been determined that a patient meets the accepted criteria for diagnostic epidurography, a detailed discussion of the potential



FIGURE 10.3. (A) Loculated contrast filling with no epidural runoff of contrast. (B) Cannulated right L5 neuroforamen. (C) Epidurolysis (decompression) of right L5 neuroforaminal soft tissue stenosis (graded 5/5A).



FIGURE 10.3. Continued.

risks and reasonable benefits of the procedure should take place. The risks are those typically associated with an intraspinal procedure and should be made clear to the patient both verbally and in written form.

Basic Laboratory

Risks associated with infection and hemorrhage can be minimized with basic laboratory data. A complete blood count with differential and clotting studies should be standard and normal. Prolonged bleeding times, elevated prothrombin and partial prothromboplastin times, and platelet dysfunction should be evaluated and corrected before any intraspinal procedure is undertaken. Patients should be asked whenever possible to stop all anticoagulants 2 weeks prior to the procedure. Persistent abnormalities should be referred to an internist or hematologist for evaluation.

Patient Preparation and Monitoring

Intravenous access is advisable in case of inadvertent subdural or intravascular injection and for mild sedation as required. The injection procedure into areas of neural inflammation can be quite painful. The

injection procedure is generally well tolerated by patients who are not sedated but have been well prepared by learning relaxation techniques and the technique of distraction. An awake, alert patient is requested to give the physician feedback regarding the intensity and distribution of the paresthesias elicited by the injection sequence or catheterization. If sedation is required, a small amount of midazelam (1–2 mg) and fentanyl (25–50 μ g) will suffice for most patients.

Monitoring should consist of noninvasive blood pressure, electrocardiography, and pulse oximetry. The ability to watch trends and record vital signs is recommended.

Patient Positioning

The patient is placed prone on a cushioned fluoroscopy table. The lumbar lordosis is straightened by pillows placed under the hips for elevation. The patient's legs should be slightly spread and the toes inverted. This allows ease of access to the sacral hiatus by helping relax the gluteal musculature.

For cervical procedures, pillows are used to elevate the chest to allow the head and neck to fall naturally into a slightly flexed, direct anteroposterior (AP) position. A lateral position is often recommended to help limit patient movement during the procedure; however, the prone position allows better visualization of the spine and can make specific catheter positioning less frustrating.

Radiation Safety

Protection from harmful radiation overexposure in the form of protective gloves, glasses, thyroid shield, and lead apron should be used ritualistically with every procedure. A lead table apron is also advisable to help reduce scatter from the source (usually located beneath the table) to the gonads. This is the most often neglected source of radiation exposure and can be the most damaging. The C-arm fluoroscope is likewise of supreme importance. One should select equipment with a low scattergram and pulse mode capability. Real-time fluoroscopy can be approximated with a pulse mode of 4 pulses per second, thereby reducing radiation exposure by as much as 80%.

No protection, however, can overcome poor technique. Frequent direct beam exposure of even shielded areas of the body such as hands and forearms will produce radiation burns. The same is true for indirect exposure to the cheeks and nose. Consistent use of radiation badges should be required for all medical staff in the room. Lead-lined walls, though not required for C-arm fluoroscopic suites, are highly recommended.

Needle Placement

Lysis of adhesions located within the sacral spine to the lower thoracic spine can be best accomplished by access through the sacral hiatus. After appropriate local anesthetic infiltration of the area, needle entry is made caudal to the hiatus on the contralateral side from the anticipated epidural lesion. It is generally recommended that equipment specifically designed for the task of epidurography and epidurolysis be used. Many needles and catheters are available, but only the 16-gauge RK needle and the Racz catheter (Epimed International, Inc.) are designed specifically for this purpose. A 20-gauge needle and catheter system is now available and may offer some technical advantages over the larger needle and catheter.

The needle is advanced through the sacral hiatus across the midline, assuring proper positioning within the sacral canal by means of a lateral fluoroscopic view (Figure 10.4A). A small amount of nonionic contrast (1 mL) is injected to confirm spread within the sacral canal in both lateral (Figure 10.4B) and AP views (Figure 10.4C,D). Both views are necessary because, as seen in Figure 10.5, a needle that appears to be within the canal in one view can be clearly outside the canal in the other view. Once the needle has been confirmed to be within the canal, the tip should not be advanced past the inferior ischial spine (S3 level), since the thecal sac extends to this level in some patients, presenting the risk of an inadvertent puncture. Additionally, since catheterization of the ventral epidural space is favored, passing the catheter laterally and ventrally prior to the S3 level is the most advantageous approach.

For cervical or thoracic procedures, an interlaminar approach, approximately 5 mm off of the midline ipsilaterally, is preferred, but if anatomical difficulties arise, a contralateral paramedian approach can be utilized to enter the epidural space. Ideal entry is 3 to 4 segments below the anticipated space-occupying lesion, such that the initial needle entry does not disrupt the epidural anatomy prior to the epidurogram. A typical entry level for cervical epidurography is T1-2 or T2-3.

Epidurography

Without a technically proficient epidurogram, the therapeutic accuracy of epidurolysis is reduced. In this diagnostic portion of the procedure, good and consistent technique is essential, and a knowledgeable eye for both normal and abnormal anatomy is required. This section will address both these issues.

Once the epidural needle has been positioned, nonionic contrast medium is injected. Inadvertent injection of ionic contrast into the subarachnoid space can cause catastrophic and permanent damage to the spinal cord and nerve roots. Nonionic contrast approved for intrathecal use is suggested for epidurography.

Normal Epidurography

Figures 10.1 and 10.2 demonstrate typical differences between a normal and an abnormal epidurogram. Many variations of the contrast spread are seen with epidurography. There is so much variation that it could be said that the epidurogram is the fingerprint of a patient's spinal pain. Only after seeing hundreds of epidurograms will a practitioner begin to acquire expertise at recognizing pathology and likely sources of pain pathology. However, even the novice can see the obvious defects of filling that so often exactly match the patient's pain description and distribution.



А



FIGURE 10.4. (A) Lateral view of RK needle placement within sacral canal. (B) View of initial contrast injection within sacral canal.





FIGURE 10.4. *Continued.* (C) AP view of initial contrast injection within the sacral canal (note that the RK needle is pointed toward the side of the anticipated lesion). (D) Completed epidurogram demonstrating complete loculation of contrast at the L5-S1 disc level.



В

FIGURE 10.5. (A) Lateral view of apparent RK needle placement in the sacral canal. (B) AP view of apparent spread of contrast in the sacral canal.



С

FIGURE 10.5. *Continued*. (C) Lateral view of contrast showing superficial spread outside the sacral canal.

Space-occupying lesions producing pain can be along the proximal nerve root but are most often distal within the neuroforamen and ventral in the epidural space. Once a SOL has been identified as consistent with the patient's symptomatology, localized catheterization is needed.

At this point some attention must be given to several other epidurographic abnormalities that could be encountered. The following is a short list of some of these findings that must be recognized.

Complications in Epidurography

Vascular Runoff: Vascular runoff is seen frequently and surprisingly often is associated with negative aspiration. This is due to venous compression by the epidural fibrosis. Large venous plexuses develop, making vascular cannulation likely, as well as hazardous if unrecognized. Figure 10.6A demonstrates venous runoff of contrast on the same side as the catheter, but contralateral venous uptake can also occur, as shown in Figure 10.6B. Figure 10.7 demonstrates similar unexpected vascular uptake after cannulation at the C5 level. In each of these examples, negative aspiration preceded contrast injection.

Loculation of Contrast: Complete loculation of contrast (Figure 10.8A) can produce very high pressure gradients. Without cephalad, caudal,



В

FIGURE 10.6. Attempted epidurolysis of (A) right S1 with ipsilateral vascular runoff and (B) left L4 with contralateral vascular runoff.



В

FIGURE 10.7. (A) Cannulation of right C5 medial neuroforamen. (B) Attempted epidurolysis of right C5 with extensive ipsilateral vascular runoff.





FIGURE 10.8. (A) Caudal epidurogram with complete loculation of contrast medium. (B) Subsequent cannulation of right L5 neuroforamen with decompression adhesiolysis and runoff.

or lateral runoff, very small volumes of injected contrast or other agents can produce intraspinal pressures high enough to cause permanent barotrauma to sensitive nerve roots.^{4,27} If loculation is noted and paresthesias develop, the injection should be terminated and adhesiolysis attempted to improve runoff prior to further injection (Figure 10.8B). If a runoff cannot be produced and/or cannulation above the loculation is not possible, further injection is contraindicated. Figure 10.9 demonstrates complete loculation due to previously undiagnosed grade 4 spondylolithesis of L4 on L5. Further injection here could easily have produced permanent neurological damage.

Subdural and Subarachnoid Injections: Subdural and subarachnoid spreads are two subtle abnormalities often seen with epidurography. Each has a specific appearance distinct from, but quite similar to, a pathological epidural spread. Patients who have undergone multiple lumbar surgeries have often lost their well-defined epidural space, making cannulation of the subdural or subarachnoid space likely. Recognition of dye spread deep to the epidural space is critical to the safety and efficacy of the procedure.

Characteristic of a subdural spread are the smooth rounded edges of the contrast often accompanied by a "shifting lake" appearance: that is, the contrast moves freely in the lateral projection (Figure 10.10).

A subarachnoid or intrathecal spread is recognized by initial loss of resistance to advancement of the catheter as it enters the space filled with cerebrospinal fluid (CSF). The injected contrast material is seen to dissipate rapidly and to spread uniformly in all directions with a dilutional effect on its appearance (see Figure 10.11A,B). The exception to this is the patient with extensive arachnoid adhesions, which add resistance to catheter advancement; with loculations of contrast, the appearance can closely resemble an epidural spread.

Recognition of these areas of contrast spread is important because many steroid solutions contain preservatives and are still suspected by some to cause arachnoiditis if injected intrathecally. More important, inadvertent subdural or intrathecal administration of 10% hypertonic saline can cause permanent neurological dysfunction.^{28–30} Epidural administration has been shown to be safe by dural permeability studies³¹ and by the long-term clinical use of the procedure in thousands of cases at multiple centers since the mid-1980s. Extremely rare reports, however, suggest that anachnoiditis may result.²⁹ Novice and experienced pain professionals should still carry a high index of suspicion regarding inadvertent puncture of the intrathecal space; whenever there is doubt, hypertonic saline anytime should not be used. The addition of hypertonic saline adds benefit to the procedure²⁶ but is not essential to patient improvement and therefore should be treated as an adjunct to epidurolysis.

Catheter Placement (Mechanical Epidurolysis)

Catheter placement into the specific area of pain generating epidural fibrosis is a learned skill. One can easily thread a catheter near the general area of pathology. Guiding the catheter tip laterally into a neuroforamen filled with engorged veins and fibrosis (often thick, dense postoperative scarring) is a more challenging task. The light touch required to guide the specialized catheter into a space-occupying lesion has been described by Racz as "an elegant maneuver, as if sipping tea" (with the little finger held extended). Catheter placement is a skill that cannot be taught, only learned. This critical component of the epidurolysis



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FIGURE 10.9. (A) Epidurogram with complete loculation and paresthesias at 3 cc injected. Injection terminated owing to loculation and paresthesias. (B) Lateral view of (A) demonstrating loculation secondary to grade 4 spondylolithesis of L4 on L5 (vertebral bodies enhanced to show detail).



В

FIGURE 10.10. Subdural spread of contrast with typical smooth rounded edges loculated in the (A) spinal canal, AP view, and (B) the dorsal spinal canal (less often seen in a ventral location), lateral view.





FIGURE 10.11. (A) Epidural catheter position at right L4 with predominantly epidural spread. (B) Subarachnoid spread of contrast seen diffusely with dilutional effect and smooth dissemination. Note the presence of small nerve root evaginations and darker areas of subarachnoid adhesions with loculation (arrow). procedure can be a source of much frustration to expert and novice alike. The familiar edict "first do no harm" is the rule. Sensitive neural structures can be damaged if the technique is not given due respect or if an overly aggressive attempt is made to cannulated specific areas. Such areas of disc or neural pathology not accessible to epidurolysis on initial attempt may be more easily and safely cannulated later, on subsequent attempts. In addition to the mechanical lysis of adhesions that takes place with cannulation, injection of hyaluronidase and steroid softens epidural scarring and creates a more porous adhesion that can often be easily lysed 10 days to 2 weeks later. Subsequent epidurography demonstrates significantly improved filling of the neuroforamen and distal neural sheath, consistent with the clinical improvement of the patient (Figures 10.12).

I recommend routine follow-up evaluation approximately 2 weeks after initial epidurolysis to assess the patient's response, whereupon a repeat procedure may be considered. A second lysis of adhesions in this time frame seems to produce better outcomes, although this has not been confirmed by clinical studies. Anecdotal experience has demonstrated that more lasting clinical improvement is achieved with a second consecutive lesion-specific steroid injection. A more extensive decompression of scarred nerve roots is possible following exposure of the inflamed neural tissues by an initial epidural adhesiolysis procedure.

A specialized spring-tipped catheter designed specifically for epidurolysis is recommended.³² This catheter has a wire stylus that can be curved, giving it steerability while maintaining its coiled-spring tip. The soft tip enhances the safety to intentional cannulation of sensitive injured nerve root areas.

Injection Sequence (Injection Epidurolysis)

A detailed review of all substances discussed in this section was provided by Lewandowski in $1997.^{26}$

Contrast Injection

Once the catheter has been properly positioned, contrast medium is injected again to demonstrate the spread of injectate and the degree to which the filling defect is opened or lysed (injection epidurolysis). This is limited to a volume of 2 to 4 mL. The patient's response to this injection is noteworthy because the reproduction of a familiar pattern of painful paresthesias likely indicates the pathology responsible for the clinical symptoms.

Both the final position of the catheter tip in relation to the neuroforamen and the extent to which the contrast spreads within the neuroforamen affect the adequacy of the epidurolysis. A simple grading scale has been developed to document both results. A grading scale of 1 to 5 is employed, utilizing the neuroforamen as a reference point. The catheter tip position (all positions are assumed to be ventral epidural) is designated in one of the following ways:

- 1. Medial or midline ipsilateral or contralateral epidural space
- 2. Lateral epidural space, but still proximal to the medial border of the neuroforamen



В

FIGURE 10.12. (A) Initial epidurogram demonstrating a filling defect of the left L5 neuroforamen consistent with a clinical presentation of left L5 radiculopathy. (B) Cannulation of the left L5 neuroforamen prior to epidurolysis.



D

FIGURE 10.12. *Continued.* (C) Epidurolysis with spread of contrast transforaminally (graded 4/5B) prior to administration of hyaluronidase, local anesthetic, and steroid. (D) Epidurogram 4 weeks later, with resolution of radicular pain.

- 3. Intraforaminal space, not extending to the lateral border of the neuroforamen
- 4. Intraforaminal space extending to the lateral border, but not beyond
- 5. Catheter tip positioned beyond the lateral border of the neuroforamen

The extent of contrast spread is designated as follows:

- 1. Medial or midline ipsilateral or contralateral epidural spread
- 2. Lateral epidural spread, but still proximal to the medial border of the neuroforamen
- 3. Intraforaminal spread, not extending to the lateral border of the neuroforamen
- 4. Intraforaminal spread extending to the lateral border, but not beyond
- 5. Contrast spread beyond the lateral border of the neuroforamen

The relative volume of contrast seen within the space occupying lesion is likewise graded. Designations of A, B, or C are given to this characteristic of the contrast spread:

- A. Large volume noted with minimal striation or trabeculations (a "full" filling of the space)
- B. Medium volume noted with some striations or trabeculations
- C. Small to no amount of contrast filling of the space, with predominance of striations and trabeculations

A grading of a catheter tip placement and subsequent contrast injection of 1/1B indicates a fairly poor epidurolytic result, with the catheter tip in a medial epidural position and the contrast limited to a modest, trabeculated filling of the medial epidural space. A grade of 3/3C indicates a catheter tip positioned intraforaminally with a very poor, highly trabeculated filling within the neuroforamen, not extending all the way to the lateral border of the foramen. A grade of 5/5A similarly denotes a catheter tip positioned well outside the lateral border of the neuroforamen with a large amount of contrast spread both proximally and distally within the neural sheath.

This A, B, C grading method provides a way of scoring the adequacy of the epidurolysis for later comparison to the clinical results, which in turn helps to determine the reasonableness of a subsequent epidurolysis procedure. For instance, a poor clinical response to a well-placed and adequately decompressed neural sheath (5/5A) would make it unlikely that a second epidurolysis would yield any further clinical benefit. On the other hand, a 2/3B result with short-term clinical improvement might make a second attempt 2 to 4 weeks later well worthwhile.

I recommend recording hard copy radiographs or thermograms to provide evidence of the initial epidural adhesions, subsequent injection sequences, and the results of epidurolysis. This often provides the only evidence of the pathology responsible for the low back pain and radicular symptoms presented. Without such evidence, many patients are unfairly labeled as malingerers or "symptom magnifiers." The pain may not be sufficient to produce an objectifiable physical limitation.

Hyaluronidase Injection

Once the contrast spread has been maximized, an injection of hyaluronidase diluted with preservative-free normal saline is provided. This should have a concentration of between 150 to 500 units/mL. The volume may vary between 3 and 5 mL. There should be a noticeable washout of the contrast previously injected, along with repeat paresthesias. A delay of approximately 3 to 5 minutes should follow, allowing for the sequestration of the hyaluronidase into the adhesive tissues.

Steroid and Local Anesthetic Injection

A combination of steroid and local anesthetic is now injected again in a combined volume of 5 mL. The traditional steroid used is triamcinolone. Methylprednisolone is also used often. Each has specific properties making it more or less desirable for epidural use.²⁶ No single steroid has shown an obvious advantage or disadvantage to date. Typical steroid preparations are 40 mg/mL.

The local anesthetic recommended is bupivacaine 0.25% (2.5 mg/mL). The bupivacaine is diluted with the steroid typically in an 18:3 ratio. This lowers the concentration of bupivacaine to 0.214% with a steroid concentration of 5.7 mg/mL. This specific combination of local anesthetic and concentration has the advantage of helping clinicians to distinguish between an epidural injection and a subdural injection. This is of particular significance when one is considering the use of a hypertonic saline solution for neurolysis following the epidurolysis. This significance is discussed next.

Subsequent Steroid and Local Anesthetic Injection

Following the initial sequence of injections just described for a distinct filling defect, a second similar series can be performed on a subsequent area of suspicious fibrosis. The original Racz procedure promoted a single injection site with volumes of 9 to 10 mL each for the various solutions. Realization that there are often multiple lesion sites has led to the modification that allows multiple sites for injection during a single epidurolysis procedure. The wire stylus is replaced and the catheter is simply repositioned. Care should be taken to avoid inadvertent protrusion of the wire stylus through the side of the catheter's spring tip (Figure 10.13). Following repositioning, the sequence described earlier in the sections on contrast injection, hyaluronidase injection, and steroid and local anesthetic injection, are repeated. The total volume of local anesthetic and steroid is 21 mL, allowing typically for four separate injection sites if necessary. Some space-occupying lesions require both proximal and distal nerve root epidurolysis when distal injection demonstrates a persistent proximal filling defect. Multiple nerve roots may be involved, requiring multilevel epidurolysis.

Each site injected must be observed closely for signs of possible subdural or subarachnoid spread (Figures 10.10B, 10.11B). Any suspicion of anything other than epidural spread should put an end to consideration of the use of hypertonic saline.



FIGURE 10.13. Epidural catheter with wire stylus protruding through side of spring tip.

Hypertonic Saline 10% Infusion

The RK needle is removed, leaving the catheter in place. The catheter is secured with topical antibiotic ointment, sterile gauze, and tape. Depending upon the anticipated duration of the catheter placement and number of anticipated catheter injections, a 0.22 μ m filter should be placed in line to help prevent contamination and infection. Although the original epidurolysis procedure recommends repeat local anesthetic and hypertonic saline injections for 3 successive days, current modifications require only a single hypertonic saline administration on the first day with outpatient discharge.¹⁰ No filter is required for single hypertonic saline infusion with anticipated same-day discharge. Outcomes appear to be similar for the 1- and 3-day infusions, and costs are greatly reduced by outpatient single-day care.

Following the last injection of steroid and local anesthetic, a mandatory wait time of 30 minutes allows for onset of a significant sensory or motor blockade, which will occur if a subdural or subarachnoid injection has transpired. Again, no hypertonic saline should be infused. There should be radiographic verification of all injection sites, contrast spreads, and final catheter position, as well as no significant sensory or motor blockade before the use of hypertonic saline infusion is considered. If a 10 mL volume of 10% hypertonic saline is infused through the catheter via continuous infusion pump at no greater than 20 mL/h (10mL/30 min). Should any significant pain occur during the infusion, it should be immediately terminated and the catheter removed.

Cervical and Thoracic Epidurography and Epidurolysis

Similar symptoms in the cervical and thoracic spine can be safely treated by means of epidurography and epidurolysis. Cervical disc disruption, degenerative disc disease, spondylosis, and postherpetic neuralgia are all capable of producing epidural fibrosis and chronic pain. The pain pathologies that accompany these syndromes can be identified by epidurography and effectively treated by epidurolysis. It is generally held that cervical and thoracic procedures respond exceptionally well to this approach (Figures 10.14 and 10.15).

Recent Developments

Spinal endoscopy is now providing additional proof that epidural fibrosis is associated with the pathological changes of swollen, inflamed nerve roots responsible for radicular pain with or without evidence of disc disruption and neural compression. Direct visualization of the epidural space via spinoscopy (epiduroscopy) allows visualization of only the proximal nerve root as it exits the epidural space and enters the neuroforamen. A catheter placed transforaminally for purposes of decompressing a nerve root does not allow direct visualization, but still requires indirect visualization to verify catheter position, contrast spread and subsequent epidurolysis. Despite recent advances in our ability to visualize these pathological changes directly, indirect visualization by epidurography is still more widely utilized and is considered to be a superior method of treatment by most pain practitioners. However, this newfound ability to photograph epidural structures (both normal and pathological) adds diagnostic specificity to previously theoretical considerations of epidural fibrosis as a source of back and extremity pain.

It has also been proposed that a dual-catheter technique with both a posterior catheter (placed through the sacral hiatus or via the interlaminar space) and a ventral catheter (placed transforaminally) could be utilized with improved clinical efficacy.¹⁶ Detailed descriptions of this technique can be found in the literature^{20,33}; however, published data are not available to validate any improvements in the efficacy of this approach. The relative increased risk of the transforaminal approach has not been quantified, but one must assume the risk to be greater with a neuroforaminal approach. For these reasons, this technique is not currently in widespread use.

Conclusions

Since their inception in 1985, release to the pain management community in 1987, and assignment of an CPT code in 2000, epidurography



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FIGURE 10.14. (A) Epidurogram demonstrating filling defect on right at the C7 nerve root level. (B) Cannulation of the right C7 medial neuroforamen.



FIGURE 10.14. (C) Epidurolysis of the right C7 with transforaminal decompression (grade 3/4A).

and epidurolysis of adhesions are slowly becoming part of our standard of care. While many anesthesiologists still provide epidural steroid injections with a simple hanging drop or loss-of-resistance technique performed without benefit of fluoroscopy, the more sophisticated, fluoroscopically directed, lesion-specific administration of epidural steroid has gained favor. We now have the ability to provide a definitive diagnosis of pathology capable of producing the signs and symptoms of low back pain and radiculopathy, often in the absence of confirmatory radiological evidence. We now understand that abnormalities seen on images produced by magnetic resonance, computed tomography, or myelography do not necessarily cause pain, while normal-appearing structures can be associated with significant disabling pain. A pain physician has the unique opportunity and responsibility to believe a patient's pain complaint while remaining vigilant to any and all findings that might indicate symptom magnification.

Epidurography began as a diagnostic procedure, but the advance of epidurolysis of adhesions provides real long-term benefit to patients suffering with intractable and underdiagnosed or untreated pain. We will need continued development of improved methods to treat that suffering, just like the treatments addressed in this chapter. Innovation thrives where need is great.





FIGURE 10.15. (A) Cannulation of the left C7 neuroforamen with filling defect of proximal nerve root. (B) Epidurolysis of the left C7 nerve root with both distal and proximal spread (grade 3/5B) and slight cephalad filling of the left C6.

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11

Facet Joint Injections

Timothy S. Eckel

Current medical information on spine pain management implicates the facet joints as one causative mechanism in the etiology of spinal pain.^{1,2} Diagnostic and therapeutic facet joint blocks have long been used by anesthesiologists and physical medicine practitioners in the diagnosis and management of spinal pain syndromes, frequently without image guidance. The increasing interest of the interventional radiology community in the management of spine pain promotes the use of careful image guidance in facet therapy to promote objectivity, technical accuracy, and increased patient safety in the evaluation and treatment of these disorders. Knowledge of the anatomy of the facet joints and techniques used in diagnosis and management of facet-mediated pain syndromes is important for any interventionist involved in the treatment of patients with spinal pain. Interventionists play a critical role in objectively diagnosing facet-mediated pain syndromes and in providing accurate intervention aimed at pain relief.

Anatomy

The facet joints (zygapophyseal or z-joints) are paired synovial joints at the posterior aspect of the spinal column (Figure 11.1). Each joint consists of the articulation between adjacent superior and inferior articular processes arising from adjacent vertebrae. Functionally, the joints are thought to play some role in weight bearing in support of the disc and are also felt to play a role in limitation of motion and prevention of damage to the intervertebral disc. The facet joints provide limitations for spinal flexion, extension, and rotation.³ The joint itself is a diarthrodial joint with a fibrous joint capsule and contains synovial fluid and a synovial membrane (Figure 11.2). Hyaline cartilage lines the articular surfaces of the superior and inferior articular processes. The joint capsule is attached to the bony articular processes and is slightly redundant at the superior and inferior margins of the joint (superior and inferior recesses). Each joint is bordered medially and anteriorly by the ligamentum flavum and posteriorly by the multifidus muscle. The articular processes provide a sliding surface for motion with roughly 5 to 7 mm of motion possible along the plane of the joint.



FIGURE **11.1**. Sagittal diagram depicting the components of the lumbar facet joint. The joint is a true encapsulated synovial joint formed from the articulation of adjacent inferior and superior articular processes.

The orientation of each joint varies considerably among individuals, but certain features of the obliquities are characteristic. The cervical facet joints are typically oriented in an oblique coronal plane, angled superior to inferior in a posterior direction. The thoracic facet joints are nearly vertical and coronal in orientation, rotating toward the sagittal plane near the thoracolumbar junction (Figure 11.3). The superior lumbar facet joints are oriented in a nearly sagittal plane, and the plane of orientation rotates outward toward the coronal plane with descent in the lumbar spine so that the joints are in a sagittal–coronal oblique plane at the lumbosacral junction. The articular surfaces of the joint have variable morphology as well and may be nearly linear or convex (Figure 11.4). Familiarity with the orientation of the joint is important in selecting an appropriate needle approach for injection into a joint.

Various ranges of fluid capacity for the joints have been reported, although a reasonable estimate would be roughly 0.5 to 1 mL in the cervical spine and 1.5 to 2 mL in the lumbar spine. In normal joints the capsule is a potential space containing a barely detectable quantity of fluid. The fluid content of the joint and the thickness of the hyaline cartilage typically decrease with age, although joint pathology may result in increases in the amount of joint fluid.



FIGURE 11.2. Axial anatomical diagram of the lumbar facet joint. The articular surfaces of the superior and inferior articular processes are capped with hyaline cartilage. The fibrous joint capsule contains a synovial membrane and a small amount of synovial fluid. The joint is bordered by the ligamentum flavum anteriorly, and by the multifidus muscle posteriorly. FIGURE 11.3. Axial cross sections depicting the change in orientation of facet joints at the thoracolumbar junction. The orientation of the facet joints changes descending along the spinal column from a coronal angulation in the cervical spine to a sagittal oblique orientation in the lower lumbar spine. At the thoracolumbar junction, there is a gradual change in orientation of the joints from coronal to sagittal.



The synovial membrane and joint capsule are both innervated with sensory fibers, including unmyelinated C fibers.^{3–5} Each joint is innervated by a small nerve arising from the medial (median) branch of the primary posterior ramus, which passes over the transverse process and under the mammilloaccessory ligament. The median branch has a characteristic course. In the lumbar spine, the medial branch of the dorsal ramus courses from the neural foramen to the joint capsule directly over the medial aspect of the transverse process at the junction with the superior articular process (Figure 11.5). Each joint is innervated by two medial branches, one from above and one from the same level as the superior articular process of that joint. In the cervical spine, the medial branch courses from the foramen to the joint across a ridge in the middle aspect of the lateral mass of the vertebra (Figure 11.6). The course of the medial branch in the thoracic spine is less well established, though it is thought to be homologous to the course of the lumbar branches, extending over the medial aspect of the transverse processes.

Facet Joints in Spinal Pain

As a synovial joint, the z-joint may be affected by any of the inflammatory processes that involve joints, including rheumatoid arthritis



FIGURE 11.4. Axial computed tomography images depicting the anatomical variation in the articular surface of the facet joints. Joints may have straight or curved articular surfaces, and osteophytic ridging may make joint access difficult for intra-articular injections. (A) The L2-3 facet joints, which have a nearly straight contour in this patient, are oriented in a nearly sagittal plane. (B) The L5-S1 facet joints. In this patient, the articular processes have relatively convex and concave articular surfaces. Osteophytic ridging may make intra-articular access difficult without CT guidance.

FIGURE 11.5. Posterior view diagram of the lumbar spine depicting the typical course of the "facet nerve" or medial branch dorsal ramus. In the lumbar spine, the nerve takes a very typical course along a groove at the junction of the superior articular process and transverse process of a vertebra. Note that each facet joint is supplied by smaller branches arising from the two adjacent medial branches. To block one facet joint, two medial branch injections are typically performed.



and osteoarthritis. The fibrous, bony, and cartilaginous components of the joint may also be injured traumatically. Pain fibers (unmyelinated nerve endings) as well as substance P have been demonstrated in the synovial membrane within the joint and synovial membrane, and within the joint capsule as well. Pain innervation is also present in other local soft tissue structures adjacent to the joint including the multifidus,



FIGURE 11.6. Posterior view of the cervical spine depicting the course of the medial branch. In the cervical spine, the medial branch stereotypically courses along a small groove in the midportion of the lateral mass of a vertebra, before coursing along the bone to innervate the joint. As in the lumbar spine, each joint is supplied by medial branches from levels above and below the joint. the local spinal nerves, and the dura and epidural space. Joint inflammation may cause localized hyperemia and venous stasis, thus affecting other local tissues. The exact neurological mechanisms of facetmediated pain is incompletely understood, although demonstration of pain fibers in the joint and locally provide some possible explanation for what is now a relatively well-accepted pain syndrome (facet syndrome).⁶ Patients may also experience radicular symptoms as a consequence of irritation or mass effect on the spinal nerve locally.

The facet syndrome is characterized by one or more of the following typical complaints:

Local paraspinal tenderness over a facet joint

Posterior pain aggravated by extension and rotation toward the involved side

Hip and buttock pain in a nonradicular distribution Morning pain and stiffness Occasional improvement with heat or anti-inflammatory drugs

Positive response (pain relief) with joint injection

Images may demonstrate abnormalities in the joints including osteophytic spurring, accumulation of fluid in the joint capsule, or a localized synovial cyst. Bone scanning may demonstrate increased bony turnover locally, and examination by magnetic resonance imaging (MRI) may reveal enhancement locally about the joint. Often, however, there is a poor correlation between pain and imaging abnormalities, and the diagnosis is typically made on clinical grounds and confirmed by diagnostic facet joint block with elimination of pain.

Joint injections may be requested for either diagnostic or therapeutic indications.^{7–9} Diagnostic injection may be requested to confirm a clinical suspicion of a facet-mediated pain syndrome. The joint selected for injection may be specifically requested or determined from imaging studies or physical examination. Intra-articular injection of steroid may be used for longer acting anti-inflammatory activity, and there are reports of long-term effectiveness in pain management (>6 months pain relief) depending, of course, on the exact pathological process in the joint. Long-term pain relief appears to be most successful in treating posttraumatic facet syndrome, and injections may be useful to treat injuries of the whiplash and paraspinal strain types.

Facet Joint Block Technique

Facet joint blockade may be requested to confirm a suspected diagnosis of facet-mediated pain, to treat a symptomatic synovial cyst, as a precursor to possible medial branch neurotomy, or for management of chronic facet-mediated spinal pain.^{10–12} Contraindications are those typical for any injection procedure: specifically impaired coagulation, active infection, or allergy to the medications to be used. Levels to be injected are selected on the basis of specific request, physical symptoms (pain diagram), and imaging studies. It is often difficult to localize pain to a single level, and several joints (unilateral or bilateral) may be injected at the same setting, particularly for therapeutic purposes. Multiple injections may confuse diagnosis, however, and should be avoided when a diagnosis block is requested. Injections may be performed with local anesthetic only for diagnosis, and steroid solution may be added if more long-lasting pain relief is the goal. Steroid injection remains somewhat controversial, and long-term benefits are as difficult to prove as they are to disprove. Intra-articular injection of steroid is a well-accepted therapy for pain in other joints (hips, knees, and shoulders), and there is anecdotal evidence of long-term pain relief from facet joint blocks with steroid. While long-term relief cannot be proven, steroid injection may prove useful, particularly in the setting of a comprehensive pain management program, which may include other adjuncts such as strengthening and stabilization therapy.

Injections are typically well tolerated and are performed under local anesthetic only, although some patients may request intravenous (IV) conscious sedation, especially if multiple levels are to be injected. A patient under conscious sedation should be rousable for questioning, since there sometimes is reproduction of typical pain (concordant provocative response) on injection into the joint, which may further substantiate the diagnosis. Injections are typically performed under fluoroscopic guidance, although computed tomography (CT) may be utilized for severely diseased or arthritic joints when intra-articular access is critical.

Several permissible techniques for facet joint blocks may be used and have been described in the literature, including intra-articular injection,^{11–13} periarticular injection, and medial branch block.^{14,15} Intra-articular injection is imperative in some instances (specifically for attempt at drainage or treatment of symptomatic synovial cyst), although periarticular injections are most often used for chronic pain management. Medial branch blocks are most frequently requested as a diagnostic tool prior to planned medial branch rhizotomy (neurotomy), since some reports have suggested that medial branch block may be more accurate than direct joint injection for prediction of outcome.^{16–18}

As with all spinal injections, the procedure, potential risks, and possible outcomes are discussed with the patient, and informed consent is obtained. Potential risks discussed with the patient should include allergic reaction, transient postprocedural pain flare-up, bleeding, and infection. If steroids are to be administered, side effects and risks associated with their use should be discussed as well, and if steroids must be used on a diabetic patient, he or she should be warned of transient effects on blood glucose levels.

For lumbar injections, the patient is placed in a prone position, and the back is cleansed and draped in the usual sterile fashion. The x-ray tube is obliqued to a position parallel to the joint (more obliquity is required in the lumbosacral junction and little obliquity at the thoracolumbar junction). The orientation is selected under fluoroscopy to directly view the joint along the imaging plane, parallel to the articular surfaces of the articular processes (Figure 11.7). Once the joint has been profiled, local anesthesia is achieved in the skin overlying the joint along the selected plane of orientation. For intra-articular technique, a 22-gauge needle is advanced in the plane of the joint space until bone



FIGURE 11.7. Oblique radiograph along the plane of a lumbar facet joint. The articular surfaces of the superior and inferior articular processes are seen en face. Although this projection is the best depiction of the articular surfaces, the posterior opening in the joint may not lie directly in this plane because the articular surfaces are sometimes curved. Injecting at the superior or inferior articular recess may help maximize access to the joint for intra-articular injections.

is encountered. The needle may be advanced into the middle aspect of the joint, although I prefer to advance into the inferior or superior aspect of the joint because there is some redundancy in the superior and inferior recesses that makes intra-articular placement less difficult. If intra-articular placement is desired, a small amount (0.3-0.5 mL) of contrast material is injected slowly under fluoroscopy (Figure 11.8). If the needle tip is intra-articular, contrast material will extend into the joint and fill the superior and inferior articular recesses. If contrast material pools at the needle tip or extends into the multifidus muscle, the stylet is replaced within the needle, and the needle is partially withdrawn and redirected into the joint. The needle can typically be felt to enter the joint as it is walked off the bone locally. When placement has been confirmed by arthrogram, the block is carried out by intra-articular injection of solution containing a local anesthetic (e.g., 1-1.5 mL of 0.25% bupivacaine), with or without a long-acting corticosteroid (e.g., 10–40 mg of methylprednisolone in solution). The patient should be monitored for a pain response, since typical or concordant pain symptoms may sometimes be elicited on capsular distension. Injection of larger volumes of anesthetic should be avoided in diagnostic blockage, specifically to avoid capsular rupture and leakage of anesthetic into the soft tissues, which might anesthetize other levels and cloud diagnostic accuracy.

FIGURE 11.8. Oblique radiograph of the lumbar spine demonstrating a typical lumbar facet joint arthrogram. A small volume of contrast material can be seen between the superior and inferior articular processes, and extending into the capsular recesses.



For periarticular injection, the approach is identical to that used for intra-articular injection, but arthrography is not performed. The needle is advanced to contact bone at the level of the joint capsule. After negative aspiration to confirm needle tip positioning outside the vasculature, the injection is performed. A slightly larger volume may be injected (up to 2–2.5 mL of anesthetic with steroid), and the needle may be partially withdrawn and redirected to other sites along the same joint capsule to "pepper" the joint with anesthetic. Negative aspiration for blood should be performed prior to injection to confirm positioning outside the vascular space. For multiple injections at the same setting, corticosteroid quantities for each joint may be reduced to keep the total dose within reasonable limits (80–120 mg of methylprednisolone).

In the cervical spine, the approach is typically from posterior or posterolateral, although a lateral approach has been described as well. An IV line is typically started in all patients for cervical injections in the event that IV medication or fluid bolus may be necessary; IV conscious sedation may be used but is frequently not necessary. The cervical facet joints are angled in a coronal plane from superior to inferior. Joint access is facilitated by approaching the joint from posterior and below. The patient should be positioned prone with chest elevated on a bolster and the neck slightly flexed. Positioning with arms at the patient's sides will facilitate lateral fluoroscopy when this is needed; positioning with arms over the head prohibits lateral viewing. The fluoroscopy tube is angled in a caudocranial direction to visualize the lateral masses and articular facets (Figure 11.9). The cervical facet joints are difficult to visualize directly along the plane of the joint, and the joint space is frequently not seen directly, though its position is inferred between adjacent lateral masses. The joint can be visualized laterally. A 22- or 25gauge spinal needle is used to enter the skin roughly 2 cm below the joint and is angled superiorly to enter the posterior and inferior aspect of the joint (Figure 11.10). Local anesthesia may be used, although it is not necessary, particularly if the smaller needle gauge is used. A posterior or posterior oblique approach avoids damage to critical vascular structures. Care should be taken to ensure that the needle tip remains over the lateral masses and away from the central canal to avoid inadvertent dural puncture. When bone is encountered, the tube can be turned to lateral projection to confirm positioning in the joint. Minor readjustments of position can be made under lateral fluoroscopy. Arthrography may be performed with intra-articular injection of 0.2 to 0.5 mL of iodinated contrast medium (Figure 11.11). After negative aspiration, 0.5 to 1.0 mL of local anesthetic may be injected with or with-



FIGURE 11.9. Caudocranially angled posterior-anterior (PA) radiograph of the cervical spine, demonstrating the angulation of the cervical facet joints. Access to the joints is facilitated by an approach from the inferior direction, although a direct approach along the plane of the joint is often difficult because it may entail traversing the musculature of the upper back. A posterior approach is made from the inferior direction to maximize accessibility of the joint, although a direct approach along the plane of the joint is frequently not possible. **FIGURE 11.10.** Lateral radiograph of a cervical spine showing a needle in a cervical facet joint. An inferior approach has been taken to access the joint, although the coronal orientation of the joint makes access along the plane of the joint difficult.



out corticosteroid (e.g., 10–20 mg of methylprednisolone). As in the lumbar spine, a higher volume of injectate may be used if periarticular injection is undertaken rather than intra-articular.

Thoracic facet joint blocks are infrequently requested, although those joints in some rare instances are a source of pain. The orientation of the joint is similar to that of the cervical facet joints, although more steeply angled craniocaudally. The procedure is performed from a posterior approach similar to that used in the cervical spine, although the needle may require steeper caudocranial angulation for intra-articular technique.

Medial Branch Block (Facet Joint Nerve Block) Technique

As an alternative to joint injection, the medial branch of the dorsal ramus can be blocked directly. Medial branch blocks are typically chosen in the setting of preprocedural screening prior to medial branch rhizotomy, since some studies have demonstrated a higher predictive value for rhizotomy results when medial branch blocks are performed,



FIGURE 11.11. (A) Lateral and (B) PA radiographs of the cervical facet joints following intra-articular injection of 0.3 mL of iodinated contrast. Initial injection of contrast pooled along the posterior aspect of the joint capsule, although after repositioning of the needle in the lateral plane, the second injection demonstrates contrast within the joint extending between the articular processes.

<image><image>

as opposed to joint blocks.¹⁹⁻²¹ In the lumbar spine, patient positioning is identical to that used for facet joint injections. The approach is from posterolateral, but the target is the superior and medial-most aspect of the transverse process at the junction with the superior articular facet (Figure 11.12). The fluoroscopy tube is obliqued minimally laterally to visualize and profile the junction of the superior articular process and the transverse process of the level to be injected. Recall that each joint is supplied by two medial branches: the one just lateral to the joint of interest and the one just above. Once the anatomical target has been visualized, local anesthesia is achieved in the skin along the plane of entry. A 22-gauge spinal needle is typically used. The needle is advanced until bone is encountered, and the tube is turned to the lateral projection to confirm tip positioning at the genu between the lateral aspect of the superior articular facet and the superior aspect of the transverse process. After negative aspiration, blockade may be carried out with injection of 1.5 to 2 mL of local anesthetic with or without corticosteroid. Two medial branch block injections are required to block a single facet joint, since each joint is supplied from the medial branches of the roots above and at the level of the joint.

In the cervical spine the approach is from posterior or posterolateral. The target is the anatomical course of the medial branch along a ridge in the waist in the lateral-most and midaspect of the lateral mass (Figure 11.13). As with lumbar injections, two medial branch injections are required for blockade of one joint, injecting at the lateral masses of the



FIGURE 11.12. Posterior diagram of the lumbar spine showing needle positioning for medial branch blocks to affect the L4-5 joint. The needles are positioned at the expected location of the medial branches (junction of the superior articular process and transverse process) above and below the joint itself. Two medial branches are blocked owing to the dual nature of the innervation of the joint.



B

FIGURE 11.13. Diagram showing the needle positioning for cervical medial branch block. In the posterior projection (A), the needles are placed against bone at the midportion of the lateral masses above and below the joint, in the expected location of the medial branch. As in the lumbar spine, two injections must be performed to fully affect one joint. In the lateral projection (B), the needle tip is typically positioned adjacent to bone with the tip of the needle approximately halfway across the bony spinal canal, well behind the vertebral body and the vertebral artery.

levels above and below the joint of interest. A 25- or 22-gauge spinal needle is advanced from a direct posterior approach to encounter bone at the lateral-most and midaspect of the lateral mass. When bone is encountered, the fluoroscopy tube is turned to the lateral position to confirm needle positioning. If necessary, the needle tip is gradually walked just off the lateral edge of the lateral mass to achieve appropriate positioning. Care should be taken to keep the needle tip positioned along a plane at the midportion of the facet joints as viewed from a lateral projection, well posterior to the course of the vertebral artery. Once positioning has been confirmed fluoroscopically, aspiration is performed to confirm placement outside the vascular compartment. A small amount of contrast material (0.2–0.5 mL) may also be injected to confirm positioning. After negative aspiration, 0.5 to 1 mL of anesthetic is injected with or without corticosteroid.

Postoperative Care

Following the procedure, outpatients are monitored for 20 to 30 minutes and subsequently discharged home. Prior to leaving the department, all patients should be questioned about their symptoms to evaluate the likelihood of an immediate anesthetic response. Patients are instructed to expect that the anesthetic response will be transient and that they may experience a short-term, postprocedural pain flare-up for perhaps as long as a few days. If steroid was injected, the patient should be advised to monitor for a more delayed response typically occurring 3 days to 1 week after injection. A short-term prescription for a narcotic analgesic may be given to assist in managing a short-term, postprocedural pain flare-up.

Patients who respond well to an initial injection with subsequent recurrence of pain may potentially benefit from sequential injections, or possibly radiofrequency rhizotomy, as clinically appropriate. Care must be taken in repetition of steroid injections to avoid the potential side effects of cumulative steroid doses.

Conclusion

Treatment and diagnosis of chronic back pain is a challenge that faces nearly all medical practitioners at some time. While back pain syndromes are far from completely understood, pathology and inflammation involving the facet joints do play a role in pain generation in some patients with both chronic and acute back pain. Familiarity with the facet joints as pain generators and with injection techniques and blocks is critically important to the practicing spine interventionist. Imaging studies are frequently inconclusive, and the diagnosis of facet joint syndrome may be made only by the response to a carefully performed facet joint block. The spine interventionist and injection techniques also play a critical role in pain management for many of these patients.

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12

Autonomic Nerve Blockade

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Sensory nerves from deep visceral and somatic organs travel with sympathetic nerves of the autonomic nervous system (also see Chapter 1 for more detail about autonomic nerve anatomy). The ability to block sympathetic nerves at key points can help to reduce pain of deep somatic and visceral origin. In addition, some of these sensory inputs along the sympathetic pathways may establish reflex arcs capable of sending impulses back to deep visceral and somatic organs. These reflex arcs can exacerbate pain on aggravation or activation by pain fiber input. Blocking certain key relay centers along the sympathetic nervous system can break down such painful reflex arcs, resulting in relief from deep visceral and somatic pain cycles.

Common Sympathetic Blockades

The common sympathetic blockades are the following:

Stellate: pain from face, neck, upper extremities Thoracic/splanchnic: pain from deep mediastinum Celiac: pain from upper abdomen (especially pancreas) Lumbar: pain from lower extremity Hypogastric: pain from upper pelvis Impar: pain from lower pelvis, perineum

Stellate Ganglion Blockade

The stellate ganglion is composed of the fusion between the most inferior cervical ganglion and the most superior thoracic ganglion. It is located posterior to the junction of the subclavian and vertebral arteries at the C7-T1 level, anterior to the junction point of the C7 vertebral body and its transverse process (Figure 12.1A). The stellate ganglion represents a key relay station for sympathetic nerves from the head and neck as well as from the upper extremity.





FIGURE 12.1. (A) The sympathetic chain in the region of the stellate ganglion, which lies behind the adjacent arteries and in front of the longus colli muscles at the C7-T1 level on each side. (B) Stellate ganglion blockade in a supine patient: anterior–posterior view of the lower neck, with a fluoroscopically guided 25-gauge needle at the junction point of the transverse process and vertebral body of C7. Radiographic contrast material spreads along the muscle plane, but there is no evidence of a vascular spread.

Indications

Following are indications for stellate ganglion blockade:

Pain from upper face and neck (e.g., herpes zoster, Ménière's disease) Pain from upper extremities (e.g., chronic arterial embolic disease, Raynaud's disease, reflex sympathetic dystrophy)

Hyperhydrosis and posttraumatic shock syndromes of the upper extremity

Technique

Anterior-to-posterior image guidance is used in placing the tip of a thin, 25-gauge, 3.5 in. spinal needle at the junction of the C7 vertebral body and the proximal transverse process.^{1,2} Confirmation that the needle tip is not in a vascular structure such as the vertebral artery can be obtained by aspirating and injecting under real-time fluoroscopy 3 to 4 mL of radiographic contrast (Omnipaque 240 or equivalent). The operator should see local pooling of contrast material, never any vascular runoff (Figure 12.1B).

A slow injection of 5 to 10 mL of 0.25% bupivacaine is used for temporary relief. For permanent neurolysis, 5 to 10 mL of absolute alcohol is injected slowly under general anesthetia or heavy conscious sedation (3–6% phenol can also be used in similar volumes). Permanent neurolysis should always follow a temporary test with anesthetic. Treatment with the smaller volumes should be tried, increasing as needed for effect.

An effective stellate ganglion blockade will typically produce an ipsilateral Horner's syndrome along with ipsilateral venous engorgement of the ipsilateral upper extremity. There may also be ipsilateral paresthesia of the face and upper extremity.

The risk of stellate ganglion blockade includes intravascular injection, particularly into the vertebral artery. This could lead to vertebral dissection or occlusion, seizure, and stroke. In addition, the phrenic nerve and recurrent laryngeal nerve are in close proximity to the stellate ganglion, so that either could be temporarily or permanently paralyzed. Bilateral stellate ganglionic block is not advised because it can result in respiratory compromise and loss of laryngeal reflexes. Hypotension and brachycardia may also occur.

Contraindications to stellate ganglion blockade include contralateral pneumothorax, recent myocardial infarction (as the accelerator nerves to the heart pass through the stellate ganglion and will be affected such that any compensatory increase in cardiac output will be prevented), untreated heart block, glaucoma, and uncorrected coagulopathy.

Thoracic and Splanchnic Sympathetic Blockades

The thoracic sympathetics run vertically along the anterior lateral aspect of the vertebral bodies from T2 to T8 and supply the middle and upper deep mediastinal structures (Figure 12.2A). The splanchnic sym-



FIGURE 12.2. (A) The upper thoracic spine region, showing the sympathetic ganglia along the lateral aspect of the vertebral bodies. (B) Thoracic sympathetic blockade in a prone patient. Under computed tomography the needle is guided from posterior to anterior obliquely (small arrows) along the lateral aspect of the vertebral body. The needle tip (large arrow) should lie along the anterior– lateral aspect of the vertebral body: thoracic sympathetic block, T2-T3; splanchnic sympathetic block, T11-T12.

A



В

pathetics arise from T11-12 and give sympathetic supply to the lower mediastinum.

Indications

The indications for thoracic or splanchnic sympathetic blockade include pain from deep mediastinal structures (e.g., locally invasive esophageal cancer, lung cancer).

Technique

The technique for thoracic or splanchnic sympathetic blockade involves placing a needle (22 or 25 gauge) adjacent to the thoracic vertebral bodies just deep enough to the pleural surface so that the tip will lie along the lateral aspect of the vertebrae at the level to be treated.^{2–4} The actual location of the thoracic ganglion may vary from the anterolateral vertebral margin to 15 to 20 mm behind the anterior vertebral margin.⁴ Usually, needle positioning is accomplished from a posterior oblique approach by means of computed tomographic (CT) guidance. Injecting small amounts of saline while passing the needle along an extrapleural course may help to avoid pneumothorax by expanding the extrapleural space (Figure 12.2B).

An injection of 7 to 10 mL of 0.25% bupivacaine can be administered for temporary relief. After appropriate temporary testing, permanent neurolysis can be achieved by using 5 to 10 mL of absolute alcohol. Again, the dose should be the minimum one that will produce the desired effect.

The risk of thoracic sympathetic blockade includes pneumothorax, bleeding, and intravascular injection. The contraindications to thoracic sympathetic blockade are uncorrected coagulopathy and contralateral pneumothorax, and a relative contraindication is allergy to any of the medications that might be administered.

Celiac Plexus Blockade

The celiac sympathetic ganglia are located on both sides of the celiac artery anterior to the aorta and anterior to the cura of the diaphragms (Figure 12.3A). Celiac sympathetic nerves receive and send out impulses to upper abdominal viscera, including the pancreas, spleen, liver, gallbladder, mesentery, transverse colon, and stomach.

Indications

Indications for celiac plexus blockade include the following:

Intractable pain from terminal pancreatic cancer Intractable pain from chronic pancreatitis Intractable pain from other sources of the upper abdomen including visceral arterial insufficiency

Technique

Celiac plexus blockade should always be performed with image guidance; typically CT is used.^{2,3,5} However, some operators prefer ultrasound for needle guidance while others have employed fluoroscopic guidance. For CT guidance, one starts at approximately the T12 level to locate the celiac artery. Caudal-to-cranial tube angulation may be quite helpful to keep the needle out of the posterior inferior lung. Needles should be directed from posterior to anterior such that the tips pass very close to the adjacent T12 vertebral body and terminate on ei-





 Liver

 Aorta

 T12

D

FIGURE 12.3. *Continued.* (C) Celiac plexus blockade in a prone patient. Under CT guidance, the needles enter posterior to anterior, obliquely. The needle tips should lie on each side of the celiac artery (approximately T12 level). (D) Celiac plexus blockade in supine patient. Under CT guidance, the needle passes through the left lobe of the liver. The needle tip should be positioned immediately anterior to the celiac artery.

ther side of the aorta while passing through the cura of the diaphragms (Figure 12.3B). In some situations, it may be necessary to pass the needle through the aorta. (A 22- or 25-gauge needle should not pose a problem as long as the patient is not coagulopathic, Figure 12.3C.)

An alternative to a posterior-to-anterior approach is an anterior-toposterior approach through the left lobe of the liver (Figure 12.3D). This can be done by ultrasound or CT guidance. The needle tip should lie just anterior to the celiac artery. Often an anterior approach requires only a single needle for adequate distribution of medication along both sides of the celiac plexus. Once the needle tip has reached the target, confirmation is achieved by injecting 3 to 4 mL of iodine contrast medium (Omnipaque 240 or equivalent) to confirm that the needle tips are anterior to the cura of the diaphragms and are not in a vascular structure.

For therapy, 10 to 20 mL of 0.25% bupivacaine can be injected for temporary relief. For permanent relief, 5 to 10 mL of absolute alcohol (or 6% phenol) can be administered for a neurolysis (under general anesthesia).

Following celiac plexus blockade, it is important to hydrate the patient generously with intravenous fluids for 24 hours since vascular pooling of blood in the visceral circulation due to splanchnic vasodilation may render the patient quite hypotensive.

Contraindications to celiac plexus blockades include uncorrected coagulopathy, bowel obstruction, and allergy to any of the medications that might be used. Celiac plexus blockades should be avoided when there is an underlying bowel obstruction, since unopposed parasympathetic activity might lead to increased bowel motility.

A common complication to celiac plexus block is backache. Vascular damage or embolization can occur with intravascular injections.

Lumbar Sympathetic Blockade

The lumbar sympathetic plexus lies along the anterolateral aspect of the lumbar vertebral bodies from L2 to L5 (Figure 12.4A). To block this sympathetic chain ipsilaterally, the needle tip is placed along the anterior lateral aspect of the L2 vertebral body.

Indications

Indications for lumbar sympathetic plexus blockade include the following:

Reflex sympathetic dystrophy of the lower extremities Phantom limb pain (lower extremity) Lower extremity pain from vascular insufficiency (e.g., chronic arterial emboli, Raynaud's disease) Lower extremity pain from gangrene, frostbite

Lower extremity hyperhydrosis and posttraumatic syndromes leading to pain and venous engorgement

Technique

Needle placement is accomplished with image guidance from either CT or fluoroscopy.^{2,6,7} A long (6–8 in.) 22- or 25-gauge needle is passed via an oblique route from posterior to anterior. The needle tip is positioned along the anterior lateral aspect of the L2 vertebra (Figure 10.4B). Injection of radiographic contrast (3 mL of Omnipaque 240 or equiva-



FIGURE 12.4. (A) The lumbar sympathetic chain, which lies along the anterior–lateral border of the lumbar vertebra. The intended target for a lumbar sympathetic blockade is ipsilateral L2. (B) Slightly oblique image of the lumbar spine with a clamp marking the site for local anesthesia and needle insertion for a right lumbar sympathetic block. Note that the trajectory is slightly over the transverse process.



FIGURE 12.4. *Continued.* (C) Fluoroscopic image (slightly oblique) showing the 22-gauge needle inserted for the lumbar block. Note the bend at the tip of the needle (arrow), which facilitates steering during insertion. (D) Lateral radiograph shows the tip of the needle along the anterolateral margin of the L2 vertebra.



FIGURE 12.4. *Continued*. (E) Lateral radiograph after injection of 3 mL of radiographic contrast medium (arrowheads). The contrast material spreads along the margin of the vertebra, and there is no sign of vascular filling. It is now safe to inject the local anesthetic for the sympathetic block.



Е

lent) is used to confirm needle tip position and to ensure the absence of any vascular communication (Figure 12.4C–E). Injection of 10 to 20 mL of bupivacaine 0.25% will provide temporary relief. (This procedure may need to be repeated weekly for several weeks for reflex sympathetic dystrophy.) Administration of 10 mL of absolute alcohol (or 6% phenol) will provide permanent neurolysis, again with general anesthesia.

The risks of lumbar sympathetic blockades include intravascular injection into the aorta or inferior vena cava (which may lead to neurological or cardiac toxicity), ureteral injury, and bleeding. Psoas necrosis and visceral perforation have also occurred.

Hypogastric Plexus Blockade

The hypogastric sympathetic plexus is situated at the inferior end of the sympathetic chain and is located just anterior and slightly lateral to the L5-S1 intervertebral disc space (Figure 12.5). It is in close proximity to the iliac artery and vein.

Indications

Indications for hypogastric plexus blockade include the following:

Upper pelvic malignant pain Endometriosis to the upper pelvis



FIGURE 12.5. The hypogastric sympathetic plexus and the impar ganglion. Variability in location occurs, and the intended block is anterior to the L5-S1 disc and anterior to the sacrococcygeal junction, respectively.

Technique

The technique for hypogastric plexus blockade involves placement of needles from posterior to anterior by means of fluoroscopic or CT guidance.^{2,6} The needles pass in an anterior fashion and slightly superior to inferior over the iliac crest in a lateral to medial angulation. The needle tips will lie just anterior to the L5-S1 disc space. Aspiration followed by injection 3 to 5 mL of radiographic contrast material ensures that the needle tips are not in a vascular structure (Figure 12.6).

FIGURE 12.6. (A) Hypogastric plexus blockade in a prone patient. In this posteroanterior view, the needle is directed fluoroscopically from a starting point slightly superior to the iliac crest and lateral to the spine in an inferior-medial direction (arrow). The tip of the needle is situated anterior to L5-S1. Radiographic contrast material (arrowheads) should spread along the prespinus area but should not be in vessels or the bowel. (B) The lateral view confirms the trajectory of the needle (arrows). The needle tip lies immediately anterior to the L5-S1 disc. Radiographic contrast material (arrowheads) spreads along the anterior aspect of the L5-S1 disc without evidence of spread into the bowel or adjacent vessels.





Following confirmation of optimal needle tip location, treatment can be with either 10 to 15 mL of bupivacaine 0.25% for temporary relief. For permanent neurolysis, 10 mL of absolute alcohol (or 6% phenol) is injected (with the patient under general anesthesia).

Complications result from intravascular injection of alcohol or phenol or injury to the bowel from injection of these substances.

Impar Ganglion Blockade

The most caudal ganglion of the sympathetic chain, the impar ganglion is located anterior to the sacrum and posterior to the rectum (Figure 12.5). It marks the end of the sympathetic chain. It receives innervation from the low pelvis and perineum.

Indications

Indications for impar ganglion blockade include the following:

Intractable low pelvic pain and perineal pain as a result of rectal cancer, uterine cancer, or prostate cancer

Endometriosis causing lower pelvic and perineal pain



FIGURE 12.7. Lateral view of the sacrococcygeal region. A needle, bent to produce a back-looking curve (arrows), is introduced fluoroscopically inferior to the coccyx. It is directed superiorly and posteriorly to position the tip at the anterior face of the lower sacrum near the sacrococcygeal junction. Because the rectum lies immediately anterior to the sacrum locally, radiographic contrast material is introduced to ensure that the needle tip is not inside the bowel.

Technique

The technique for impar ganglion blockade involves placement of needle such that the tip is located just anterior to the surface of the sacrum.^{2,6} This may require a double curved needle to be angled superiorly and posteriorly such that the needle tip will lie along the anterior face of the sacrum (Figure 12.7). Alternatively, the needle may be passed through the sacrococcygeal junction. Radiographic contrast should be injected to confirm optimal needle tip location and to exclude a position within the rectum or a vascular structure.

For temporary relief, 8 to 10 mL of bupivacaine 0.25% is administered. For permanent relief, 6 to 10 mL of absolute alcohol or 6% phenol can be administered (with the patient under general anesthesia).

Complications include puncture or injury of the rectum and nerve root injury during neurolysis.

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13

Sacroiliac Joint Injection

M.J.B. Stallmeyer and Gregg H. Zoarski

Sacroiliac (SI) joint dysfunction or arthopathy is thought by many to be a significant source of low back pain and referred lower extremity pain. Bernard and Kirkaldy-Willis¹ reported that 22.5% of 1293 patients with low back pain were symptomatic as a result of SI joint disease. Schwarzer et al.,² using fluoroscopically guided SI joint injections, estimated that the prevalence of SI joint pain in patients with low back pain was between 13 and 30%. From the results of provocation tests and SI joint blocks, Maigne et al.³ concluded that 18% of patients experienced pain attributable to the SI joint.

Sacroiliac joint pain is presumed to be caused by abnormal movement or malalignment of the SI joint. It may result from a variety of causes including spondyloarthropathy,^{4–6} crystal⁷ and pyogenic arthropathy,⁸ pelvic and sacral fractures,⁹ and diastasis resulting from trauma, pregnancy, or childbirth,^{10,11} but it also may be idiopathic.^{12–13}

The patterns of pain referral from the SI joint are variable and are thus difficult to distinguish from other causes of low back pain.^{2,14–16} Presenting symptoms and signs include lower lumbar pain, buttock pain, groin pain, lower abdominal pain, pain radiating to the leg or foot, and focal pain and tenderness over the joint.^{1,2,14,15,17,18} The complex pain referral patterns are explained by the innervation of the joint. The SI joint and the sacroiliac ligaments contain myelinated and unmyelinated axons that are thought to conduct proprioception and pain sensation from mechanoreceptors and free nerve endings in the joint.^{19–21} The anterior aspect of the sacroiliac joint likely derives the majority of its innervation from the dorsal rami of the L1-S2 roots but may also be innervated by the obturator nerve, superior gluteal nerve, and lumbosacral trunk.^{13,22-24} The posterior aspect of the joint is innervated by the dorsal rami of L4-S4, with major contributions from S1 and S2.^{19,22–24} Additionally, the piriformis muscle, which originates from the ventrolateral aspect of the sacrum and inserts into the greater trochanter, may contribute to the production of pain; spasm of the piriformis may produce a compression syndrome of the sciatic nerve, which may pass through or just beneath this muscle.²⁵ Patterns of innervation vary between individuals and may even vary slightly from side to side in an individual patient.

The SI joint has been classified as an amphiarthrosis (two hyaline cartilage surfaces connected by fibrocartilage). In an alternative classification scheme, the superior portion of the sacroiliac joint has been defined as a synarthrosis (articular surfaces connected by fibrous tissue), while the anterior portion and inferior third of the SI joint has been described as a true synovial joint¹³ (Figure 13.1A). In adults, the joint is S or C shaped. On cross-sectional imaging, the joint space, which is usually 0.5 to 4 mm, is oriented along a posteromedial-to-anterolateral plane (Figure 13.1B).

The SI joint is stabilized by a strong ligamentous support system composed of the interosseus sacroiliac ligament, the dorsal and ven-



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FIGURE 13.1. (A) Coronal reconstructed CT image of the sacroiliac joint. The upper portion of the joint is a synarthrosis, while the inferior third is a true synovial joint. (B) Axial CT image of the sacroiliac joint, demonstrating orientation of the joint along a posteromedial-to-anterolateral plane.

tral sacroiliac ligaments, and the sacrospinous and sacrotuberous ligaments.^{26–28} Although the SI joint is mobile, motion is limited to only a few millimeters of translation and 3° of rotation.^{29,30}

Diagnosis

The diagnosis of SI joint pain is a diagnosis of exclusion. Other etiologies of pain such as spinal stenosis, herniated disc, and facet degenerative disease must first be excluded. Various physical maneuvers (e.g., Patrick's test, Gillet test, Gaenslen's maneuver, pain with pressure application to the SI ligaments at the sacral sulcus with the patient prone) have been described to diagnose SI joint pain^{3,16,31–32} but may be unreliable due to the lack of intraobserver and interobserver reproducibility.^{14,33,34} Additionally, many of these maneuvers also stress the lumbar spine or hip joints,³⁵ which may confound interpretation.

Findings of sacroiliitis obtained by computed tomography (CT) include joint space widening or narrowing, juxta-articular demineralization, osteophytes, subchondral sclerosis, erosions of the cortical surfaces and subchondral bone, and ankylosis (Figure 13.2). However, imaging abnormalities on standard CT images are relatively poor predictors of which patients have pain or which patients will obtain relief from SI joint injection. Elgafy et al.³⁶ evaluated the CT scans of 62 patients with SI joint pain who responded to SI joint injection and compared these with the CT scans of 50 asymptomatic age-matched controls. At least one CT finding suggestive of SI joint pathology (osteophytes, joint space narrowing <2 mm, subchondral sclerosis, joint erosions, or ankylosis) was seen in 57.5% of symptomatic patients and 31% of controls. In contrast, CT findings were negative in 42.5% of symptomatic patients.



FIGURE 13.2. Axial CT image demonstrating degenerative changes in the sacroiliac joint, including osteophytosis and subchondral sclerosis.

Bone scan findings also have been determined by some authors to correlate poorly with SI joint symptoms. Slipman et al.³⁷ demonstrated poor sensitivity (12.9%) of positive bone scan findings in patients responding to SI joint injection. In comparison with conventional bone scintigraphy, imaging by means of single-photon emission CT (SPECT) permits better differentiation of radiotracer uptake in the ventral synovial portion of the joint, suggestive of inflammatory causes of sacroiliitis, from uptake in the dorsal syndesmotic portion of the joint, more typical for bony changes due to axial loading.^{38,39}

Magnetic resonance imaging (MRI) allows for detailed evaluation of the SI joint and adjacent soft tissues and is particularly valuable in detecting early changes in the joint in inflammatory and infectious sacroiliitis.^{39–45} Typically, MRI (Figure 13.3) demonstrates focal hyperintensity in periarticular bone on T2–weighted and short tau inversion recovery (STIR) sequences.^{45–46} Bollow et al.⁴² found evidence of early periarticular erosions and contrast enhancement of the joint capsule in MRI imaging of 72% of patients with seronegative spondyloarthropathy and early sacroiliitis but essentially no enhancement in control patients with mechanical causes of low back pain.

Injection of the SI joint has emerged as a diagnostic test, as well as a therapeutic procedure. Diagnostic intra-articular injection was first described by Haldeman and Sotohall.⁴⁷

More recent investigators have described the use of fluoroscopic,^{5,6,48,49} CT,^{43,44,50,51} and MR⁵² guidance to perform the procedure, which greatly improves accuracy of injection.⁵³ Reported clinical effectiveness of SI joint steroid injection has been variable, with some authors reporting little or only transient patient relief⁵¹ and others reporting significant decrease in low back pain.^{5,6,49,52}

Indications for the procedure include edematous change in the SI joints on inversion recovery MR sequences⁵² or a positive response to stress maneuvers on physical exam in patients who fail to improve with physical therapy.⁴⁹

SI Joint Injection Technique

SI joint injections are performed on an outpatient basis and can be performed with fluoroscopic, CT, or MR guidance. Intravenous sedation before or during the procedure is generally not required.

The patient is placed in the prone position and wide sterile preparation of the soft tissues over the sacrum and buttocks is performed. If C-arm fluoroscopy is to be used in imaging the joint, the x-ray beam is angled medial to lateral and is rotated until the anterior and posterior projections of the inferior third of the joint are superimposed on each other (Figure 13.4). For fixed fluoroscopy, the patient is positioned in the prone oblique position to align the x-ray beam with the inferior third of the joint. If two joint planes are seen, the more medial one should be targeted, since it most likely represents the posterior aspect of the joint. Sections measuring 3 to 5 mm are obtained for cross-sectional imaging guidance. The inferior third of the joint is identified,






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FIGURE 13.3. MRI images of infectious sacroiliitis. (A) Axial T1-weighted image demonstrating hypointense signal along the anterior aspect and posterior iliac surface of the right SI joint. (B) STIR image demonstrating hyperintense signal representing edema in corresponding regions.

and the skin marked to identify the entry point for the planned needle trajectory (Figure 13.5).

The overlying skin and soft tissues are infiltrated with lidocaine. A 22-gauge spinal needle is then directed along the axis of the x-ray tube

FIGURE 13.4. Fluoroscopically guided SI joint injection. (A) The x-ray beam is initially directed anterior to posterior; it is rotated medial to lateral until (B) the anterior and posterior projections of the inferior third of the joint are superimposed on each other.



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FIGURE 13.4. *Continued*. (C) The needle is then directed down the x-ray beam axis into the joint. The tip should remain within the joint if placed correctly (D).

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and advanced into the joint. For fluoroscopic imaging, injection of 0.2 to 0.5 mL of contrast material (e.g., Omnipaque 300) can be used to confirm position. Alternatively, the C-arm or patient can be rotated to confirm position; if the needle tip is placed correctly, it should remain within the joint (Figure 13.4C,D).



FIGURE 13.5. A CT-guided SI joint injection. Axial 3 mm images are obtained through the SI joint. The inferior aspect of the joint is identified, and a 22-gauge spinal needle is directed into the joint.

In general, injection of contrast and medication will be difficult if good positioning within the joint has not been obtained. The SI joint can accommodate only a small volume \sim 3 mL. A mixture of 1 mL of 0.5% bupivacaine plus 40 mg of methylprednisolone acetate (Depo-Medrol, Pharmacia and Upjohn; Kalamazoo, MI) is injected with a 1 or 3 mL syringe. Alternatively, 12 mg of betamethasone acetate and betamethasone sodium phosphate suspension (Celestone Soluspan, Schering-Plough, Kenilworth, NJ) may be used as the steroid component.

Recent Developments

Srejic et al.⁵⁴ have reported that injection of the SI joint with hylan, a viscous hyaluronic acid derivative, can give prolonged pain relief in some patients diagnosed with SI joint pain. Four patients reported pain relief beginning approximately 45 to 60 minutes after injection and persisting for up to 8 months.

Conclusion

Sacroiliac joint injection is a minimally invasive procedure that is easily performed with either fluoroscopic or CT guidance. Diagnostic injection is helpful in identifying the etiology of back pain. Therapeutic injection provides pain relief of variable duration in appropriately selected patients.

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14

Percutaneous Vertebroplasty

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Vertebroplasty is a term that describes a surgical therapy that has been performed as an open operative procedure for decades, using bone graft, cement, or metal implants to modify or reconstruct damaged or destroyed vertebra.^{1–12} In these procedures, polymethylmethacrylate (PMMA) has been the cement most often used for reconstruction and augmentation of bone damaged by trauma or tumor invasion.^{1,3,11,12}

Shortly after Galibert and Deramond¹³ performed the first percutaneous vertebroplasty (PV) in 1984 (by injecting PMMA into a C2 vertebra that had been destroyed by an aggressive hemangioma), Dusquenel adapted the procedure to treat the pain resulting from the compression fractures associated with osteoporosis and malignancy; this was reported by Lapras et al. in 1989.¹⁴ A small series followed in 1991 by Debussche-Depriester et al. that reported good pain relief in five osteoporotic compression fractures treated with PV.¹⁵ Even though the procedure was known to be useful in osteoporotic compression fractures, its early use in Europe focused on the treatment for pain resulting from tumor invasion of the spine.

In 1993, PV was introduced into the United States at the University of Virginia by Dion and colleagues (Jensen, DeNardo, and Mathis). These investigators focused their work primarily on osteoporotic compression fractures and subsequently provided the first clinical series from the United States in which PV was used.¹⁶ Their report noted significant pain relief in 85 to 90% of patients treated for painful osteoporotic compression fractures. This was similar to the early reports about PV from Europe. Since that time, the procedure has grown in popularity and is now becoming the standard of care for pain produced by osteoporotic compression fractures of the spine.¹⁷

The osteoporotic population at risk of fracture is huge, with between 700,000 and 1,200,000 vertebral compression fractures a year in the United States resulting from osteoporosis alone.¹⁸ The incidence of compression fracture exceeds that for hip fracture, and the direct costs of fractures yearly in the United States due to osteoporosis is in excess of \$15 billion.^{18–20} Osteoporosis is greatest in elderly Caucasian females,

and the number of affected individuals is growing yearly.²⁰ Additionally, significant numbers of fractures occur in males and in patients receiving steroids for conditions such as cancer, collagen vascular disease, transplant therapy, and severe allergy or asthma.

Percutaneous vertebroplasty is indicated in patients who exhibit pain resulting from vertebral compression fractures (VCFs) that are due to the weakening associated with bone mineral loss secondary to osteoporosis and who are not effectively treated by medical or conservative therapy (i.e., analgesics, bed rest, external bracing, etc.).^{16,17,21–33} Without PV, chronic pain in these individuals typically lasts from 2 weeks to 3 months.³⁴ The chronic debilitation, limitation of activity, and decline in quality of life resulting from these fractures has been shown to result in depression, loss of self-esteem, and physical impairment. Recent data reveal that vertebral compression fractures are associated with an increased mortality of 25 to 30% compared with age-matched controls.³⁵

Though less common than osteoporosis, neoplastic disease is well known as a cause of painful VCFs. These fractures can be associated with primary malignant or metastatic lesions, myeloma, and with aggressive benign tumors such as hemangiomas. Painful compression fractures may have a clinical picture similar to that of the osteoporotic variety. If the etiology is in question, biopsy should precede or accompany the PV, which will not alter or impair other therapeutic measures such as chemotherapy or radiotherapy. The risk of cement leak is higher with a tumor etiology for VCF than with osteoporosis, generally because the vertebra is less intact. The risk of significant cement leak (or tumor extrusion by the cement) is increased with destruction of the posterior wall of the vertebra. With tumor extension into the spinal canal (even without symptoms), PV will have a high risk of creating or exacerbating neural compression and should generally be avoided.

Patient Workup and Selection

Some osteoporotic fractures may generate only mild pain, or there may be a rapid decrease in the initially severe pain after VCF. In either of these situations, PV is not usually indicated. However, persistent pain that limits the activities of daily living or requires narcotic analgesics (with or without hospitalization) may be rapidly diminished with the use of PV. The time between fracture and therapy may be prolonged by failed attempts at conservative management or delayed referral. Patients with severe disability that requires hospitalization and parenteral analgesics should be treated immediately. There is no definite medical requirement for delay of therapy with PV if significant benefit to the patient is to be gained by its use. Some patients may present later with chronic, persistent pain and limitation of normal activity. There are no absolute exclusion criteria based on the time between fracture and PV. However, old fractures (>3 months) are less likely to have beneficial



FIGURE 14.1. (A) Extreme vertebral compression with the patient in expiration. The vertebral height at the point measured is 8 mm. (B) In inspiration the vertebral height increases to 11 mm. This motion is consistent with nonunion and usually associated with severe pain.

results from PV unless one can show signs of nonunion or signs of recurrent fracture (Figure 14.1). Nonunion is indicated by persistent motion noted on fluoroscopy and can signify osteonecrosis (Kummell's disease). Also the finding of persistent marrow edema on magnetic resonance imaging (MRI) scans (which may indicate new or recurrent fracture) is a good indication for PV.

Preoperative augmentation of vertebra prior to instrumentation and routine prophylactic use of PV are not validated for benefit or safety at this time, and these measures should be used with extreme caution under investigational protocols.

On physical examination, the patient's pain location should be consistent with the anatomical location of the fracture considered for treatment with PV. The patient's pain should not be radicular, since this suggests nerve root compression. However, it is not uncommon to have referred pain, and this should not be considered to be a contraindication to treatment (i.e., referred intercostal pain associated with a thoracic vertebral fracture or referred hip pain associated with a lower lumbar fracture). It is often helpful to place a metallic marker at the site of maximal pain and to correlate fluoroscopically the anatomical location of the pain and the compression fracture. It should be remembered that pain localization is limited to no better than plus or minus one vertebral level in most patients.

Simple clinical situations in which physical findings are well correlated with recent radiographic exams may be treated without the addition of complex studies such as MRI, computed tomography (CT), or nuclear medicine (Figure 14.2).

Patients with multiple fractures or nonfocal pain often pose diagnostic dilemmas and require a more complex imaging evaluation. These patients should have magnetic resonance imaging in addition to a recent, standard radiographic evaluation. Acute fractures will be easily demonstrated on T1-weighted sagittal images as having loss of signal in the affected vertebral marrow space (Figure 14.3). Also offering



FIGURE 14.2. Lateral radiograph showing a typical osteoporotic compression fracture (arrow). Compression is typically more in the anterior two thirds of the vertebra, with sparing of posterior wall height.





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FIGURE 14.3. Three sagittal views. (A) The T1-weighted MRI shows an acute vertebral compression (arrow) with low signal in the marrow space. Chronic (healed) compressions have normal (bright) marrow signal (stars). (B) The STIR MRI reveals high signal in the marrow space of the acutely fractured vertebra (arrow). (C) The T2-weighted MRI demonstrates a high signal zone below the superior endplate in a recently fractured vertebra (arrow). This is believed to represent a fluid-filled cleft. Filling of the cleft with cement is essential for pain relief.

high sensitivity for recent fracture and marrow edema (represented by an abnormal bright signal in the involved region) are short-tau inversion recovery (STIR) images with fat suppression. Images made with T2 weighting occasionally give additional information as these sequences can show fluid-filled clefts that can result after fracture. These findings are important because the clefts or spaces should be filled with cement for dependable pain relief.

On T1-weighted MRI sequences, normal marrow will exhibit high (bright) signal, including any vertebra that were previously compressed and have undergone healing. One should be reluctant to perform PV for pain based on MRI unless an acute fracture or persistent marrow abnormality can be demonstrated.

If MRI cannot be performed or leaves doubt with respect to the need for therapy, a nuclear medicine (NM) bone scan may be utilized. However, NM may not be as useful as MRI for primary screening because the former has poorer anatomical resolution [even when single-photon-emission computed tomography (SPECT) is used] and does not give information about conditions such as spinal stenosis, disc herniation, or tumor extension into the epidural space. Also, abnormal activity on a bone scan may persist long after healing has been demonstrated on MRI. A low-level positive NM scan may indicate only normal, progressive healing, which in turn might mislead a physician about the possible benefit of PV.³⁶ However, there is a definite place for NM in patient evaluation. Some patients cannot tolerate MRI, and NM becomes the next best alternative. Rarely, information from the MRI will be insufficient to accurately localize an acute fracture. This usually happens in a very heterogeneous marrow (which may be found as a normal variation in the elderly or with conditions such as myeloma). Then, NM will usually add sufficient information to identify an acute fracture or determine the need for treatment (Figure 14.4).

Computed tomography offers anatomical information (as do standard radiographs) but is unable to distinguish acute from chronic fractures under most circumstances. Therefore CT is not part of the routine initial patient workup. It may be very helpful to evaluate the cause of complications that are possible after PV, such as a cement leak outside the vertebral body. This mode of diagnosis should be used immediately if symptoms worsen or new symptoms present after PV.

The degree of compression does not correlate with the quantity of local pain. Minimal compressions, as measured radiographically, may cause incapacitating pain to some individuals. Even with minimal deformity, acute fractures are easily identified on MRI because they demonstrate local marrow edema. MRI may also show more than one acute compression injury (Figure 14.5). This finding will indicate a need for therapy at each of the involved and painful levels. As the amount of compression increases, the degree of technical difficulty of performing the PV may increase as well. This is particularily true when

FIGURE 14.4. Nuclear medicine bone scan showing increased uptake at T12 (arrow) resulting from an osteoporotic compression fracture.



the compression exceeds 70%. With complete or nearly complete vertebral collapse, the likelihood of successful PV is reduced but not eliminated.^{37,38} Before one attempts PV in a nearly complete collapse, one should obtain an MRI indicating no additional cause of pain. The same MRI should be evaluated to identify residual vertebral marrow space laterally. Often, severe collapse is greatest centrally and will show residual marrow space laterally that can be successfully treated with PV (Figure 14.6). Patients with these lesions should be made aware that there may be a reduced chance of pain relief (in comparison to a modestly compressed vertebral fracture) and higher risk of complication.

Although PV has been shown to be very durable, on rare occasions one may see a refracture with progressive height loss after PV. This



FIGURE 14.5. Sagittal T1-weighted MRI revealing two acute fractures (arrows) at different locations in the spine.



FIGURE 14.6. (A) Sagittal T1-weighted MRI (midline) reveals extreme compression of the center of the L1 vertebral body (arrow). (B) Images along the lateral edge of L1 reveal less compression and more residual marrow space, which can accept bone cement (arrow).

usually occurs when the patient had had a less than optimum fill during an initial treatment (even with good initial pain relief) or in the situation of an extremely fragile vertebra. In either case, the amount of cement introduced probably was not sufficient to restore adequate strength to resist recurrent compression. Pain relief and cement filling are poorly correlated. Recurrence of pain, marrow edema, and additional vertebral collapse may indicate the rare need for repeat treatment.

Cement Selection and Preparation

The first bone cement used for PV was the PMMA Simplex P (Stryker-Howmedica-Osteonics; Rutherford, NJ).¹³ This is the only cement approved by the U.S. Food and Drug Administration (FDA) for use in the treatment of pathological fractures in the spine. It is not specifically approved for PV. Multiple other PMMA cements have been used for PV and seem to have similar clinical results.^{16,17,33} It is important to note that bone cement is not treated as a pharmaceutical by the FDA but rather as a device. Alterations in the composition are therefore equivalent to making a new (nonapproved) material. It has been suggested by other authors that such alterations constitute "off-label" use.³⁹ Off-label use would be correctly applied if an unaltered cement were used in a nonindicated application or location. Alteration in the ratio of monomer to copolymer (liquid to powder) or addition of other materials (opacification agents or antibiotics) results in the creation of a new material, and FDA approval no longer exists. Patients should be informed that such alterations in the cement are to be used and the reasons and consequences behind these changes should be discussed.

Inherent in performing PV safely is the need to accurately monitor the injection of cement in real time.³³ This is usually accomplished with fluoroscopy and requires that the cement be opacified so that it may be adequately seen in small quantities during introduction. It has been determined that barium sulfate, in quantities of 30% by weight mixed with the PMMA, will provide an appropriate level of opacification.^{33,40,41} Simplex P as supplied contains only 10% by weight of barium sulfate, therefore additional barium sulfate needs to be added to obtain an adequate mix for visualization. In vitro, biomechanical evaluations have been performed that demonstrate that this change alters the handling and mechanical properties of the cement minimally. However, a more significant mechanical alteration occurs with changes in the ratio of liquid to powder.^{40–42} I use two methods to slow the polymerization of Simplex P. First, 20 mL of powder is removed from a full dose package (40 g) of powder, discarded, and replaced by 12 g of barium sulfate to bring the barium load above 30% by weight. During mixing, all the monomer (20 mL) is added, having been chilled near 0°C for 24 hours or more. The second technique used to retard polymerization involves chilling the cement once mixed. Immediately after mixing, all syringes to be used for injection are placed in a bath of chilled, sterile normal saline (Figure 14.7). The change in monomer-to-powder



FIGURE 14.7. Filled 1 mL syringes are placed into a bath of chilled normal saline (arrow) to retard cement polymerization. An additional measure to retard polymerization was the initial removal of 20 mL of cement powder (star). This was done with a sterile 5 mL teaspoon (arrowhead).

ratio and chilling of the mixed cement will give a working time for Simplex P of over 15 minutes. Clinical studies using the modified cements have reported uniformly positive results.^{16,7,33} Indeed, the safety of the procedure seems mainly to depend on preventing cement leaks, rather than on which cement is used.³³ No untoward results related to cement alterations have been reported clinically.

Some investigators add antibiotics routinely to PMMA prior to injection, the most common antibiotic being tobramycin.^{16,33} However, the infection rate with PV is very low, and the efficacy of adding antibiotics to the cement has not been scientifically substantiated in normal, uninfected patients. One report in the orthopedic literature did show reduced infection rates in hip replacement in which cement containing antibiotics was used for immunosuppressed patients.⁴³ For these reasons, I do not recommend the addition of antibiotics to cements except in the situation of immunocompromise.

Adequate precaution should be used during cement mixing to maintain sterility. Cement manufacturers provide closed, vacuum mixing materials that aid in maintaining a sterile environment. Open mixing, which increases the risk of cement contamination and reduces the cement strength by the inclusion of air bubbles and may produce inhomogeneous mixing of opacifiers with the cement, should be avoided whenever possible.

Vertebroplasty Technique

Informed Consent

Written permission for the procedure is recommended, following a complete discussion with the patient and/or the patient's representative of the procedure, including the risks and complications. This may include a discussion of the need to modify cement for use in this procedure.

Image Guidance

Since the first PV procedure,¹³ fluoroscopy has been the preferred method of image guidance for performing PV, although CT has infrequently been used as a primary or adjunctive tool.^{44,45} Because this procedure was initiated and popularized by interventional neuroradiologists, biplane fluoroscopic equipment was commonly available and often used. This equipment allows multiplanar, real-time visualization for cannula introduction and cement injection and permits rapid alternation between imaging planes without complex equipment moves or projection realignment (Figure 14.8). However, this type of radiographic equipment is expensive and is not commonly available in interventional suites or operative rooms unless it is used for neurointerventional procedures.

It takes longer to acquire two-plane guidance and monitoring information with a single-plane than with a biplane system. However, it is feasible and safe to use a single-plane fluoroscopic system as long as the operating physician recognizes the necessity of orthogonal projection visualization during the PV to ensure safety. With a single-plane system for PV, these C-arm moves will mean a slower procedure than that offered by a biplane system.

Gangi et al.⁴⁵ introduced the concept of using a combination of CT and fluoroscopy for PV. This method gained a brief period of popularity in the United States with the study published of Barr et al.⁴⁴ Barr subsequently abandoned CT for routine PV. Although the contrast resolution with CT is superior to that of fluoroscopy, with CT one gives up the ability to monitor needle placement and cement injection in real time. Even so, CT may be acceptable for needle placement, particularly if a small-gauge guide needle is first placed to ensure accurate and safe location before a large-bore bone biopsy system is introduced. However, CT certainly is not optimum for monitoring the injection of cement. For this reason, Gangi et al.⁴⁵ and Barr et al.⁴⁴ used fluoroscopy in the CT suite during cement introduction. CT does not afford one the opportunity to watch the cement as it is being injected or to alter the injection volume in real time if a leak occurs. Also, unless a large section is scanned with each observation, if leaks occur outside the scan plane, they may be missed if one is looking only locally in the middle of the injected body. Barr et al.44 used general anesthesia with CTguided surgery because of the need to minimize patient motion. This



FIGURE 14.8. Biplane fluoroscopy/angiography room. The ability to perform fluoroscopy in two projections without having to move equipment greatly speeds and simplifies vertebroplasty.

was successful but added a small additional risk to the procedure and considerable complexity and cost. For all these reasons, CT has not found a primary role in image guidance for PV; it is reserved for extremely difficult cases.

Laboratory Evaluations

Coagulation tests results should be normal, and the patient should not be taking Coumadin. Coumadin may be discontinued and replaced with enoxaparin sodium (Lovenox; Rhône-Poulenc Rorer Pharmaceuticals, Inc., Collegeville, PA), given once or twice a day on an outpatient basis. Coumadin may also be stopped and replaced with heparin, but this medication must be administered intravenously, requiring hospital admission. Both enoxaparin sodium and heparin can be reversed with protamine sulfate before PV and restarted postoperatively. Aspirin use is not a contraindication to the procedure.

PV is not recommended for patients with signs of active infection, but elevated white blood cell counts clearly associated with medical conditions such as myeloma or secondary to steroid use are not contraindications.

Antibiotics

For PV, as for other surgical procedures that implant devices into the body, intravenous antibiotics are routinely given (usually 30 minutes) before the procedure is begun. The most common antibiotic used in this application is cefazolin (1 g).⁴⁶ If an alternative must be used because of allergy, ciprofloxacin (500 mg orally, two times daily) may be substituted and continued for 24 hours after the completion of the procedure. Optimally, an oral antibiotic should be started 12 hours before a PV procedure.

As mentioned earlier, antibiotics are added to the cement itself only in the situation of immunocompromise.

Anesthesia

During PV, it is common to use both local anesthetics and conscious sedation to make the patient comfortable and relaxed. Patients who request not to receive intravenous sedation or cannot have it for safety reasons still can be treated with only mild discomfort if appropriate attention is given to local anesthetic placement. To reduce the sting and discomfort associated with locally administered anesthetics (lidocaine, etc.), one may buffer the anesthetic by the addition of a mixture of 1 mL of bicarbonate and 9 mL of lidocaine. This mixture reduces, but does not eliminate, the anesthetic sting. I commonly use a mixture that includes both bicarbonate and Ringer's lactate (Table 14.1), which essentially eliminates the sting of the local anesthetic. At my institution, this mixture is prepared daily for all procedures requiring local anesthetics. The excess is discarded at the end of each day. This preparation has a low concentration of lidocaine (0.5%) and allows the use of a more generous volume locally with less risk of toxicity.

Whatever the chosen local anesthetic preparation, the skin, subcutaneous tissues along the expected needle tract, and periosteum of the bone at the bone entry site must be thoroughly infiltrated. When this has been accomplished, the patient will experience only mild discomfort while the bone needle is being placed, regardless of whether conscious sedation is used.

Conscious sedation has become a common adjunctive method of pain and anxiety control in awake patients who undergo minimally

		Amo		
Solution ^a	Lidocaine (4%)	Lactated Ringer's	Bicarbonate	Epinephrine
1	4	24	2	0
2	4	24	2	0.15 (1:1000)

^aSolution 1 makes a "sting-free" local anesthetic with 0.5% lidocaine. Solution 2 is "sting free" with 0.5% lidocaine and 1:200,000 epinephrine. These preparations should be mixed daily and discarded at the end of the day. The total volume of each mix is 30 mL.

invasive procedures. I use a combination of intravenous midazolam (Versed, Roche; Manati, PR) and fentanyl (Sublimase, Abbott Labs; Chicago). To decrease anxiety and diminish the discomfort associated with positioning, it may be helpful to begin these medications before the patient is placed on the operating table. Dosages are chosen according to patient size and medical condition. The final amount is determined with titration while observing the patient's response.

General anesthesia is rarely needed for PV, but it is used occasionally for patients in extreme pain who cannot tolerate the prone position used in PV or for patients with psychological restrictions that preclude a conscious procedure. It is not needed for routine PV and should be avoided when possible because it adds a mild risk and considerable cost to the procedure. As described earlier, Barr et al.⁴⁴ used general anesthesia routinely with CT-guided procedures to ensure minimum patient motion.

Needle Introduction and Placement

The original choice of a device for percutaneous cement introduction was based on device availability. The size of these devices was empirically chosen to allow the viscous PMMA cement to be injected. Originally 10- to 11-gauge trocar–cannula systems were used. It is becoming progressively common to see smaller gauge (13–15) needles used routinely. All will work with the least resistance during injection found with the larger bore, while the smaller needles are useful in small pedicles or in the cervical spine. From the thoracic through lumbar spine, a 13-gauge cannula can be placed through the adult pedicle without fear of its being too large.

Several introductory routes for needle delivery are possible, including (1) transpedicular, (2) parapedicular (transcostovertebral), (3) posterolateral (lumbar only), and (4) anterolateral (cervical only). The classic route for most PV is transpedicular. It offers the following advantages.

- 1. It usually provides the operating physician with a definite anatomical landmark for needle targeting (Figure 14.9).
- 2. It is very effective for PV and for biopsy of lesions inside the vertebral body.
- 3. It is inherently safe and does not carry the risk of needle damage to other adjacent anatomical structures (nerve root, lung, etc.) as long as an intrapedicular location is maintained.

In the upper thoracic region and in small patients, the pedicle may be too narrow for an 11–gauge needle. In this situation, a 13–gauge needle should be used.

The parapedicular or transcostovertebral approach (Figure 14.10) was devised to allow access when the transpedicular route is not desirable (e.g., small pedicle). Since the needle passes along the lateral aspect of



FIGURE 14.9. (A) Typical transpedicular route for needle placement into the vertebral body. (B) Anterior–posterior radiograph demonstrates the placement of the needle through the pedicle, which is seen as a well-circumscribed oval (arrow). In this projection, the needle is initially positioned during fluoroscopy while being held with a clamp (arrowhead) to avoid x-ray exposure to the operator's hands. (C) Lateral fluoroscopic image demonstrates the final needle position beyond the midline of the vertebra.





the pedicle, rather than through it, a small pedicle does not preclude using an 11-gauge needle for cement introduction. Also, this approach angles the needle tip more toward the center of the vertebral body than does the transpedicular approach. At least in theory, this angle may allow easier filling of the vertebra with a single injection. There is a higher chance of pneumothorax with a parapedicular approach than with the transpedicular route. A second potential problem with the parapedicular route is that the needle enters the body only through its lateral wall. This approach may increase the risk of paraspinous hematoma after needle removal. Because with a parapedicular approach the osteotomy site occurs laterally along the side of the vertebra, one cannot apply local pressure after needle removal as can be done with the transpedicular route.

In the cervical spine, a transpedicular route is very difficult, so an anterolateral approach may be used as an alternative. Needle introduction must avoid the carotid–jugular complex. To accomplish this goal, the operating physician (as in cervical discography) can manually push the carotid out of the path of the needle. Alternatively, CT can be used to visualize the carotid, and a trajectory that will miss the vascular structures can then be chosen. A small guide needle can be inserted to ensure accurate placement outside the carotid complex. I prefer the guide needle alternative because it gives positive guidance and confirmation without excessive fluoroscopy to my hands during needle introduction. However, because osteoporotic fractures in this area are rare, the cervical spine only occasionally undergoes PV. Neoplastic disease may produce an occasional need for PV intervention in the cervical spine.

Once the needle route is chosen, local anesthesia is administered, and a small dermatotomy incision is made with a no. 11 scalpel blade. The trocar-cannula system is introduced through the skin incision and subcutaneous tissue to the periosteum of the bone. This introduction can be facilitated with a sterile clamp to guide the needle during fluoroscopy, thus avoiding radiation to the operating physician's hands (Figure 14.9B). In osteoporotic bone, penetrating the bone cortex and advancing the needle into the body is usually very easy. In a patient with neoplastic disease, the bone may still be very dense and strong (except where it has been destroyed by a tumor). The use of a mallet to advance the needle through very dense bone is a technique clearly superior to manual advancement. Regardless of whether a transpedicular or parapedicular route has been chosen, the tip of the needle should lie beyond the vertebral midpoint as viewed from the lateral projection. I usually try to obtain an even more anterior position by placing the needle tip at the junction of the anterior and middle thirds.

Two needles are routinely placed, usually via the transpedicular approach. This takes minimally longer than a single needle placement and affords a large margin of safety for being able to dependably complete a vertebral fill with a single mix of cement. There is no question that a single needle placement can give an adequate fill in a large number of cases. However, the single-needle method fails to produce uniform fills more often than the double-needle technique and may oblige the operator to accept a larger cement leak during filling (if the second needle is not in place as an alternate injection route).



FIGURE 14.10. (A) Needle location for parapedicular (extrapedicular) placement. (B) Lateral projection demonstrating that the needle must enter above the transverse process on the parapedicular approach.

Venography

Venography was never used much in Europe and was introduced in the United States in an attempt to discover potential leak sites prior to injecting cement. However, this technique worked poorly because the contrast material and the bone cement differ hugely in viscosity. I discontinued using venography in 1996 and have found no disadvantage or added risk without its use.⁴⁷ Other long-term proponents have belatedly stopped its use in routine PV as they found no safety benefit to its use.⁴⁸

Cement Injection

Cement is prepared only after all needles are placed, as described earlier ("Cement Selection and Preparation"). Cement with an appropriate opacification is prepared and injected using small syringes (typically 1 mL) or devices made specifically for injection (Figure 14.11). This allows easy control of the cement introduction. Either the cement



FIGURE 14.11. Cement injection with a 1 mL syringe. Note bipedicular needle placement prior to beginning cement injection.

injection should be monitored in real time or small quantities (i.e., 0.1–0.2 mL) injected and the result visualized before additional cement is introduced. The latter approach, which allows one to step back from the fluoroscopy beam during visualization, minimizes radiographic exposure to the operator.

Any cement leak outside the vertebral body is an indication to stop the injection. When using a rapidly polymerizing cement (e.g., Simplex), this may be necessary only for a minute or two while the injected cement hardens. Restarting the injection may then redirect flow into other areas of the vertebra. If leakage is still seen, it is advisable to terminate the cement injection through this needle and move to the second needle. This will usually allow completion of the vertebral fill without further leakage, since the original leak now will be occluded by the initial cement, which will have hardened. One should work through a single needle at a time. This avoids contamination of both needles at once and preserves a route for subsequent injection if a leak is encountered. Injection of thick cement should be safer than a very liquid consistency. Cement can still be introduced beyond the point at which the injection devices are able to deliver it. The trocar is useful to push additional thick cement from the cannula into the vertebra. The 5 in., 13-gauge cannula holds 0.5 mL, and the 5 in., 11-gauge cannula holds 0.9 mL. Reintroducing the trocar will push the additional cement into the vertebra. This is done only if the additional amount of cement is desired. The cannula can be removed safely without reintroduction of the trocar when the cement has hardened beyond the point at which it can be injected. Simply twisting the needle through several revolutions will break the cement at the tip of the cannula and will prevent leaving a trail of cement in the soft tissues. However, removing the cannula before the cement has hardened sufficiently can allow cement to track backward from the bone into the soft tissues and may create local pain.

The amount of cement needed to produce pain relief has not been accurately documented in available clinical reports. We believe that pain relief is related to fracture stabilization, and thus the amount of cement needed to restore the initial vertebral body's mechanical integrity should also give an approximation of the quantity needed to relieve pain clinically. In an in vitro study, we showed that the initial prefracture strength and stiffness of a vertebra could be restored by injecting 2.5 to 4 mL of Simplex P in the thoracic vertebra, while 6 to 8 mL provided similar augmentation in the lumbar region.⁴⁹ A reasonable guideline for the quantity of cement to be injected is the amount that is needed to fill 50 to 70% of the residual volume of the compressed vertebra. These amounts should not be taken as absolute but rather as a guide. The above described study suggests that relatively small amounts of cement are needed to restore initial biomechanical strength and that these amounts vary with the position in the spine, as well as individual vertebral body size and the degree of vertebral collapse.

We have also demonstrated that significant strength restoration is provided to the vertebral body with a unipedicular injection, where cement filling crosses the midline of the vertebral body.⁵⁰ This would imply that unipedicular fills that achieve adequate cement injection volumes are likely to be successful at achieving pain relief. This fact notwithstanding, there is a higher likelihood of achieving more uniform fills, with fewer leaks, when two needles are used rather than one (Figure 14.12).

Postoperative Care

After adequate vertebral filling has been achieved, the needle is removed. Occasionally, venous bleeding is experienced at the needle entry site. Hemostasis is easily achieved with local pressure for 5 minutes. The entry site is dressed with Betadine ointment and a sterile bandage. The patient is maintained recumbent for 1 to 2 hours after the procedure and monitored for changes in neurological function or for signs of any other clinical change or side effects. (Table 14.2 lists typical postoperative orders.)

Any sign of adverse events should trigger the use of appropriate imaging modalities (usually CT) in the search for an explanatory cause. It is well known that 1 to 2% of patients will have a transient period of benign increase in local pain following PV. However, this is a diagnosis of exclusion and should prompt extended monitoring (or hospitalization if the pain is severe and requires aggressive therapy) and imaging evaluation to exclude other causes for the pain (such as cement **FIGURE 14.12.** (A) Anterior–posterior radiograph showing a good bipedicular vertebral fill of bone cement. (B) Lateral radiograph show the same vertebra. Note that the entire central volume of the vertebra is not filled.



TABLE 14.2.	Sample	postoperativ	e orders	and	discharge	instructions
Postoperative orders						

Bed rest 1 hour (may roll side to side).

May sit up after 1 hour with assistance.

Vital signs and neurological examinations (focused on the lower extremities) every 15 minutes for the first hour, then every 30 minutes for the second hour.

Record pain level (Visual Analog Scale, 1–10) at end of procedure and at 2 hours postoperatively (before discharge). Compare with baseline values and notify physician if pain increases above baseline.

May have liquids by mouth if no nausea.

Discontinue oxygen (if used) after procedure (if saturation is normal).

Discontinue intravenous drips after 1 hour if recovery is otherwise uneventful.

Discharge patient home with adult companion after 2 hours if recovery is uneventful.

Discharge instructions

Return home; bed rest or minimal activity for next 24 hours.

May resume regular diet and medications.

Keep operative site covered for 24 hours. Bandages may then be removed and site washed with a damp cloth. Do not soak.

- Notify physician or facility if there is increasing pain, redness, swelling, or drainage from the operative site.
- Notify physician or facility if there is difficulty with walking, changes in sensation in hips or legs, new pain, or problems with bowel or bladder function.
- The area of the procedure will be tender to the touch for 24 to 48 hours. This is to be expected.
- If there is pain similar to that before the procedure, prescribed pain medications may be continued as needed.

extravasation). Pain alone will usually be adequately treated with analgesics, nonsteroidal anti-inflammatory drugs (such as Toradol), or local steroid injections adjacent to affected nerve roots or in the epidural space. Large cement leaks (Figure 14.13) or neurological dysfunction should prompt an immediate surgical consultation.

PV is easily performed on an outpatient basis with the patient discharged after 1 to 2 hours of uneventful recovery. (Table 14.2 gives typical discharge instructions.) Follow-up is indicated to monitor the results of therapy and should be incorporated into a quality management program. Reports of complications and results should be maintained by the facility as well as for each individual provider. Additional information and recommendations about the credentialing and quality management for PV can be found in the American College of Radiology manual on standards of practice.

Results

To date there are no prospective, randomized trials evaluating PV published in the literature. However, Zoarski et al. presented a small prospective (nonrandomized) evaluation of the effectiveness of PV



FIGURE 14.13. CT scan of a patient who experienced paraplegia following vertebroplasty as a result of a large cement leak. The cement (stars) occupies a large amount of the spinal canal at the level of the CT scan and creates cord compression.

for relieving pain.⁵¹ This report utilized the MODEMS method to establish that 22 of 23 patients improved after PV and remained satisfied during the 15- to 18-month follow-up. Additionally, several retrospective series are available and uniformly report good pain relief and reduced requirements for analgesics following PV.^{16,17,22,27,44} This is especially true of pain related to compression fractures produced by osteoporosis, where significant pain relief of between 80 and 90% has been observed. This pain relief is persistent with no reports of additional compression of vertebra previously treated with PV. Additional fractures at other levels remain a possibility and source of morbidity. If osteoporotic compression fracture occurs, every effort to minimize future bone loss medically should be made. Also, modifications in lifestyle should be attempted to minimize mechanical stress on the spine and thereby lessen the risk of additional fractures.

Complications

Complications, though initially considered to be low and reported as such, unfortunately are higher for inexperienced physicians or those who attempt the procedure without adequate image guidance or cement opacification. Appropriate training needs to be completed before the procedure is attempted. Recommendations can be obtained from the American College of Radiology Standards of Practice on Percutaneous Vertebroplasty.

In osteoporosis-induced vertebral fractures, clinical reports of complications are around 1%.^{16,17,22,27} Many of these are transient and include increase in local pain after cement introduction (nonradicular and not associated with neurological deficit). This is usually easily treated with nonsteroidal anti-inflammatory drugs and resolves within 24 to 48 hours. Uncommonly, cement leaking from the vertebra adjacent to a nerve root will produce radicular pain. Analgesics combined with local steroid and anesthetic injections usually provide adequate relief. A trial of this type of therapy is warranted as long as there are no associated motor deficits. The discovery of a motor deficit (or bowel or bladder dysfunction) should initiate an immediate surgical consultation. This type of severe complication will almost always be associated with large-volume leaks that have resulted in neurological compression.

Cement leaks have also been implicated in producing pulmonary embolus.¹⁶ These are usually not symptomatic but rarely have produced the clinical symptoms accompanying pulmonary infarct. With a right-to-left shunt, this can result in cerebral infarct.⁵² Likewise, infection has been rare with PV.

The complication rate found when treating compression fractures resulting from malignant tumors is considerably higher.^{22,26,29,30,53} This occurs because there are frequently lytic areas involving the vertebral cortex and a greater propensity for cement to leak into the surrounding tissues or vessels. Cement leaks causing symptoms in this setting occur in up to 10% of patients (again most are transient).

Until recently, death had not been a complication associated with PV. Now, however, in two multilevel procedures patients have died. Though the exact details are not known, there was pulmonary compromise, which is suspected to have been due to fat (from the vertebral marrow) or cement emboli. A safe number of vertebrae to treat at one time has yet to be definitely established. Mathis et al. reported treating seven vertebrae in a 35-year-old patient with multiple fractures associated with steroid use for lupus.⁴⁶ This patient's therapy occurred in three treatment sessions. Because the introduction of cement is a hydraulic event with as much marrow pushed out of the intertrabecular space as cement injected, there is concern about fat emboli in large-volume cement injections. For reasons described earlier, I recommend treating no more than three vertebrae in any one session. Additionally, there are no data that support the prophylactic use of PV to treat vertebra that are believed to be at risk of fracture. Except for pro-

phylactic use, there is little conceivable reason to perform PV on large numbers of vertebrae at one time.

Any deviation from an expected good result (such as increased pain or neurological compromise) should initiate an immediate imaging search with CT to look for a cause of the clinical change. Unremitting or progressive symptoms may require surgical or aggressive medical intervention, and outpatients should be hospitalized and monitored.

Conclusion

Percutaneous vertebroplasty has been shown to be very effective at relieving the pain associated with compression fractures of vertebra caused by both primary (age-related) and secondary (steroid-induced) osteoporosis. It also has substantial benefit in neoplastic-induced vertebral compression fracture pain but with a higher chance of associated complication. PV is rapidly becoming the standard of care for compression fracture pain that does not respond to conservative medical therapy. However, this simple procedure must be treated with respect, for its application without appropriate judgment and physician training can quickly result in increased pain, permanent neurological injury, and even death.

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15

Implanted Drug Delivery Systems

John C. Oakley

With the discovery that opioid drugs administered into the subarachnoid space could access spinal cord receptor sites and produce effective analgesia in malignant and nonmalignant pain syndromes, implanted drug delivery systems became a standard intervention for pain management. In 1979 Wang and colleagues reported that the use of morphine in cancer-related pain at doses of 0.5 to 1.0 mg resulted in excellent pain relief for 8 to 30 hours.¹ Yaksh documented the physiological basis of the pain relief produced by intraspinal administration of opioids as the modulation of inhibitory mechanisms occurring at the spinal cord.²

It is known that opioids produce a marked inhibition of the evoked discharge of spinal cord nociceptive neurons, correlating with an elevation in the pain threshold of animals.³ This effect is not associated, at analgesic levels, with alterations in primary sensory modalities such as touch, or in autonomic changes or changes in voluntary motor function. Analgesic effects of these drugs are dose dependent and stereospecific. Opioid effects are antagonized by naloxone and have a highly regular structure–activity relationship. This suggests that their primary site of action is on spinal cord receptors. High levels of opioid binding have been found in the substantia gelatinosa, where the majority of the small primary afferent fibers terminate. The local action of morphine in the substantia gelatinosa inhibits the discharge of nociceptive neurons, resulting in the inhibition of pain transmission.^{2–4}

The numerous external methods of accessing the intrathecal space for drug administration include epidural catheters relying on transdural absorption, tunneled externalized intrathecal catheters, and internalized ports requiring percutaneous access. These methods are acceptable for short-term treatment. However, their vulnerability to infection, as well as economic considerations, preclude serious consideration for long-term use (>3 months).^{5,6}

Coombs and Poletti and their coworkers were the first to describe the use of an implanted reservoir that, with repeated compression, delivered a bolus of medication into the epidural space.^{7,8} Percutaneous injection of a subcutaneously implanted infusion port connected to a spinal catheter was also described.⁹ Bolus dosing in this manner was demonstrated to result in rapid drug tolerance in primates and fell out
of favor.¹⁰ These external techniques also called for highly skilled personnel and demanded monitoring on an outpatient basis. Infusion ports were connected to external infusion pumps but suffered from an increased risk of infection and patient discomfort.¹¹

Strato-Infusaid Corporation (now Arrow International) developed and manufactured a constant flow rate pump for the delivery of intravascular, and occasionally intrathecal, chemotherapeutic agents. A constant flow rate device (Figure 15.1) is a hollow titanium shell separated into two chambers by a metal bellows. In one chamber, a twophase (gas and liquid) charging fluid (Freon) is permanently sealed between the bellows and the outside wall of the cylinder. The other chamber is the drug reservoir, which is filled percutaneously via a selfsealing septum.

As the reservoir is filled, the charging chamber is compressed and the charging fluid returns to a liquid state. As the fluid is warmed to body temperature, it converts to a vapor at a reasonably calculable rate, exerting pressure on the drug chamber. This pressure then forces the infusate through an outlet filter and a flow-restricting capillary tube assembly. The infusate then enters a silicon rubber delivery tube and exits the pump. The final result is a constant flow of medication if the surrounding temperature and pressure remain constant. These systems are reliable and simple; they are limited in their longevity only by the lifetime of the self-sealing septum, which must be punctured for refills. The systems are subject to variable flow rates with altitude, as in mountain travel or on airplanes (increased flow), and most commonly elevated temperatures such as fever or a hot tub (increased flow). An inconvenience of these systems is the need to drain the reservoir and existing drug waste to add a more or less concentrated drug when the prescription is altered.

The early efficacy and safety of intraspinally administered medication was established by constant flow rate systems.^{7,9,12–18} Several constant flow rate systems are commercially available; they are used when a stable dosing regimen is determined or when there are drug compatibility concerns with other systems. Medtronic and Arrow International in the United States, and Tricumed and Medtronic in Europe currently offer such systems.

In 1988 the Medtronic Corporation introduced an externally programmable, fully implantable pump in response to the demand for the ability to change a drug prescription without the need to physically re-



FIGURE **15.1.** Isomed factory preset constant flow rate during infusion pump. (Used with permission, Medtronic, Inc.)



FIGURE 15.2. Synchromed programmable drug infusion pump. (Used with permission, Medtronic, Inc.)

move the drug from the pump and replace a new drug or concentration. This device was originally released for the treatment of cancerrelated pain in the late 1980s and became commercially available for pain of all types in 1991, after 7 years of clinical trials. This device is an implantable, programmable, battery-powered pump that stores and delivers medication according to instructions delivered by an external programmer (Figure 15.2).

Like constant flow rate pumps, the programmable pump is filled through a self-sealing septum into a drug reservoir. A bellows configuration allows the drug reservoir to collapse as drug exists the chamber and to expand as the chamber fills. The programmable pump consists of a battery module, an electronic module for programming and pump control, and a peristaltic pump motor that pulls infusate from the reservoir by compressing internal tubing. The rate of drug delivery is determined by the turning rate of the pump motor, which is controlled by the programming of the microprocessor in the electronic module. A telemetry unit allows communication with an external programming unit (Figure 15.3), allowing troubleshooting and adjustments. An internal 0.22 μ m retention filter filters out bacteria and other contaminants. Medication passes through the pump tubing by action of the peristaltic pump, exits the pump through the catheter port, and flows through an extension catheter to the intraspinal catheter and to the epidural or intrathecal space.

The programming unit is essentially a laptop computer, printer, and a programming wand, as illustrated in Figure 15.3. The programming wand establishes a two-way radiofrequency link with the implanted pump. The programmer transmits interrogation and programming signals to the pump and receives information from the pump. This capability has established the implantable, programmable pump as the ideal approach for patients with chronic pain.



FIGURE 15.3. Synchromed programmer. (Used with permission, Medtronic, Inc.)

Intraspinal Drug Delivery Clinic

The effective utilization of drug administration systems within the pain management community requires a minimum level of resources. A designated implant coordinator does coordination of patient education and follows a patient through the implant routine. This person should be a healthcare professional skilled in monitoring all aspects of the technique, including preoperative screening trials, surgical implantation and support, pump programming, pump refilling, long-term management of the patient, and recognition of potential adverse events.

The management clinic should have the customary multidisciplinary access necessary to fulfill the requirements for patient selection, including psychological services. The team approach optimizes patient outcomes.

Patient Selection

Intrathecal medication therapy for pain management should be considered for patients for whom treatment with oral opioids failed owing to lack of efficacy or intolerable side effects if, in addition, they have a life expectancy of greater than 3 months and good cerebrospinal fluid (CSF) circulation. In general this intervention should be reserved for patients whose pain syndrome is considered to be chronic. Drug administration systems are not indicated for acute pain. Chronicity may be defined in terms of pain lasting longer than 3 or 4 months and inadequately relieved by standard medical management¹⁹ or as pain present more than a month beyond a normal expected healing time for the diagnosis.

In cases of malignant disease, pain expected to last longer than 3 months may be considered to be chronic. The indication for the use of a drug administration system then includes the treatment of chronic pain of nonmalignant origin and chronic cancer-related pain.

Patient selection is further refined by pain type. There are three specific pain types with characteristic symptoms. Table 15.1 lists the symptoms of the visceral nociceptive pain, somatic nociceptive pain, and neuropathic pain types. Nociceptive pain is pain mediated by receptors widely distributed in cutaneous tissue, bone, muscle, connective tissue, blood vessels, and viscera. These are classified as thermal, chemical, and mechanical according to the stimulus that activates them. Neuropathic pain is elicited by damage to the peripheral, central, or

TABLE 15.1. Characteristics of different pain types				
Nociceptive pain				
Well-localized				
Sharp				
Aching				
Throbbing				
Pressurelike				
Visceral pain				
When associated with obstruction of a hollow viscus:				
Gnawing				
Cramping				
When associated with organ capsule involvement or mesentery:				
Sharp				
Throbbing				
Aching				
Neuropathic pain				
Spontaneous pain (suggesting tissue damage or impending damage;				
may be steady or intermittent)				
Sharp				
Aching				
Crampy				
Stabbing				
Knifelike				
Crushing				
Evoked pain				
Can occur as hyperesthesia from stimulation of receptors, often				
associated with areas of somatosensory malfunction				
Allodynia (painful perception of normal stimulation)				
Hyperpathia (heightened pain of a normally painful stimulus)				
Burning				
Stinging				
Radiating				
Electric shock–like				

autonomic nervous system. Although the pain responds to opioid analgesics in high concentrations, it is less responsive than nociceptive pain at the usual levels.^{17,20,21}

Assessing the pain type and characteristics requires an adequate history and physical examination. In addition, any medical risk factors should be well understood. Table 15.2 gives general inclusion and exclusion criteria for intraspinal opioid therapy. The patient should have progressed to level 3 of the World Health Organization (WHO) pain ladder (Table 15.3) and should have demonstrated opiate responsivity.¹⁹

Psychological assessment has become an important part of ongoing management for chronic pain patients as well as an integral part of selection for implantable therapies. The question asked of the neuropsychologist or psychiatrist is whether any untreated psychosocial problems exist that might lead to a bad outcome from the therapy. The question of whether a patient is a candidate for implantable therapy is answered by the implanter, generally not by the psychologist. However, certain psychiatric diagnoses such as psychosis or conflicting motives and expectations may lead to nonselection. Olson has identified several risk factors for chronic pain and poor outcomes with treatment, including major psychopathology, mood disorder, potential for self-harm, dementia, anxiety, catastrophizing, high magnitude of distress, addictive issues, and sleep disturbances.²² Socioeconomic problems and family and social support mechanisms should be identified and problems dealt with before and concurrently with implantation.²³

If there has been a failure of standard pain management techniques to obtain long-term control of the pain, implantable therapies including spinal cord stimulation (SCS) and intraspinal drugs should be con-

Exclusion criteria
Absolute exclusion
Aplastic anemia
Systemic infection
Known allergies to the materials in the implant
Known allergies to the intended medication(s)
Active intravenous drug abusers
Psychosis or dementia
Relative exclusion
Emaciated patients
Ongoing anticoagulation therapy
Children whose epiphyses have not fused
Occult infection possible
Recovering drug addicts
Opioid nonresponsivity (other drugs may be considered)
Lack of social or family support
Socioeconomic problems
Lack of access to medical care
Inclusion criteria
Pain type and generator appropriate
Demonstrated opioid responsivity
No untreated psychopathology that might predispose to an
unsuccessful outcome
Successful completion of a screening trial

Level of pain	Analgesic requirement		
1. Mild pain	Nonopioid ±Adjuvant		
2. Persistent or increasing pain	Opioid for mild to moderate pain ±Nonopioid ±Adjuvant		
3. Cancer pain	Opioid for moderate to severe pain ±Nonopioid ±Adjuvant		

 TABLE 15.3. World Health Organization analgesic ladder

sidered. As a rule, SCS is considered to be less invasive or more conservative than chronic intraspinal drug administration and may be more effective for neuropathic pains. In the past SCS was considered for peripheral and some central neuropathic pains and drug administration systems (DASs) for opioid-responsive nociceptive pain. As more novel intrathecal analgesics have appeared that are effective for neuropathic pain and dual-lead SCS systems have been used for more nociceptive pain, the strict selection criteria have become blurred.²⁴

Patient Screening

Patients adhering to the general selection criteria described previously move to the trial stage of the use of intrathecal medication. Before an implanted pump is used, it is important to perform an adequate trial to assure patient and physician that the long-term administration of intrathecal opiates will be successful.

There is no proven method for trial screening to determine safety and efficacy of the intrathecal treatment. The response to the acute administration of these medications is believed to predict long-term efficacy. The goals of screening are to determine whether the patient has side effects with the drug used and to document pain relief. Just as there are no proven methods of screening, there is no proven length for a screening trial. Single intrathecal bolus dosing, epidural infusion, and intrathecal infusion trials have all been performed and continue to be the predominant techniques utilized.¹⁷ Only epidural infusion has decreased in popularity, since it is not now believed to represent the true effects of intrathecal dosing. Bolus intrathecal doses are administered by lumbar puncture, and the patient is monitored for side effects and analgesia. This technique may maximize the side effects of nausea and vomiting and may provoke a higher incidence of urinary retention. Reported pain relief may last up to 24 hours but generally peaks after a few hours. Paice et al. reported that 33.7% of 429 physicians in a retrospective review used this method at some point.¹⁷ Many practitioners do not think the bolus dosing technique can control for placebo effects, although few physicians believe that a blinded placebo trial is necessary.²⁵ Even so, Paice et al. reported that 18.3% of the physicians still used this method.¹⁷ It is not appropriate, however, to deny a patient implantable pain therapy based on a prior placebo response.^{26–29}

The screening trial seeks to mimic the effects of chronic administration of the intraspinal analgesic. Epidural catheters placed through a tunneled approach have been used for prolonged trials of days to weeks. Dosing tends to be a factor of 10 times higher than the expected intrathecal dose. This method seems to predict efficacy but may not screen for side effects seen with intrathecal administration. Some clinicians feel that the higher systemic doses associated with this method make it suboptimal for screening. At the time of the Paice article, which was published in 1996, 35.3% of the participating physicians were using this method.

The most frequently used method is said to be the placement of a percutaneous or tunneled intrathecal catheter.³⁰ This technique best predicts the side effect profile and pain relief. It also provides a starting infusion rate for the pump and allows sequential trials of different drugs if the initial drug is ineffective. Intuitively this method closely approximates the response of an implanted drug administration system.

Screening Techniques

Percutaneous Technique

A paramedian approach is used to enter the intrathecal space. Under fluoroscopic guidance, the catheter is threaded to the level of the substantia gelatinosa at which pain transmission is modulated. Contrast is often injected to confirm appropriate catheter placement and to document free flow of fluid. After a tract of local anesthetic is applied, the stylet of a Tuohy needle is placed beside the first needle and threaded laterally. A second 17-gauge Tuohy needle is advanced over the stylet. At this point the first (intrathecal) Tuohy needle is withdrawn and the catheter is threaded down the second needle. After the patient has completed the trial, the original catheter cannot be internalized and must be removed and discarded. This approach has the advantage of not creating incisional pain that can confuse the trial; another benefit is that the device can easily be removed if the trial is unsuccessful. On the other hand, instrumenting the spine twice is necessary if the patient does well and then undergoes implantation.

Surgical Technique

When the patient is in the operating room and has been placed prone on a fluoroscopic table, the back is prepped and draped in a sterile fashion. The area is squared off with sterile towels and a largeopening "chest–breast" drape is applied. The wide exposure enables placement of the catheter and tunneling to the side. A 1 to 2 in. incision is made inferior to the desired intrathecal entry point of the Tuohy needle, and a paraspinous intrathecal puncture is performed under fluoroscopic guidance. The catheter is then introduced to the desired target level under fluoroscopic guidance, most often at the T10 level but locations may be selected according to the pathology or placement of the pain generator. A second "extension" catheter, which is disposable, is tunneled to the flank by means of a malleable catheter passer. This catheter is then connected to the intrathecal catheter with a suitable connector, tied with a 2-0 silk suture, and then anchored to the lumbar fascia with another 2-0 silk suture in a figure-of-8 configuration. The wound is closed with an interrupted inverted stitch of 3-0 absorbable material, and Steri-Strips are applied to the skin edge. Alternatively, staples may be used. An antiseptic bandage is placed around the percutaneously exiting catheter. A Biopatch (Johnson & Johnson) impregnated with chlorhexidine gluconate (Hibiclens) is used in the author's clinic. Some external extension catheters require fitting a Luer-Lok adapter on the externalized catheter to facilitate mating with the infusion catheter coming from the external pump. The back wound is dressed, and the patient is now ready to begin receiving medication for the screening trial.

Management of the patient's opioid use at the time of screening is important. Eliminating opioids before screening may lead to unwarranted discomfort to the patient and may add to the expense of the trial.²⁵ A complete conversion from systemic opioid to intraspinal opioid may result in an abstinence syndrome. Therefore a clinical protocol during the screening trial is necessary to prevent withdrawal side effects. One such protocol, suggested by Krames, involves converting 50% of the pretrial oral dose to an intrathecal equivalent dose and withdrawing the remaining oral dose by 20% per day, converting to an equianalgesic intrathecal dose. The dose may then be increased to an intrathecal effect while the systemic medication is decreased.³¹

For the tunneled catheter trial, the patient is usually kept in the hospital for 3 days, although some clinicians are beginning to utilize outpatient trials of 1 week or longer. The length of trial may be an important consideration. Presumably, the longer a trial proceeds, the less likely it is that a placebo response will affect the outcome. Many clinicians believe that a longer trial better predicts a successful outcome.

If the screening trial is successful, the patient generally reports a 50% decrease in pain as measured by some standardized self-reporting measure or Visual Analog Scale (VAS) and reports no intolerable side effects. The patient then proceeds to implantation of the chosen drug administration system.

System Implantation

Pump Preparation

The details of permanent implantation will vary slightly according to the type of pump implanted. It is most efficient to have an implant assistant perform the necessary steps for pump preparation while the surgeon prepares the pump pocket and tunnels the appropriate catheters.

Constant Flow Rate Pump

Preparation for this variety of pump follows a straightforward algorithm. The factory preset flow rate is checked for compatibility with the desired flow rate for the patient. The pump is filled with the selected infusate and placed in a body temperature saline bath. The attached catheter is trimmed and monitored for flow of infusate. The pump is then ready for implantation and connection to the intrathecal catheter.

Programmable Pump

The sequence for preparation of a programmable pump is more complex because of the internal peristaltic pump motor and its controller. The entire process takes about 20 minutes to complete. The pump model number, reservoir size, and the presence or absence of an access port are noted. The pump is not removed from its sterile packaging until CSF access has been obtained.

When CSF access has been obtained, or if the trial intrathecal catheter is used as the permanent catheter, the pump is interrogated in its sterile container to verify that the calibration constant matches that on the packaging. An error in the calibration constant when downloaded into the programmer will result in faulty readouts of pump performance or calculation of dosing. The pump is then warmed to 35 to 40°C. If this warming step is skipped, the reservoir valve may be activated, preventing infusion.

The pump reservoir is then drained of the fluid supplied by the manufacturer by inserting a Huber-type needle through the refill septum and into the reservoir and allowing the fluid to escape into a 20 mL syringe. The volume removed should be within 20% of the predicted volume after initial interrogation of the pump. If there is more than 20% variation, the pump may be faulty. The initial recommended fill of the reservoir is 10 mL, to avoid overpressurization. However, it has been determined that a full filling of the reservoir to 18 mL of infusate is safe. The advantage of fully filling the reservoir at the time of implantation is that the surgical wound is allowed to heal thoroughly, and any swelling will resolve before the next filling. Each subsequent refill is at 18 mL for safety, although the reservoir volume is 20 mL in the standard pump. A pump with a smaller reservoir (10 mL) is also available. During the pump filling, care must be exercised to avoid allowing air to enter the reservoir, since air in the reservoir chamber could lead to overpressurization and faulty volume estimates.

Using the pump programmer, the implant assistant programs a purge of the reservoir while it is still in the sterile container or on the sterile field after it has been removed. The pump has been placed on the sterile field, the catheter port cover is removed and the port is observed for flow. If after several minutes a drop of fluid is visualized, the pump is submerged in warm saline until the internal purge is completed, about 15 minutes. The pump is then ready for implantation.

Surgical Implantation Technique

The implantation procedure may be accomplished under general or local anesthesia with anesthesia monitoring. The latter technique is often preferred in an outpatient setting because it lends itself to rapid recovery following the procedure.

Prior to implantation, some time should be spent with the patient to optimize the side and location of the pump. About the only area amenable to the implantation of these generally large devices is the right or left lower quadrant of the abdomen. Some time should be spent with the patient preoperatively discussing which side and where the pump will be placed. The anatomical constraints tend to be the iliac crest, the symphysis pubis, the ilioinguinal ligament, and the costal margin. These structures should not contact the pump with the patient in the seated position. The task is easier in more obese patients and can be very difficult in cachectic cancer patients.

The patient is positioned on the operating table in the lateral decubitis position, with the implantation side upward. At this stage C-arm fluoroscopy may be necessary if a new intrathecal catheter is to be placed. The instrument is positioned to allow an anterior–posterior view for an easy lumbar puncture and identification of the catheter tip level. A 5 cm incision is made in the skin, down to the lumbar fascia, and then the catheter is implanted through a paraspinous approach. A good flow of spinal fluid is documented, the catheter is clamped to the drape to prevent CSF loss, and the incision is packed with an antibiotic-soaked sponge.

If the existing catheter is to be used as the permanent delivery catheter, the patient is positioned on the operating table in the decubitis position with the implant side upward and the exiting screening extension catheter downward. Prepping and draping for implantation then proceed as usual. The previous back incision is reopened and the disposable extension catheter is disconnected from the permanent intrathecal catheter and pulled from under the patient by the circulating nurse. The intrathecal catheter is then clamped to prevent CSF loss, and the implantation proceeds in the usual manner.

Attention is then turned to the lower quadrant of the abdomen, where a 10 cm incision is made down to the underlying subcutaneous fat layer. A subcutaneous pocket large enough to admit the particular pump being used is then fashioned. Generally, if all four fingers can be admitted to the metacarpal phalangeal joints in the pocket, it is large enough. The upper side of the incision is undermined roughly as the width of the pump, or about 2.5 cm, to allow closure without tension. The eccentric location of the pocket allows the pump to be placed so that the refill port is clear of the incisional scar and easier to locate. An ideal pocket is one that will allow placement of the pump without difficulty but is tight enough to aid in preventing pump rotation. The depth of the pocket below the skin is critical for programmable pumps. A depth greater than 2.5 cm may not allow reliable telemetry. In fashioning the pocket, meticulous hemostasis is important to avoid a postoperative hematoma. At this point, the pocket is packed with an antibiotic-soaked sponge.

The catheter connecting the intrathecal catheter to the pump, or the extension catheter, is then tunneled from the pump pocket to the back incision by means of a malleable tunneling device. The author uses a cardiac pacemaker tunneling tool. Shunt tunneling tools may also be

used, and a tunneling system is provided with the programmable pump, which works well. Most constant flow rate pumps come with the extension catheter connected to the pump at the factory; the catheter must be attached to the programmable pump.

A connection is now made between the extension catheter and the intrathecal catheter, using a titanium or plastic male-to-male tubing connector, usually provided with the catheter selected. This construct is covered by some type of anchoring device, which is secured to the connector with 2-0 nonabsorbable braided tie. The construct is anchored to the underlying muscle fascia in a figure 8 fashion. Do not skip the anchoring. The intrathecal catheter will migrate, usually coiling itself under the skin.

The extension catheter is now connected to the previously prepped programmable pump and secured to the pump with a 2-0 braided tie. Pumps with a previously attached catheter must be placed into the pocket at the time of catheter tunneling.

The programmable pump is now placed into the subcutaneous pocket. The Synchromed pump in its Dacron pouch may be placed without need for further suturing. Some pumps without this pouch have anchoring loops manufactured around the pump circumference, but their use may be problematic. A nonabsorbable stitch must be placed into a tissue that will not necrose. This may be the case with fat or muscle. At least two stitches are necessary to prevent rotation, and three may be necessary to prevent flipping (it happens!). This usually requires a dermal or fascial stitch, with the risk that the anchor will be painful. If this technique is used, the stitches should be placed into the pocket first, then through the pump suture loops, whereupon the pump is placed into the pocket and the sutures tied. If the pocket is carefully fashioned, even a pump lacking a Dacron pouch may be placed without suturing, especially in thin patients.

The incisions are now carefully closed. An interrupted, inverted layer of 2-0 absorbable suture in the abdomen and 3-0 absorbable suture in the back will suffice, followed by apposing the skin edges with Steri-Strips. If tension is a problem, surgical staples should be used to reinforce the closure.

Outcomes

While the majority of patients with chronic pain, either cancer related or not, are adequately managed with oral analgesic medications, electrostimulation, or behavioral techniques, studies indicate that only about half the patients so treated for back pain or neuropathic pain achieve good reduction in their pain, and a full 21% are unresponsive to opioid therapy.^{32,33} Long-term results are even less satisfactory, with only 16.7% reporting good relief.³⁴

Cancer-Related Pain

Early studies in cancer-related pain demonstrated that intrathecal administration of opioids was much more effective than other routes of administration.^{3,6,10,20,25} The most common early use of intrathecal infusion of morphine was in cancer-related pain. In a retrospective multicenter study of the use of intraspinal morphine for all types of pain, 32.7% of the patients analyzed had cancer pain.²⁵ The average length of treatment in the study was 14.6 months (8-94 months). Cancer patients were treated with higher initial doses and escalated to a stable level more rapidly than patients with non-cancer-related pain. The most frequently used drug was morphine. In the cancer population 13.6% had somatic pain, 25.4% neuropathic pain, 16.9% visceral pain, and 44.1% a mixed pain presentation. The long-term stability of dosing in the cancer population has also been documented elsewhere.³¹ Cancer pain of all types remains an excellent indication for the use of intrathecal opioids especially in the case of a programmable pump, which can aid in the matching of pain relief to progression of disease. It is probable that about 5 to 10% of those in the cancer pain population are candidates for an implantable pump system using the selection criteria noted earlier.

Non-Cancer-Related Pain

The use of intrathecal opioids for pain not due to cancer has burgeoned in recent years in spite of a lack of prospective studies. The most definitive data to date supporting such an increase in use are provided by the survey of physicians in the United States by Paice, Penn, and Shortt,¹⁷ cited in connection with cancer-related pain and including data on pain not related to cancer, and in the retrospective study by European authors Winkelmuller and Winkelmuller.³⁴

In the American study, two thirds of the patients were suffering pain of noncancerous origin. The most common pain type was failed back syndrome (42.4%). Other pain syndromes treated included complex regional pain syndrome (5.6%), postherpetic neuralgia (5.1%), and peripheral nerve injury (3.7%). The most common screening technique was continuous epidural infusion (35.3%), followed by bolus intrathecal injection (33.7%). More than half (77.6%) underwent psychological screening. Morphine was by far the most commonly infused drug (95.5%), but a wide variety of medications were used. Doses for neuropathic pain tended to be higher at 6 months than for somatic or visceral pain. Nearly one fifth (19.8%) of patients were treated with a local anesthetic (bupivacaine) as an adjuvant to morphine. These patients exhibited a linear increase in dose over time, eventually reaching stable levels by one year at 9.2 mg/24 h. By physician report, 52.4% of the patients had excellent pain relief, 42.9% had good relief, and pain relief was poor in 4.8%, testifying to the considerable efficacy of this technique.¹⁷

Specific outcome measures employed by Paice et al. included activities of daily living (ADLs), employment, percent pain relief, a global pain relief score incorporating intensity and pain medication changes, and activity levels.¹⁷ In 82% of respondents there was improvement in handling ADLs. Patients with visceral pain showed the greatest improvement in ADLs. Return to work occurred in 24 of the patients with non-cancer-related pain. In a long-term follow-up of 120 non-cancer-related pain patients in Europe with a mean follow-up of 3.4 years (0.5–5.7 years), 73 patients had mixed neuropathic and nociceptive pain due to multiple back surgeries, while 34 had varying etiologies such as postherpetic neuralgia, stump and phantom limb pain, and various peripheral nerve injuries.³⁴ Six months following implantation the average pain intensity score was 30.5. At the conclusion of follow-up, the score was 39.2. The best initial response was seen in the nociceptive pain group, with a 77% initial reduction in pain intensity that declined to 48% at last follow-up. Deafferentation and neuropathic pain groups benefited from therapy and in fact over the long term showed the best results, with 68 and 62% pain reduction as measured by VAS, respectively.

While these results are impressive in a population of patients unresponsive to more conventional methods, prospective studies comparing this and alternative therapies would more rigorously establish intrathecal infusion of medication as a treatment of choice. The current acceptance in clinical practice empirically validates the technique but also makes prospective and certainly randomized studies difficult to implement.

Complications

Any technique involving a surgical procedure, prosthetic device, and the infusion of medication will have complications. With implantable drug administration systems, complications may be divided into three categories: surgical complications, device-related complications, and drug-related complications.

Surgical Complications

In the perioperative period, bleeding with the subsequent development of a pocket hematoma is perhaps the most troublesome and preventable problem. Meticulous attention to hemostasis during pump pocket formation will avoid this problem. An additional aid in prevention is the placement of an abdominal binder, such as a 6 in. Ace wrap, around the abdomen and lightly compressing the fresh pump pocket for 24 to 48 hours. This compression dressing helps to avoid the accumulation of blood or fluid in the pocket.

The possibility of epidural and intrathecal hemorrhage is frequently mentioned, with the obvious risk of neurological injury. This complication, unfortunately, tends to occur at the time of catheter implant. Preoperatively, care should be taken to discontinue nonsteroidal antiinflammatory drugs and reverse any anticoagulation. Signs of a developing hematoma are usually a sudden increase in focal back pain associated with tenderness, progressing numbness and/or weakness in the lower extremities, and loss of bowel or bladder control (in the form of retention/constipation or incontinence). This clinical presentation warrants immediate imaging with MRI or CT/myelogram and emergent neurosurgical intervention if there is neurological deterioration.

With implantable devices, one of the most feared complications is

wound infection. The use of prophylactic antibiotics has been controversial, but a consensus seems to have developed around the practice of using some preoperative antibiosis. One method is to use a cephalosporin intravenously an hour prior to surgery without subsequent antibiosis. Some clinics use daily prophylaxis while an externalized screening electrode trial is under way. Intraoperatively, antibiotic irrigation may be used. Attention on the part of surgical personnel to handle all sterile parts with care, avoiding unnecessary contact with any, even prepped, skin may reduce contamination.

While not all wound infections require removal of the device, general experience with foreign bodies implanted in the body (e.g., CSF shunts, spinal instrumentation, prosthetic devices) indicates that all but superficial infections will require system removal. Implantable pumps contain an internal filter that guards against direct contamination resulting in meningitis. However, with infection tracking along the intrathecal catheter, either an epidural abscess or meningitis may result.

Neurological injury is a definite possibility whenever the CSF space is entered. Needle placement, even when guided fluoroscopically, is essentially blind with respect to intraspinal neural structures. Potential injury to the nerve roots can to some extent be mitigated by performing the catheter placement under local anesthesia. The patient under local anesthesia will, in the case of nerve root injury, report a radiating electric shock-like or burning sensation in the distribution of the involved nerve root. The needle should be immediately withdrawn and placement at a different level considered. With catheter placement, the spinal cord becomes at risk. Catheters that are spring wound or have internal stiffening wires must not be forced through the spinal canal because the tip could become buried in an intramedullary position. Often penetration of the spinal cord results in the production of dysesthesias and a burning or stinging pain below a nondermatomal lesion; this may not result in noticeable neurological signs immediately. Intramedullary infusion of drug may result in the progressive signs of a spinal cord lesion and should be immediately evaluated as such with MRI scanning or CT/myelography and appropriately dealt with by the neurosurgeon.

Cerebrospinal fluid leaks are a natural consequence of placing catheters in the subarachnoid space. The opening created in the dura mater by the introducing needle will be larger than the entering catheter, creating a predisposition to some potential leakage. The dura mater has a moderate amount of elasticity, and this property probably accounts for why the incidence of leaks is not higher. If the particular technique used seems to result in a relatively high incidence of spinal headache or CSF collection under the skin, a blood patch injecting 10 to 20 mL of autologous venous blood one level above the catheter entry point or at the entry point under fluoroscopic control may prevent CSF leakage.

Device-Related Complications

The most frequently reported complications with implantable pump systems involve some failure in the system itself. Early reports noted many catheter-related complications.^{7,35} This problem seems to have decreased in frequency¹⁶ with the development of more thick-walled and reinforced catheters, new anchoring techniques, and the use of paraspinous approaches to placement.

Catheter tip obstruction or replacement can be a problem and may require revision of the catheter. This problem is usually suspected when comparison of the expected and actually measured residual volumes vary by more than 20%. A complete evaluation of the catheter must be performed if obstruction, kinking, or separation is suspected. This is made more important by the increasing reports of sterile granulomatous masses forming at the tip of the catheter. These may present as an obstruction, but most commonly they are productive of increasing pain and progressive neurological deficit.¹⁷

Evaluation of a catheter problem calls for some type of imaging. Simple radiography with a soft tissue technique will demonstrate breakage or suggest a kink, migration, or disconnection from the extension or pump catheter. The evaluation of either suspected obstruction due to an intraspinal problem or catheter leakage requires the use of the injection side port, if present. Injection of nonionic contrast material will confirm obstruction and often show the point of leakage. The risk of this technique is the delivery of a large bolus of medication directly into the subarachnoid space, leading to the possibility of significant overdosage. Thus preparation for management of overdose should be made before such injections are begun. To avoid this problem, an attempt should be made to aspirate the catheter before the contrast is injected. In the absence of a side port, it is more difficult to evaluate catheter problems. A radioisotope may be injected into an emptied pump and a bolus programmed into a programmable pump or, an appropriate time may be allowed to elapse and the catheter scanned in the case of a nonprogrammable device.

Treatment of catheter problems usually requires removal and replacement of the catheter. Occasionally, a disconnected catheter may simply be reconnected, usually under local anesthesia. The demonstration of a granulomatous mass may require neurosurgical intervention to resect the lesion.

Pump-related complications common to nonprogrammable and programmable systems include overfilling of the pump, failure of the selfsealing septum at the refill port, and movement of the pump in the pocket. Overfilling can result in overpressurization, with the delivery of an unpredictable amount of drug, failure of the system, or activation of the reservoir valve, which in turn prevents infusion with a programmable pump. Nonprogrammable pumps may show a slight decline in drug delivery as they approach their refill time, most likely because the pressure of gas against the bellows decreases as the Freon reaches the maximum volume it has to occupy. This behavior should be anticipated and may require a slight shortening of the refill time if the weaker dose is troublesome to the patient.

Programmable pumps have an additional set of potential problems owing to the internal modules and mechanical components necessary to this type of device. Battery failure, pump rotor failure, and failure of the telemetry or electronic modules may occur. The battery lifetime of the pumps has been quite acceptable, generally in the 3- to 5-year range. Battery depletion requires surgical removal of the existing pump and replacement with a new pump. Pump rotor stalls may be confirmed by taking a radiograph of the pump to show the rotor, programming a bolus dose, and repeating the radiograph 15 minutes later. The pump rotor should have turned 90° if the rotor is functioning. If a rotor is stalled, the pump must be replaced. Failure of the electronic or telemetry module will result in a pump that is unable to receive a change in programmable pump at its last prescription infusion rate. Decision to replace the pump is based on the need to make programming changes.

Movement of the pump in the pocket may result in dislodgement of the catheters, extension and/or intrathecal. The pump may rotate in the pocket, resulting in a coiling of the catheter much like a fishing reel, or it may flip in the pocket, resulting in a progressive winding of the catheter. Revision of the pump and possibly the catheters may be necessary if catheter movement is occurring. A flipped pump is usually noticed by the patient, but it may be noted and verified in the clinic at the time of attempted refill. Revision of the pump will probably be necessary, often requiring anchoring the pump. In one case in the author's clinic, an abdominoplasty was performed with good results.

Infusate-Related Complications

Errors involving the infusate may occur if meticulous attention is not paid to the type of system being used, the drug being used, the drug concentration being used, the dead space in the system, and the prescription entered with programmable systems. Errors that occur may result in a life-threatening overdose. Some type of verification of these parameters should be in place at initial filling and at each refill procedure. When more than one drug is placed into the pump, the potential errors in compound dosing require a skilled operator and careful calculation.

Systems containing a side port unfortunately also have the disadvantage of possible direct injection of an overdose volume of drug at high concentration. Medtronic has offered a solution to this problem by producing a side port with a fenestrated screen that will not admit the standard refill needle, thus preventing inadvertent overdose when standard refill technique is attempted. When the side port is used for bolus dosing or troubleshooting, care must be taken to account for whatever concentration and volume of drug exist in the catheters. Forcing fluid through the side port also forces whatever fluid is in the line into the intrathecal space. Proper technique would suggest aspirating the side port to clear the line before injecting. Some physicians, including the author, avoid errors of these types by not implanting pumps with side ports, believing that the advantages of troubleshooting are not outweighed by the risk of overdose.

Treatment of an overdose should begin by immediate removal of CSF, with replacement by preservative-free saline. An intravenous line

should be placed and the patient admitted to the intensive care unit with careful monitoring for respiratory depression. Naloxone should be administered for respiratory depression, keeping in mind the possibility of exacerbating the hypertension associated with massive doses of opioids.³⁰ Other signs of overdose such as neurotoxicity and seizure activity should be managed symptomatically.

Conclusion

Intraspinal drug delivery systems have made the chronic delivery of intrathecal medication a manageable and safe tool in the management of chronic pain due to cancer, as well as other causes. Careful attention to patient selection, screening, drug selection, implantation technique, and refill technique will assure that this modality will be an important adjunct to any pain management clinic.

Additional acceptance and understanding by the lay community is necessary to bring reasonable expectations regarding pain relief with this technique. The best driving force for the acceptance of this technique by third-party payers is informed and expectant patients.

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16

Endovascular Therapy of the Spine

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Spinal Vascular Malformations

The following entities have been listed as spinal vascular malformations: hemangioblastomas, cavernous malformations/angiomas, spinal aneurysms, arteriovenous fistulas, and arteriovenous malformations. With regard to vascular lesions of the vertebral bodies, aneurysmal bone cysts and vertebral hemangiomas can also be mentioned. Many different classification schemes have been suggested over the past three decades. The newest proposed classification for spinal vascular lesions is by Spetzler et al.¹ We will list the most prevalent classification scheme for arteriovenous fistulas and malformations along with the new classification and the angiographic/ anatomical classification (Table 16.1).

Epidural Arteriovenous Fistulas (AVF)

Fistulas to the ventral epidural venous plexus, which are usually slowflow lesions, are called arteriovenous fistulas. Usually AVFs drain only into the epidural venous system and present with compressive myelopathy or radiculopathy due to enlarged epidural veins. Lesions have been reported that drain primarily into the ventral epidural venous plexus and then secondarily into the intradural/medullary venous system. These lesions can cause venous hypertension or subarachnoid hemorrhage (SAH). Most of the reported cases are sacral, with arterial supply from the lateral sacral arteries.²

Therapy

The treatment for AVF consists of endovascular acrylate (*n*-butylcyanoacrylate) (NBCA) embolization, with obliteration of the proximal draining venous system or surgical obliteration.

Dural Arteriovenous Malformation (Dorsal Intradural AVM, or Type I)

The type I AVF represents the most common type of spinal vascular malformation and should be in the differential diagnosis in an adult presenting with gradually worsening myelopathy. This lesion, which

Angiographic/anatomic classification	New classification (Spetzler et al. ¹)	Prevalent classification	Other nomenclature	Pathophysiology	Presentation	Diagnostic tests
Neoplastic vascular lesions: Hemangioblastoma Cavernous angioma	Neoplastic vascular lesions: Hemangioblastoma Cavernous malformation	classification	Cavernous angioma	T unophysiology	resentation	Diagnosite tests
Spinal aneurysms	Spinal aneurysms					
Vascular malformations: Epidural arteriovenous fistula	Arteriovenous fistulas: Extradural Intradural		Epidural AVF	Cord compression (enlarged veins), vascular steal, venous congestion	Progressive myelopathy	MRI, angiography
Dural arteriovenous malformations	Dorsal	Type I (subtypes A, B)	Dorsal extramedullary AVM	Venous hypertension/ compression; hemorrhage is rare	Progressive myelopathy	MRI, angiography
Intradural (pial) arteriovenous fistula	Ventral	A, B) Type IV (subtypes A, B, C)	Peri-medullary AVF	Compression (enlarged veins/venous varix), hemorrhage, vascular steal, venous hypertension	Progressive myelopathy	MRI, angiography
	Arteriovenous			JT T		
Extradural/ intradural AVM	malformations: Extradural/ intradural	Type III	Juvenile AVM, metameric AVM	Cord compression, hemorrhage, vascular steal	Pain, progressive myelopathy	MRI, angiography
Intramedullary AVM	Intradural Intramedullary	Type II	Classic AVM, glomus AVM	Hemorrhage, compression, vascular steal	Acute myelopathy, pain, progressive myelopathy	MRI, angiography
	Compact Diffuse Conus medullaris			Venous hypertension, compression, hemorrhage	Progressive myelopathy, radiculopathy	MRI, angiography
Paraspinous vascular malformation: Vertebro-vertebral AV fistula					I J	

TABLE 16.1. Classification

most authors have classified as a dural malformation, is subdivided into type A (single arterial feeder) and type B (multiple arterial feeders). The most common location for these malformations is between T4 and L3, with the peak incidence between T7 and T12.³ Malformations very uncommonly occur above the level of the heart, possibly owing to the helpful effect of gravity on venous drainage above the level of the right atrium. This lesion is composed of a direct fistula between the dural branch of a radicular artery (only rarely of a radiculomedullary artery) at the level of the proximal nerve root and a radiculomedullary vein (type A, Figure 16.1), or several abnormal connections between branches of adjacent radicular arteries and a radiculomedullary vein (type B).

The arterialized radiculomedullary vein then transmits the increased flow and pressure to the valveless coronal venous plexus and longitudinal spinal veins. The radiculomedullary vein is usually enlarged and tortuous as a consequence. The mean intraluminal venous pressure is increased to 74% of the systemic arterial pressure.⁴ The normal venous pressure in the coronal venous plexus is approximately 23 mmHg, which is almost twice that of the epidural venous plexus; this gradient is necessary for venous drainage. In one series, the mean venous pressure in the coronal venous plexus was measured at 40 mmHg.¹ The consequent venous hypertension causes progressive myelopathy, often leading to paraplegia and bowel, bladder, and sexual dysfunction, with gradual worsening over months to a few years.

The majority of patients become severely disabled within 3.5 years.¹ The overwhelming majority of patients (79–85%) are men, and 86% of patients are 41 years of age or older at presentation.^{2,3} The mean age at presentation is 55, with patients as young as 26 reported as presenting with this kind of malformation. The most common presentation is progressive paraparesis of the lower extremities with sensory changes also.

Complaints of back and leg pain are common. Although the progression is usually continuous, it can also present in a stepwise fashion, or a waxing–waning course with gradual progression. Between 10 and 20% of patients can present with an acute exacerbation. The symptoms can be exacerbated by any physical activity that increases intraabdominal pressure, and thus central venous pressure, as well as by an upright posture (venous drainage hindered by gravity).

FIGURE 16.1. Dural arteriovenous malformation (fistula). (A) Schematic illustration of a dural arteriovenous malformation: 1, descending aorta; 2, lumbar artery; 3, dural artery; 4, dorsal somatic artery; 5, nerve root sleeve, 6, nerve-arteriovenous malformation complex; 7, radiculomedullary vein, 8, dorsal longitudinal vein. (B) Contrast-enhanced T1-weighted magnetic resonance image of a dural arteriovenous fistula (DAVF), a nonspecific diffuse enhancement, and swelling of the spinal cord (arrow). (C) Three-dimensional TOF magnetic resonance angiogram in coronal plane shows congested radiculomedullary vein (arrow) and dorsal median vein (open arrow). Superselective angiogram of an intercostal artery (D, arrow) shows (E) the DAVF (curved arrow), the retrograde draining and congested radiculomedullary vein (open arrow), and the congested dorsal median vein (heavy black arrow).













Van Dijk et al.⁵ reported a series of 49 consecutive patients treated between 1986 and 2001. The mean age of the population was 63, and 80% were men. Almost all these patients (98%) exhibited myelopathy, with 96% displaying leg weakness and/or paraparesis. Ninety percent had sensory numbness or paresthesias, and 55% had pain either in the lower back or lower extremities. Eighty-two percent had urinary incontinence/retention, and 65% complained of bowel dysfunction.

Atkinson et al.⁶ reported a second series of 94 patients treated between June 1985 and December 1999. All the patients had lower extremity weakness with or without perineal or bowel/bladder dysfunction. Five patients also had upper extremity symptoms, all of whom had high T2 signal within the cervical cord. Eighty-eight patients reported sensory loss, and 61 patients had bowel/bladder dysfunction. A very interesting finding in this series was an essentially 50-50 split among patients with symmetric versus asymmetric lower extremity symptoms; in addition, approximately 50% of patients demonstrated worsening of symptoms with erect posture/Valsalva maneuver and improvement with recumbent position. This effect was not as prominent in the group of patients with the most severe symptoms. Eight of the patients included in this series had posterior fossa dural arteriovenous shunts with drainage into the medullary venous system, which is a well-described phenomenon and necessitates the injection of the posterior fossa and external carotid arteries in completion of a total spinal angiogram. The most common misdiagnosis for these lesions was transverse myelitis.

Therapy

The surgical treatment for type I malformations has been well described and essentially consists of performing one or more laminectomies and surgical disconnection of the draining vein, just distal to the fistulous site. In experienced hands, this is a very effective technique. Atkinson et al.⁶ reported a 97.9% success rate for obliteration of the fistula, with morbidity equal to that of patients undergoing decompressive laminectomy [one superficial wound and two deep venous thromboses (DVTs)].

The endovascular treatment of these lesions has also been well described. Before the availability of acrylate products ("glue"), treatment consisted of selective microcatheterization of the feeding artery, with particulate embolization of the fistula by means of polyvinyl alcohol (PVA) particles. Despite high rates of angiographic success immediately after treatment, this technique was associated with a high recurrence rate (\leq 83%), owing to recanalization of the arterial feeding pedicles. With the availability of acrylate products, the recurrence rate has significantly diminished.

The consensus among interventional neuroradiologists at this time is that successful treatment of these malformations consists of penetration of the fistula and the proximal radicular draining vein to obviate the need for future surgery (Figure 16.1). The treatment protocol used in the series of patients presented by Van Dijk et al.⁵ used endovascular therapy as the first line of treatment because it is noninvasive, has a low complication rate, and offers the ability to obtain immediate angiographic control and confirmation of obliteration of the malformation. Using their endovascular treatment criteria, which included both the ability to penetrate the fistula and proximal portion of the draining vein, as well as the ability to treat the malformation in a single session, only 11 (25%) of the patients were treated via the endovascular route, all of whom demonstrated a clinical success rate and stability equivalent to that of surgery (mean follow-up of 32.3 months) with no permanent complications. Under less stringent criteria, other endovascular specialists using acrylate have reported success rates of up to 90%, but with recurrence rates of up to 23%.

Intradural (Pial) Arteriovenous Fistula (Ventral Intradural AVF, or Type IV)

The type IV AVF represents a direct fistula from the anterior spinal artery to the coronal venous plexus (Figure 16.2). Radiculopial supply may also be involved. The intradural arteriovenous fistula has three subtypes, A, B, and C. These lesions can be seen anywhere along the spine.

Subtype A (also classified as Merland subtype I) represents a small shunt, with moderate venous hypertension. There is no enlargement of the anterior spinal artery (ASA) and only minimal dilatation of the ascending draining vein.^{1,7} The fistula is located at the point that a vessel caliber change is seen.⁸ The ASA is the only feeder, and the AVF is typically located along the anterior aspect of the conus medullaris or proximal filum terminale.⁹

Subtype B (Merland subtype II) represents a moderate-sized shunt with moderate enlargement of the feeding artery or arteries and the draining veins. The location of the fistula is marked by venous ecta-sia.⁸ There are several abnormally dilated feeding arteries, composed



FIGURE 16.2. Schematic illustration of a pial arteriovenous malformation (AVM type IV). 1, lumbar artery; 2, longitudinal pretransverse anastomosis; 3, nerve root sleeve; 4, dorsospinal branch; 5, dural artery; 6, radiculomedullary artery; 7, dorsal somatic artery; 8, anterior spinal artery; 9, coronal venous plexus; 10, anterior median vein; 11, arteriovenous fistula between anterior spinal artery and the anterior median vein. of the ASA and one or two arteries from the dorsolateral pial network [posterior spinal artery (PSA)], all of which converge on the fistula. These are typically located at the level of the conus. Venous drainage is into tortuous and dilated ascending perimedullary veins.⁹

Subtype C represents a giant fistula with one or more very large arterial feeders from the ASA and dorsolateral pial network (PSA) converging into the fistula and draining directly into a giant venous ectasia, often embedded within the substance of the cord. These fistulas are rare,⁸ although in at least one large series they represented the largest subtype of ventral intradural AVFs.⁹ The location of the fistula is more difficult to ascertain because of the giant ectatic draining vein.⁸ The giant ectatic draining vein usually drains into the local metameric efferent veins, which are also dilated.⁹ These lesions are typically located at the thoracic or cervical levels.⁹

Signs and symptoms may be due to vascular steal (more so with higher flow), venous hypertension, mass effect (with venous enlargement/aneurysms), and hemorrhage (SAH).¹ The clinical signs and symptoms almost always appear before age 40 and often present during the first decade (mean age at diagnosis being between 11.5 and 13.5 years). Subarachnoid hemorrhage is the presenting sign in approximately 40% of patients in one series, but according to some authors, only type C fistulas present with hemorrhage.^{8,10} Occasionally, hematomyelia has also been reported. Paraparesis or paraplegia is the most common sign, with progressive deterioration over time. Radiculomyelopathy or radiculopathy can also be present, presumably due to the mass effect from dilated venous structures.

These lesions can be seen anywhere along the spine. While the fistula is often ventrolateral, a posterolateral location may also occur when there is significant involvement of the dorsolateral pial network (PSA).

Therapy

In subtype A, the blood supply generally occurs through a minimally dilated anterior spinal artery with slow flow, and thus endovascular obliteration remains difficult. Frequently, superselective catheterization for an AVF obliteration may be hazardous. Surgical obliteration is frequently the only choice. In case the fistula is located in the ventral surface of the spinal cord and surgical access is difficult, a PVA particle embolization from a proximal catheter position may be considered. Subtype B shows higher flow within one or multiple dilated pial arteries; thus, an endovascular approach is feasible, with curative obliteration of the arteriovenous fistula by means of NBCA. In the case of a complex AVF, intraoperative transvenous embolization has been described.¹¹ In subtype C, the AVF is large and the feeding arteries extremely dilated. Detachable balloons or fibered coils have been used in the past for a permanent obliteration. Under flow control, NBCA may be used safely for a complete closure.¹⁰

Extradural/Intradural AVM

The extradural/intradural AVM is also known as metameric or juvenile AVM. If all derivatives of the metamere (i.e., skin, muscle, bone, dura, and cord) are involved, the malformation is known as Cobb's syndrome.

Therapy

Because of the complex nature of the malformation, a combined endovascular and surgical approach is recommended.¹² However, in rare situations, we have been successful with staged endovascular NBCA embolization, achieving curative results.

Intramedullary AVM

The intramedullary arteriovenous malformation is also known as a type II or classic AVM. Spinal cord AVMs are the second most common spinal vascular malformation. The angioarchitecture of these lesions is similar to that of classic brain AVMs, with multiple arterial feeders, a nidus, and draining veins. The nidus can be compact (glomus type) or diffuse (occasionally called juvenile type, not to be confused with the metameric type). The arterial feeders are usually multiple branches of the ventral spinal axis (ASA) and/or dorsolateral pial network (PSAs). These lesions are high-flow, high-pressure, low-resistance malformations.¹ In their new proposed classification, Spetzler et al. subdivided these lesions into those with compact (glomus-type) nidus and those with a diffuse nidus.

The natural history is difficult to ascertain, but the majority of patients present before the age of 40.⁸ The most common presentation is an acute myelopathy due to intramedullary and/or subarachnoid hemorrhage.^{1,8} A proportion of patients present with intermittent or progressive myelopathy with deterioration of limb function or bowel and bladder function.

The progressive myelopathy can be due to vascular steal, venous hypertension, or venous compression.¹ Pain also is a common presenting symptom in these patients. If left untreated, patients can be expected to experience an episodic but progressive deterioration due to repetitive bleeding.⁸ In one 8-year study of 60 patients, 36% of patients younger than 41 years of age, and 48% of patients aged 41 to 61 were wheelchair bound within 3 years of diagnosis.¹³ Based on Djindjian's original series of 150 patients, 13% of patients at the 5-year follow-up, 20% of patients at the 10-year follow-up, and 57% of patients at the 20-year follow-up had experienced clinical deterioration.^{14a}

Therapy

Surgical resection is difficult and bears high morbidity because of the intramedullary location and because blood is supplied from tiny perforators arising from sulcocommissural branches. These may arise as en passage arteries that supply normal cord tissue. A carefully planned, staged embolization with obliteration of the most proximal draining pial vein with NBCA may be curative (Figure 16.3). Frequently, repeated PVA particle embolization may be the only alternative to reduce the size of the AVM nidus and to effect temporary symptomatic relief.^{15–17} If a surgical resection is planned, preoperative particle or NBCA embolization may be helpful.

Conus Medullaris AVM

Spetzler et al.¹ have proposed the conus medullaris AVM as a new category characterized by multiple feeding arteries, multiple niduses, and



FIGURE 16.3. Images of the brain of a 21-year-old male who presented with subarachnoid hemorrhage associated with an intramedullary arteriovenous malformation. The AVM was treated in multiple staged sessions with *n*-butylcyanoacrylate. (A) Computed tomographic image without contrast shows extensive SAH. (B) T1-weighted MRI without contrast shows flow voids within the AVM nidus located at the craniocervical junction (arrows). (C) Gradient echo T2-weighted axial MRI shows the extensive involvement of the anterior and central aspects of the spinal cord and an enlarged anterior median vein with flow void.



Е

FIGURE 16.3. *Continued.* (D–F) Vertebral artery injection in the lateral and anterior–posterior projection shows the extent of the intramedullary AVM, with early drainage of the lower parts of the nidus through the enlarged anterior median vein (D, arrow). (E) Late arterial phase shows both enlarged veins of the middle cerebellar peduncle draining via the superior petrosal vein into the superior petrosal sinus (F, black arrow) and the dilated median anterior pontomesencephalic vein (F, open arrow).

(Continued)



G

FIGURE 16.3. *Continued.* (D–F) Vertebral artery injection in lateral and anterior–posterior projection: (G) Superselective injection of the anterior spinal artery (open arrow) through a flow-guided microcatheter, which has been placed over a guide wire (straight black arrow). Multiple sulcocommissural arteries are feeding the AVM nidus (curved arrow). A few of them have already been embolized with acrylate (see subtraction artifact).

9.





FIGURE 16.3. *Continued*. (H) Superselective injection of a sulcocommissural artery (thin arrow) shows a compartment of the intramedullary AVM that drains into the enlarged anterior median vein (thick arrow) cranially the vein of middle cerebellar peduncle. The caudal drainage occurs through the anterior median vein (small arrow). (I,J) A staged embolization with complete AVM obliteration was achieved. Note the caliber reduction of the anterior spinal artery because of the shunt reduction. Note the displacement of the anterior spinal artery (J, curved arrow).

complex venous drainage. The lesions are composed of multiple direct arteriovenous shunts with feeders from the ventral spinal axis (ASA) and dorsolateral pial network (PSAs), with glomus-type niduses that are usually extramedullary (pial) but can occasionally be intramedullary.¹ The lesions are always located in the conus medullaris and cauda equina and can extend along the filum terminale all the way down.¹ Symptoms can be caused by venous hypertension, venous compression of the cord/cauda equina, or hemorrhage. Unique to this type of spinal vascular malformation is frequent production of radiculopathy in addition to myelopathy.¹

Neoplastic Vascular Lesions of the Spinal Cord

Cavernous Malformations (Cavernous Angiomas)

Cavernous angiomas are slow-flow vascular lesions consisting of sinusoidal vascular channels lined by a single layer of endothelium, separated by collagenous stroma, and without any normal intervening neural tissue. Grossly, they are well-circumscribed reddish-purple lesions, often likened to a mulberry or cluster of mulberries. There is a characteristic gliotic reaction in the surrounding parenchyma, which may form a pseudocapsule. Within the lesion, there is often evidence of hyalinization, thrombosis in various stages of organization, calcification, cholesterol crystals, and cysts.¹⁸ The immediate surrounding parenchyma may contain small, low-flow feeding arteries and draining veins. In a review of 57 reported cases of spinal cavernomas, Canavero et al.¹⁹ found that 69% of the patients were women, with a mean age of 36.4 years at diagnosis. They estimated a 1.6%/person/ year risk of bleeding, with a higher risk in cervical lesions. Magnetic resonance imaging (MRI) was found to be diagnostic in all cases, while angiography was negative in 100%. This latter finding is not strange, considering that cavernomas are one of the classically "angiographically occult" vascular malformations.

Therapy

Treatment is by conservative approach or surgical resection. There is no role for an endovascular approach.

Hemangioblastomas

Hemangioblastomas are true neoplasms of blood vessels. They can arise spontaneously, but they also can be associated with von Hippel–Lindau syndrome. In the spinal cord, they constitute 3.3% of intramedullary tumors and most commonly present in the fourth decade.²⁰ Up to 30% of patients with spinal cord hemangioblastomas have von Hippel–Lindau syndrome. The majority of spinal hemangioblastomas (79%) are single. The thoracic cord is the most common site, followed by the cervical cord.²⁰ Angiographically, they are very vascular lesions, often with arteriovenous shunting.

Therapy

A preoperative embolization significantly reduces the risk of a surgical resection^{21,22} (Figure 16.4).

FIGURE 16.4. (A) A hypervascular intramedullary mass of the upper cervical region consistent with a hemangioblastoma. Major blood supply occurs through the C2 radicular artery (large arrow). Note the anterior spinal artery (small arrow). (B) Superselective placement of a microcatheter within the radicular artery for a preoperative PVA particle embolization. (C) Control angiogram after complete devascularization.



A





Systemic Syndromes Associated with Spinal Vascular Malformations

Osler–Weber–Rendu Syndrome (Hereditary Hemorrhagic Telangiectasia)

The autosomal dominant syndrome named after Osler, Weber, and Rendu consists of two genotypes (types 1 and 2). Type 1 is associated with mucocutaneous telangiectasias, pulmonary arteriovenous fistulas, and arteriovenous shunts of the central nervous system. The associated spinal arteriovenous shunts are most often seen in the pediatric population and are always intradural (pial) arteriovenous fistulas, sub-type C (ventral intradural AVF; or type IV, subtype C). The endothe-lial cells in this syndrome lack the molecule "endoglin" and form abnormal vessels, especially after injury.²³

Cobb's Syndrome

The synonym for the complete manifestation of the metameric type of spinal vascular malformation is Cobb's syndrome.

Klippel-Trenaunay (KT) and Parkes-Weber (PW) Syndromes

The KT and PW syndromes consist of vascular malformations involving the lower limbs primarily, with the following dominant features: cutaneous capillary malformation, varicose veins, and limb hypertrophy. The KT syndrome comprises primarily venous anomalies, while the PW syndrome has more arteriovenous shunts.²³ Spinal cord involvement with pial arteriovenous fistulas or malformations can be present.

Therapy

Staged embolization and surgical resection, if feasible, are the recommended therapies.

Miscellaneous Vascular Lesions of the Vertebrae

Vertebral Hemangiomas

Vertebral hemangiomas are benign vascular malformations of the bone with a very well-known and well-described appearance on conventional radiography, computed tomography (CT), and MRI. The incidence of hemangiomas is variable, depending on age, but has been reported to be around 11% with increasing age. Up to 30% of patients have multiple lesions.

Pathologically, these hemangiomas are considered to be postcapillary vascular dysembryogenetic malformations. Microscopically, they are divided into capillary, cavernous, and mixed types.^{24,25} The vast majority of these lesions are asymptomatic and are incidental findings on MRI examinations performed for other reasons. Less than 1% of hemangiomas become symptomatic.²⁴

A review of 3 series describing the treatment of hemangiomas causing cord compression, with a total of 34 patients, suggests the following characteristics of hemangiomas presenting with neurological symptoms (cord compression or radiculopathy): 22 of 34 patients (65%) had holovertebral (body, pedicles, and laminae) involvement, 8 of 34 (23.5%) had partial body and pedicle/posterior element involvement, and 4 of 34 (11.8%) had involvement of the body only. The majority (25 of 34, or 73.5%) were women. Young adults formed a large portion of patients presenting with cord compression and/or radiculopathy. The majority of lesions (17 of 23 in two series, or 74%) were in the thoracic spine.^{24–26} Fox et al. noted that neck or back pain often preceded the neurological symptoms and that thoracic myelopathy was the most common neurological presentation. An additional known risk factor for development of neurological symptoms is pregnancy, with symptoms developing in the third trimester,²⁵ perhaps owing to the role of estrogen and/or increased venous pressure due to abdominal distention and pressure of the growing uterus on the venous structures. The mechanism for cord compression can be epidural extension of the lesion from the bone (vertebral body or posterior elements) into the spinal canal, expansion of the bony vertebra by the hemangioma, a pathological fracture of the vertebra, epidural hematoma from bleeding from the lesion, or compression by enlarged feeding arteries or draining veins.²⁵ Djindjian et al.^{14b} divided vertebral hemangiomas into three groups based on clinical and imaging characteristics:

Type A

The type A vertebral hemangiomas present with signs and symptoms of cord compression. Imaging demonstrates extraosseous extension of the lesion, usually related to a fracture (insufficiency fracture) due to the presence of the lesion weakening the vertebral body (Figure 16.5). Angiography demonstrates dense opacification of the vertebral body via enlarged osseous (somatic) branches of normal-sized intercostal/ segmental arteries. The appearance of the lesion in the vertebral body is described as dense pools of contrast appearing in the midarterial phase and persisting into the venous phase.

Therapy: The usual treatment for these lesions consists of preoperative embolization of the lesion with particles and/or NBCA and operative decompression of the spinal cord/canal, possibly with resection of the lesion and spinal reconstruction and stabilization (Figure 16.5). Doppman et al.²⁴ made the important observation that even when there is epidural extension, the lesion does not penetrate the dura but is confined by the periosteum, which results in the characteristic bilobed posterior margin of these lesions, indented centrally by the posterior longitudinal ligament.

An additional treatment option in these patients, in whom timely treatment is a medical necessity, is the technique of percutaneous transpedicular injection of ethanol, which Doppman et al.²⁴ used successfully in the treatment of 11 patients. All the patients in this series had appropriate cross-sectional imaging workup. The vascularity of the lesions was determined by doing a CT scan with injection of iodinated contrast medium through arterial catheters placed selectively in the segmental arteries at the appropriate vertebral level.





В





With current imaging technology, it is possible that dynamic contrastenhanced CT or MR images may be adequate in this regard. The needles were placed percutaneously through the pedicle, with the tip of the needle usually positioned at the vertebropedicular junction (these lesions invariably had posterior extension and/or involvement of the posterior elements). Initially, contrast material was injected through the needles, and a CT scan was performed to demonstrate opacification of the lesion. Subsequently, dehydrated ethanol opacified with metrizamide powder was forcefully injected. Because of the pain associated with ethanol injection, MAC anesthesia was recommended. For lower thoracic and upper lumbar lesions, the artery of Adamkiewicz was identified to ensure that it did not arise at the same level. Doppman et al. recommended an ethanol volume of less than 15 mL, since higher volumes were associated with subsequent avascular necrosis and compression fractures of the treated vertebrae.²⁴ Their recommendation was that the injection of ethanol be stopped when no blood could be aspirated from the needle, or when the volume reached 15 mL. In this series of patients, five had complete and five had partial relief of symptoms (one with no relief). Improvement of symptoms began within 1 or 2 days. Prior to discharge MRI was performed, and the images demonstrated nonenhancement and shrinkage of the lesions.

Type B

Vertebral hemangiomas of type B are associated with local pain and tenderness over the involved vertebral body, and/or radicular signs. Imaging does not reveal any extraosseous extension. The angiographic appearance is similar to that of type A lesions.

Therapy: The type B lesions are generally large. The first step in their evaluation is to exclude the more common causes of back pain, with the help of imaging and physical examination.²⁵ Imaging further helps to exclude involvement of the posterior element, cortical disruption, and epidural spread of the lesion. In the absence of these findings, percutaneous vertebroplasty with poly(methyl methacrylate) (PMMA) is probably the treatment of choice. Other treatment options include endovascular transarterial embolization of the lesion by means of particles, NBCA, or ethanol. Embolization has been reported to be effective

FIGURE 16.5. (A) Fast spin echo T2-weighted image shows a vertebral body hemangioma with spinal canal stenosis and cord compression due to extraosseous extension. (B) Contrast-enhanced T1-weighted image shows the enhancing extraosseous epidural extension of the hemangioma with cord compression (arrows). (C) Selective angiogram of a left intercostal artery shows a hypervascular vertebral body with blood supply through perforating somatic branches of the intercostal artery. (D) Preoperative/PVA particle embolization through a microcatheter, which was placed coaxially through the diagnostic catheter. A fibered coil has been placed distal to the origin of somatic branches within the intercostal artery (arrow) to flow direct PVA particles preferentially into the feeding pedicles. The control angiogram shows a nearly complete devascularization. The patient received a high dose of corticosteroids prior to the procedure.
in 60 to 100% of cases.²⁵ Percutaneous injection of opacified ethanol was described by Doppman et al.²⁴ but for the treatment of type A lesions.

Reizine et al.²⁷ suggested that if a painful lesion is located in the cervical or lumbar spine, without involvement of the posterior elements or cortical disruption, these lesions could be considered to be nonevolutive (without potential for future growth causing cord compression). On the other hand, a painful lesion located in the thoracic spine (especially in a young female) and demonstrating involvement of the posterior elements, or cortical disruption, or soft tissue extension should be considered to be an evolutive lesion, with serious potential for future cord compression.

Type C

The vast majority of hemangiomas, which are incidental findings, are of type C. There are no associated symptoms, and the angiogram is normal.⁸

Therapy: Generally, unless the patient develops symptoms (i.e., pain and/or neurological deficits), follow-up imaging is not necessary, nor are additional studies required.²⁵ An exception can be made for very large type C lesions (e.g., holobody lesions) in a young woman, where the chance of further growth of the lesion is higher, and yearly follow-up may be considered.

Aneurysmal Bone Cysts

Aneurysmal bone cysts (ABCs) are benign lesions of bones that primarily affect young people; 80% of patients present under the age of 20. There is no sex predilection. While ABCs can occur at any location, 90% are seen in the spine. Within the spine, most lesions involve the posterior elements, although the vertebral body can also be involved. Additionally, ABCs (in addition to vertebral hemangiomas) can involve two contiguous vertebral bodies.²⁸

The radiographic appearance of ABCs has been well described. Pathologically, the lesions consist of enlarged communicating spaces within the bone, containing venous blood under higher than normal venous pressure. The lining of the spaces consists of a fibro-osseous patchwork and some giant cells.²⁸ Interestingly, up to one third of ABCs are found in conjunction with other lesions, such as fibrous dysplasia, osteoblastoma, or chondrosarcoma,²⁹ and others may be associated with previous trauma.³⁰

With regard to pathogenesis, most authors believe that a hemodynamic imbalance or abnormality within the bone is the etiological factor, especially with regard to impaired venous drainage.^{30,31} Some have suggested the presence of a congenital vascular abnormality in cases of de novo ABCs, and impairment of venous drainage by a secondary factor (associated lesions, or trauma) in other cases.³⁰

Angiographically, there is no pathognomonic pattern for ABCs. Findings can vary from faint or moderate vascularity to dense vascularity with a rich network of dilated, tortuous feeding vessels and a dense stain of the lesion within the vertebral body.²⁸ Djindjian described arteriovenous shunting in some lesions,^{14a} while others have described patchy collections of contrast within the cystic spaces, persisting into the late venous phase.

Therapy

The most common approach to symptomatic ABCs is surgery, whether with curettage or with resection of the lesion and reconstruction of the spine if necessary. In many cases, owing to the vascularity of the lesion, the operating surgeon will request preoperative angiography and embolization of the lesion to decrease intraoperative blood loss, which can be significant (Figure 16.6).

At least two separate papers have described the successful use of endovascular embolization as the sole therapy for ABCs. Cigala and Sadile³² described the results of embolization of six large ABCs in children, in whom operative therapy would have been difficult. Long-term follow-up showed almost complete healing of the lesions and restoration of the normal shape of the affected bone. None of the patients required subsequent surgery. Radanovic et al.³³ described the endovascular embolization of ABCs in five patients, all of whom had relief of their primary symptom (pain) and a decrease in size of the ABC. In patients who were followed up for more than 12 months, sclerosis and recalcification of the lesions was described.

Metastatic Lesions Affecting the Spine

Neoplastic and metastatic lesions can involve the vertebral bodies as well as intra- and extramedullary structures. The goal of endovascular treatment remains devascularization prior to a planned surgery or biopsy (Figure 16.7). Embolization significantly reduces the blood loss and improves the surgical resection.^{34–37} Because the embolization is performed with Gelfoam, PVA, or on some occasions with dehydrated ethanol, attention has to be paid to the potential supply of radiculomedullary/radiculopial arteries to the anterior or posterior spinal arteries. An embolization can on rare occasion lead to tumor necrosis, with subsequent swelling and spinal cord compression. Preprocedural high-dose corticosteroid medication has been suggested.³⁸ On rare occasions and in nonsurgical patients, embolization can be helpful for pain reduction and treatment of radicular compression.³⁸ Although a reduction of tumor growth may be seen, embolization for spinal metastasis and malignant spinal tumors is not curative.

An endovascular or direct percutaneous embolization of a vertebral body metastasis or malignant tumor can be achieved. The latter can be performed under CT or fluoroscopic guidance,³⁹ with the use of NBCA, PMMA, or dehydrated ethanol.^{40,41} Use of PMMA can additionally import biomechanical stability to the vertebral body.⁴² The percutaneous approach to treatment of spinal metastases can also employ radio-frequency ablation (RFA) with or without the use of PMMA (polymethylmethacrylate).



FIGURE 16.6. Spinal images of an 11-year-old boy who presented with intractable neck pain associated with an aneurysmal bone cyst after a football match. A preoperative transarterial PVA embolization was performed. (A) Lateral plain spine x-ray film shows a sharply demarcated osteolytic lesion of the posterior part of the C5 vertebral body (arrow) and narrowing of the spinal canal. (B) T1-weighted image shows the C5 lesion with well-defined calcified boundaries (arrow). There is no epidural extension or spinal cord compression visible.





FIGURE 16.6. Continued. (C) Contrast-enhanced CT image shows a hypodense lesion (arrow) with enhancement of the margins. Note the involvement of the vertebral and neuronal foramina and extension into the lateral recess. (D) Selective right vertebral artery angiogram (lateral plane) shows tortuous feeding posterior and lateral somatic branches arising from two major supplying radicular arteries (arrows); moderate vascularity with a rich network of dilated and tortuous feeding vessels, and patchy collections of contrast material in the cystic spaces, persisting into the late venous phase (see E). (E) Late arterial (lateral plane) phase shows the prominent filling of the epidural venous network and depicts the persisting blush of the C5 vertebral body (arrows).







Recommended Technique for Spinal Angiography and Intervention

This brief overview of techniques and intervention is not intended to replace standard textbooks in this field. Generally speaking, contrary to popular opinion, with modern catheter techniques in the hands of trained physicians, spinal diagnostic workup should have no complications higher than that of a diagnostic angiography of the peripheral vascular system. Infrequently, minor asymptomatic iliac or aortic dissections may be encountered in patients with significant arteriosclerosis.

Diagnostic angiography of the spine should be a focused study. Generally, MRI findings guide the invasive diagnostic workup. It is often pertinent to locate the artery of Adamkiewicz or radicularis magna as the major supply to the anterior spinal cord. However, if a vascular lesion, especially a dural arteriovenous malformation (fistula), is suspected, a more thorough angiogram may be required. This would include an angiogram of the aortic arch, the descending aorta, the abdominal aorta, and the pelvic system, and in the case of a cervical spinal cord malformation, the vertebral arteries, the thyrocervical trunk, and the deep and ascending cervical arteries. More recent magnetic resonance angiographic (MRA) studies have shown improved sensitivity in depicting dural AVFs and defining the level of the blood supply.⁴³ This will help to focus the time needed for angiography.

An aortogram can be accomplished best by using a 5-Fr pigtailconfigured catheter and a standard amount of contrast material (30–40 mL), which is injected over 2 seconds by means of a high-pressure pump. This helps occasionally in finding the level of the feeding arteries of the expected vascular lesion and may serve as a map for the selective spinal angiography, especially in patients with several missing intercostal or lumbar arteries. However, the disadvantage is that a large amount of contrast material is required for the study, thus, especially in patients with impaired renal function, it may be necessary to stop the procedure prematurely, and complete it the following day. The recent development of nonionic isomolar contrast agents (Visipaque, Iodixanol; Nycomed, Inc., Princeton, NJ) may be helpful because larger amounts can be used.

FIGURE 16.6. *Continued*. (F) Vertebral artery angiogram (frontal plane) prior to superselective catheterization demonstrates the dilated and tortuous radicular and somatic branches (arrows) and the patchy collection of contrast material in the lateral aspect of the vertebral body. (G) Superselective microcatheter injections of the lower radicular artery (arrow) prior to PVA embolization shows the contrast-filled "lakes" filling within the lateral aspects of the vertebral body. (H) A 5–Fr catheter has been placed into the ascending cervical branch of the thyrocervical trunk (open arrow). The microcatheter is placed through the guide catheter into the radicular artery anastomosis feeding the ABC prior to PVA embolization (arrow). (I) Control angiogram through the vertebral artery after embolization shows nearly complete devascularization. Note that the microcatheter tip is still within the radicular artery (arrow). The mild vasospasm of the vertebral artery noted distal to the second radicular artery origin occurred after a balloon test occlusion.



В

FIGURE 16.7. Pelvic images of a 50-year-old female who presented with lower back pain and sensory deficit associated with a recurrent giant cell cancer of the sacrum. A preoperative PVA embolization was performed to reduce the intraoperative blood loss. (A) Contrast-enhanced T1-weighted image shows the patchy and irregular enhancement of the sacral body and epidural space (arrows). The nerve roots are encased in the tumor tissue. (B) Pelvic angiogram shows the tumor blood supply from both internal iliac artery branches and the median sacral artery.

FIGURE 16.7. *Continued.* (C) Superselective microcatheterization of the right lateral sacral artery (arrow) prior to PVA embolization shows the diffuse tumor blush. (D) Superselective catheterization of the median sacral artery (arrow) prior to embolization shows the significant tumor blood supply through small anterior somatic branches.



С





FIGURE 16.7. Continued. (E) Left internal iliac artery angiogram shows the tumor supply through lateral sacral arteries (black arrow) and the iliolumbar artery (open arrow). (F) Control pelvic angiogram shows a complete tumor devascularization. Fibered coils were used to protect normal distal branches of the iliolumbar arteries (see artifacts superimposing on both internal iliac arteries).

Е



Selective catheterization of intercostal or lumbar arteries is done by means of a 4-Fr or, on rare occasions, a 5-Fr H-1 catheter. Other catheters used are C-1 and C-2 catheters, Sidewinder I or II catheters, or, by some experts, a steam-shaped 4-Fr catheter with a distal hookshaped tip. An amount of 2 to 4 mL is injected within a second, and the angiogram is acquired in anterior–posterior projection. To reduce the time involved in placing the catheter and switching the contrastfilled syringe back and forth, it is recommended to have an assistant inject the contrast if an injector pump is not available. If injection by hand is preferred, the small syringe should be attached to a three-way stopcock, while another attached syringe, filled with 20 mL of contrast material, serves as a reservoir. The digitally subtracted angiographic run (acquisition) should be long enough to capture both the arterial and venous phases. This is especially true in the evaluation of spinal vascular malformations.

If an intervention is planned and a 6-Fr guide catheter is preferred for the coaxial microcatheter placement, it may be helpful to place a 6-Fr femoral sheath or, if the region of interest is located higher, a long femoral sheath bypassing the often tortuous aortic–iliac system. Infrequently, the guide catheter may require to be changed over an exchange wire for a stable position within the intercostal or lumbar artery. It is easier and less traumatic to use hydrophilic-coated exchange guide wires for straightening the proximal part of the segmental arteries. With the introduction of 5-Fr guide catheters with larger lumina, a larger catheter may not be required.

A range of microcatheters, including flow-guided catheters and microwires, are available for interventional procedures. The selection must be tailored to the size of the vessel and the embolic material used. For diagnostic purposes, heparin is not given. Heparin may be given for interventional procedures, but only on rare occasions to prevent inadvertent thrombosis, especially if catheters are navigated within the spinal cord vasculature. In selected cases of high-flow AVMs that have blood supply from anterior or posterior spinal arteries, we put the patient on aspirin and/or Plavix to prevent a retrograde thrombosis after embolization.

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17

Epidural Blood and Fibrin Patches

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Cerebrospinal fluid (CSF) hypovolemia may result from dural puncture, surgery, trauma, or spontaneously. When loss of CSF exceeds CSF production, the resultant low CSF pressure may result in traction on the dura, epidural veins, and cranial nerves. Postural headache and cervicalgia are common presenting symptoms. However, the sagging of the brain could lead to more serious complications owing to potential compression of the diencephalon or ischemic traction on the cranial nerves resulting in permanent neurological deficits. Coma and even death due to spontaneous intracranial hypotension have been reported. Frequently, CSF hypovolemia resolves spontaneously without treatment, since CSF production is a continuous process and CSF equilibrium may be restored with spontaneous sealing of a dural leak without any intervention. However, both conservative and interventional therapies exist for treatment of symptomatic patients. This chapter will address the potential application of epidural blood patches and fibrin patches for treatment of CSF hypovolemia syndromes. Patient selection criteria, techniques, and potential complications will be discussed.

Pathophysiology and Diagnosis of CSF Hypovolemia

Cerebrospinal fluid hypovolemia may occur from several causes. Etiologies include post-dural puncture syndrome (PDPS), spontaneous intracranial hypotension (SIH), trauma, and postoperative dural tears.

PDPS may occur after lumbar puncture or myelography. It has also been described as a potential complication of spinal anesthesia. PDPS may also occur after inadvertent dural puncture during attempted epidural injection or epidural catheter placement.

The syndrome of SIH may occur in patients who have an underlying connective tissue disorder such as Marfan's syndrome or Ehlers– Danlos syndrome. Some of these patients may have single or multiple meningeal diverticula that probably serve as underlying areas of weakening in the dural sac that are predisposed to tearing or leaking.¹ SIH may occur in the absence of trauma or may be seen in association with minor traumas. Associations of SIH have been made with activities such as chiropractor visits, roller coaster rides, childbirth, gymnastics, and yoga.² Two cases of SIH due to dural tears from cervical bone spurs have also been described.^{3,4} Dural leaks related to SIH are usually cervical or thoracic in origin but, rarely, may occur in the skull base, particularly in the region of the cribriform plate. Dural tears may occur during surgery of the brain, spine, head and neck, or lung. Dural leaks may occur after transphenoidal surgery or mastoid surgery.

The Monro-Kellie rule, which has been used to describe the physiology of CSF hypovolemia, states that CSF volume fluctuates with the intracranial blood volume under normal physiological conditions. A reduction in the CSF volume and pressure will result in dilation of the venous and arterial structures of the brain and spinal column. The resultant symptoms of CSF hypovolemia include postural headache and neck stiffness. Cranial nerve palsy has been described in some cases and may result in permanent deficits.⁵ Thoracic back pain and cervical radiculopathy may be presenting symptoms, which may occur in the absence of headache or neck pain. Radicular symptoms are attributed to traction on spinal nerve roots due to the hypovolemia. Isolated auditive complaints of hearing loss and tinnitus are presenting signs of SIH that sometimes go unrecognized. However, these symptoms can be reversed if treated.⁶ The diagnosis of a PDPS or CSF hypovolemia after surgery is often clear-cut on a clinical basis. However, there is at least one case report of a patient with unrecognized PDPS who was successfully treated with an epidural blood patch 2 years after lumbar puncture.7

The diagnosis of SIH is usually more difficult to establish. The condition was first described in 1939 in the German literature. If discovered, this syndrome may be treatable. In severe cases, however, the diagnosis is often delayed. There may be complications of stroke or subdural hematomas with brain herniation. Some patients die before the diagnosis is reached.

If SIH is suspected, MR imaging of the brain with and without contrast may be helpful in demonstrating some of the classic findings such as smooth pachymeningeal enhancement, spontaneous subdural hygromas or hematomas, spinal epidural fluid collections, or cerebellar tonsillar descent.^{8,9} Marked epidural distention may be seen both intracranially and in the upper cervical canal.¹⁰ The dilation of the anterior vertebral plexus may actually indent the thecal sac and displace the dura.¹¹ An MRI workup of the entire spine may be useful to search for the site of a leak. In addition, T2-weighted fat saturation sequences and contrast material administered intravenously may be helpful in pinpointing the site of a leak. The MRI may demonstrate a meningeal diverticulum or focal extraspinal fluid collection. However, it should be noted that epidural fluid collections may be seen quite a distance from the actual source of the leak. Therefore, further evaluation with simultaneous radionuclide cisternogram and computed tomographic (CT) myelography may be needed. The myelogram should be obtained with imaging in the lateral decubitis position with cross-table views taken intermittently to look for a ventral or dorsal leak. Repeating the sequence in the opposite decubitis position may be helpful if no leak

is seen. The injection for the radionuclide cisternogram can be performed at the same setting. Complete myelography should be performed as well as a CT myelogram with 3 to 5 mm thin axial cuts to search for a potential site of the leak. Some patients with CSF hypovolemia will not demonstrate any imaging findings. Therefore, even if the results of imaging tests are normal, an epidural blood patch in the proper clinical setting may still be of benefit.

Lumbar puncture may also be used to establish the diagnosis of the CSF hypovolemia. Opening CSF pressure measurements are usually below 60 mm H₂O. There have been reports of patients with normal opening CSF pressure measurements who subsequently underwent epidural blood patch with resolution of their symptoms.^{12,13}

Some MRI abnormalities may persist for a few weeks even after symptoms of CSF hypovolemia are resolved. MR findings should be completely resolved by 3 to 5 months after treatment.¹⁴

Epidural Blood Patch

Performed since 1960 for PDPS, the epidural blood patch (EBP) has also been successfully used in the treatment of spontaneous intracranial hypotension and postlaminectomy leaks. The mechanism of action is likely due to the thrombotic plug patching the hole or a rent in the dura as well as the generation of increased pressure in the epidural space.

It has been reported that up to 60% of patients with postdural puncture headache recover spontaneously, with symptoms rarely lasting more than a week. Patients with persistent or severe headache may be relieved by EBP. Cure rates of 85 to 98% have been reported. In a large study of 504 patients, 75% had complete relief, 18% had incomplete relief, and only 7% were considered failures.¹⁵ Repeat EBP is more common after inadvertent dural puncture with a Tuohy needle than with smaller gauge spinal needles. There are no controlled studies evaluating the efficacy of epidural blood patch to the author's knowledge. For these reasons, rules for determining when to perform the EBP are not clearly defined in the literature. Some authors perform EBP in as little as 24 hours after a dural puncture in a symptomatic patient; others recommend up to 3 weeks of conservative therapy.¹⁶ For a patient with cranial nerve palsy or auditory disturbance, it is probably preferable to perform the epidural blood patch sooner rather than later owing to the potential risk of ischemic damage to the cranial nerves. Also, one must consider the severity of the patient's symptoms and whether earlier treatment might facilitate that patient's return to work and/or normal daily activities.

Once an epidural blood patch has been administered for PDPS, relief of symptoms may be almost immediate. Anecdotally, some patients may report relief of their headache even while the injection is being performed. Most patients with hearing loss secondary to CSF hypovolemia will demonstrate significant improvement in hearing within an hour, as demonstrated on audiometric testing.¹⁷ An in vitro study in a canine model showed that the coagulation time of autologous blood was accelerated when the blood was mixed with CSF. It was suggested that CSF accelerates the coagulation cascade.¹⁸ The acceleration of the coagulation cascade might explain why the epidural blood patch may invoke such a rapid response. Another proposed reason for the rapid response is that the injected volume raises the pressure in the epidural and subarachnoid space, forcing CSF back inside the cranium. In vivo pressure measurements during epidural injection support this theory.¹⁹

Potential contraindications to EBP include presence of intracerebral subdural hematoma. There is a case report of a patient with SIH who developed so significant an increase in subdural hematoma after an epidural blood patch that surgical decompression was required.²⁰ The epidural blood patch is contraindicated when sepsis or leukemia are present, to avoid the theoretical risk of seeding infection or malignancy into the neuroaxis. Other contraindications include severe coagulopathy or a patient who is a Jehovah's Witness. Relative contraindications include HIV infection and severe anemia. Patients infected with HIV have been treated with autologous EBP with no reports of subsequent HIV-related infections of the central nervous system in a 2-year follow-up period. Epidural blood patches have been performed in children and do not appear to be contraindicated in the proper clinical setting. Previous EBP is not thought to be a contraindication to subsequent epidural anesthesia.

The risks of EBP are low, but reported complications including sepsis, transient facial paralysis, exacerbation of postdural puncture symptoms, seizure, encephalopathy, arachnoiditis, and transient brachycardia. Intrathecal and subdural hematoma have been described. Transient backache or radiculopathy has been reported in patients receiving a lumbar blood patch. Acute meningeal irritative reaction has also been described. Some of these symptoms might be attributed to inadvertent subarachnoid or subdural injections of blood. Image-guided EBP with epidurography is believed to be more accurate and likely to have a lower complication rate than blind EBP. In general, fluoroscopically guided spinal injections are more accurate than blind injections, and the use of image guidance is advocated for EBP if feasible. It has been demonstrated in the literature that blind epidural injections are highly inaccurate. Twenty-five percent of non-image-guided, attempted epidural injections were shown to be not epidural in location when checked under fluoroscopy.²¹ A recent large study has demonstrated that fluoroscopically guided epidural steroid injections are highly accurate, and the associated complication rate is very low.²²

Other alternative treatments for CSF hypovolemia include bed rest, intravenous fluid hydration, epidural dextran or saline injection, continuous infusion of dextran through an epidural catheter, and oral or intravenous caffeine infusion. Intravenous caffeine sodium benzoate (500 mg) in 1 liter of fluid over 90 minutes may provide immediate relief, though symptoms may recur. Caffeine may alleviate symptoms via its vasoconstrictive properties or by decreasing cerebral blood flow, increasing cerebral vascular resistance, and increasing CSF production. Other pharmacotherapeutic agents that have been described for treatment of CSF hypoglycemia include steroids and subcutaneous sumitriptan. A bolus of saline or dextran (10–30 mL) may provide a tamponade effect and is an alternative treatment for a septic patient or a Jehovah's Witness. In patients lacking venous access for withdrawal of autologous blood, a fibrin patch might be an alternative. The fibrin patch is described in another section of this chapter.

A prophylactic epidural blood patch has been described in the literature, with some authors advocating its use in some situations. However, the overall literature shows no definite benefit when this procedure is performed on a routine basis in patients undergoing spinal anesthesia or lumbar puncture for other reasons.

When MRI has been performed on patients who have undergone epidural blood patch, the epidural blood has been seen consistently 45 minutes afterward and may be seen up to 18 hours postinjection.²³

Epidural Blood Patch Technique

The technique for the EBP is the same as used for epidural steroid injection except that autologous unclotted blood is injected. The use of fluoroscopy permits the targeting of the site of previous dural puncture or suspected dural leak.

To perform the epidural blood patch, it is probably best to start a heparin lock in the patient first. If the heparin lock cannot be placed, then up to 15 mL of blood should be drawn up from the patient's vein by means of a butterfly needle. A technologist or nurse can then slowly agitate the blood to keep it from clotting until it is needed for the epidural injection. For highest accuracy, the patient is placed prone on an x-ray table and fluoroscopy is used to identify the site of known or suspected dural puncture or tear. A sterile technique is used to place a spinal needle or an epidural needle into the dorsal epidural space. A 22-gauge Whitacre needle or an 18-gauge Tuohy needle, 3.5 in. long, should be sufficient for most patients. Rarely, a 6 in. needle will be needed in a very obese patient. The needle can be placed into the epidural space by using the loss-of-resistance technique or by administering gentle pressure on a syringe filled with contrast medium as the needle is advanced. When contrast is seen in the epidural space, needle advancement is discontinued. Nonionic contrast material should be used to perform epidurography. Between 2 and 3 mL should be sufficient to document accurate needle placement (Figure 17.1). Following needle placement and epidurography, the autologous unclotted blood can be slowly administered through the needle. The duration of the supine position after EBP may affect the efficacy of the patch. Decubitus position for 2 hours was more effective than 30 minutes in one study.24

The volume of blood to be injected for an epidural blood patch is not clearly known. The early literature describes injected volumes of 2 to 3 mL of blood, but it has been subsequently shown that larger volume injections have a higher cure rate. Recent literature describes in-



FIGURE 17.1. Epidurography prior to epidural blood patch: x-ray views of the spine in two patients after the injection of nonionic contrast material into the dorsal lumbar epidural space. The use of fluoroscopy and epidurography enhanced the accuracy of the needle replacement. The blood patch is then performed by injecting 10 mL of autologous blood.

jected volumes of 10 to 15 mL for non-image-guided lumbar EBP. A 20 mL injection has been shown to cover about 7 to 14 spinal segments.²⁵ In the setting of a known dural puncture site, targeted injection with a smaller volume may suffice. As a rule, 10 mL is usually for a symptomatic patient with a history of a documented prior dural puncture with a spinal needle. However, a larger volume probably should be given in the setting of SIH if the site of the dural leak is unknown. In that setting, a large-volume lumbar epidural blood patch with 20 mL of blood and even up to 30 mL is recommended if tolerated by the patient.²⁶ If a thoracic or cervical leak is suspected, the patient's head should be tilted downward for 5 to 10 minutes to allow the blood to move up into the cervical segments. Subsequent EBPs can be administered at thoracic and cervical levels if a lumbar EBP fails in the setting of occult SIH.

Lidocaine inhibits the effect of coagulation and has a fibrinolytic effect.²⁷ Therefore, an effort should be made to limit the amount of lidocaine that enters the epidural space when performing EBP.

Fibrin Glue Patch

Fibrin glue has been used for various surgical procedures including cardiac and abdominal surgery. Fibrin glue augments hemostasis, seals tissues, and may prevent adhesions. The main action of fibrin glue is to enhance wound healing by increasing fibrous mesh, and it is completely bioabsorbable. Animal research suggests that fibrin glue may decrease epidural scar formation. Fibrin glue has been widely used in open neurosurgical procedures and may be effective as an ancillary method in preventing postoperative extradural fluid leakage after dural closures. Percutaneous injection of fibrin glue under CT guidance has been successfully performed in the treatment of dural leaks after spinal surgery^{28,29} or CSF leaks after suboccipital craniectomy or transphenoidal surgery.³⁰

The combination of fibrinogen and thrombin leads to the formation of a fibrin clot. Fibrinogen is present in cryoprecipitate, which is present in fresh frozen plasma or can be harvest from autologous blood. As long as 5 days may be needed to complete the harvesting of cryoprecipitate from autologous blood, although a more rapid technique has been described. At some centers, the technique can be performed in as little as 5 hours.³¹ Commercial fibrin glue has been available in Europe for years; approval for limited applications by the U.S. Food and Drug Administration (FDA) came in 1998. Fibrin glue is FDAapproved for cardiopulmonary bypass surgery, trauma surgery for repair of splenic injuries, and colostomy closure. Tisseel (Baxter) and Hemaseel (Haemacure) are the only FDA-approved fibrin sealants, and neither is specifically approved for application in the neuroaxis. However, the product has been widely used for dural closure during open surgical procedures of the brain, spine, and head and neck³² in the United States and in other countries.

The drawback of using cryoprecipitate is that its fibrinogen concentration may vary. Also, preparation of autologous cryoprecipitate may take several days, particularly when the cryoprecipitate has to be processed at an outside facility such as through the Red Cross. Preparation of autologous cryoprecipitate may cost up to \$400 per unit. Cryoprecipitate from a nonautologous donor is more readily available for immediate use but does not go through a viral inactivitation process as thorough as that of the commercial version. The commercial product includes several manufacturing steps designed to significantly reduce the risk of viral transmission. In addition, all donors for commercial glue are thoroughly prescreened, and donor plasma is held for up to 3 months until retesting rules out the possibility of an interval seroconversion. The manufacturing process used for the commercial products is more rigorous than that used at most blood bank facilities in preparation of nonautologous cryoprecipitate. The disadvantage of the commercial product is the higher cost if a large amount of fibrin glue is needed.

Both blood-banked cryoprecipitate and the commercial fibrin glue have been administered percutaneously for treatment of postoperative dural tears and for treatment of PDPS and SIH. Fibrin glue has been reported in a single case report to be successful in treating SIH that was unresponsive to two epidural blood patches.³³ Fibrin glue patch is a reasonable alternative for patients who cannot have an epidural blood patch. The fibrin patch may be used in patients with CSF hypovolemia who have concurrent HIV infection, leukemia, severe anemia, or lack of venous access. A fibrin glue patch can also be considered in patients who have persistent CSF hypovolemia symptoms despite epidural blood patch, and there is no risk of injecting blood into the sub-arachnoid space. Fibrin glue is probably a better treatment for postsurgical dural tears than EBP.

Transient fever and headache after fibrin patch were described in one patient and may be indicative of aseptic meningitis.^{28,29} The fibrin patch is a potential medium for infection, but addition of antibiotics to the glue may inhibit clot formation or decrease tensile strength. Allergic reaction to bovine thrombin or bovine aprotinin is possible. The patient should be informed that he or she will be receiving a blood product. Some hospitals may have a separate consent form for patients who are about to receive blood products. There is a rare potential risk of viral transmission, although this has not been reported in connection with fibrin glue patches.

Prophylactic fibrin glue injection for prevention of CSF leak has been studied in an animal and an in vitro model, but there are no published human studies.

Fibrin Patch Technique

A CT-guided fibrin patch may be successful in treating postlaminectomy headache secondary to dural tear (Figure 17.2). MRI may be helpful to help identify and characterize the site of the tear and the extent of pseudomeningocele formation (Figure 17.3). CT guidance can then be used to drain the pseudomeningocele and patch the tear at the same time, thereby saving the patient from a major repeat surgery. Most spine surgeons dread such a complication and are grateful for this service. The fibrin patch can also be administered under fluoroscopic guidance by means of the same technique described for EBP.

If frozen cryoprecipitate is to be used, the blood bank will need 30 minutes' notice to allow time for thawing. Once thawed, the cryoprecipitate must be used within 4 hours. Thrombin comes in a powder form. Twenty thousand (20,000) units of thrombin is reconstituted in 10 mL of 10% calcium chloride solution and 0.5 mL of nonionic contrast. The thrombin solution and cryoprecipitate are drawn up into separate 3 mL Luer syringes. Equal volumes of thrombin and fibrinogen are then injected simultaneously by means of a three-way stopcock, through an 18-gauge spinal needle placed at the site of the suspected



FIGURE 17.2. CT-guided fibrin patch for treatment of postoperative CSF leak. Axial image after percutaneous aspiration of the pseudomeningocele through an 18-gauge needle and application of fibrin glue patch through the same needle. Contrast material is added to the fibrin glue to enhance visualization. This patient had complete relief of symptoms within 24 hours.

tear. The mixture forms a fibrin glue patch almost instantaneously. The glue is gelatin-like and rubbery in appearance. Administered volumes of 4 to 18 mL have been described.^{28,29} Postoperative CT, overnight bed rest, and intravenous hydration are then prescribed. Steroids may be helpful in temporarily alleviating CSF hypovolemia symptoms.

The commercial fibrin glue is usually stocked in hospital operating rooms, not in the hospital pharmacy. Tisseel and Hemaseel are actually the same product but packaged under the two different names by different distributors. The commercial glue is available in vials of 2 or 5 mL, both of which reconstitute to make a slightly larger volume. The commercial glue comes as a kit comprising sealer protein concentrate (the main component is pooled human cryoprecipitate), fibrinolysis inhibitor (bovine aprotinin) solution, thrombin (human), calcium chloride solution, and a double-barreled syringe with a common plunger. This plunger ensures that equal volumes of the two main components (fibrinogen and thrombin) are drawn up separately but can be fed through a common needle for administration. Once the kit has been opened, the product must be used within 4 hours following reconstitution. The



FIGURE 17.3. Sagittal MRI T2-weighted fat-suppressed sequence. By demonstrating the site of laminectomy and pseudomeningocele, MRI may be helpful in characterizing a postoperative CSF leak prior to intervention.

sealant is reported to reach about 70% tensile strength in about 10 minutes and its ultimate strength about 2 hours after administration.

Conclusion

Both epidural blood patch and fibrin glue patch injections may be useful in the treatment of CSF leaks. The fibrin glue patch has a more rapid and greater adhesive effect than the autologous blood patch. It is also readily available and may be useful when injection of autologous blood is contraindicated. However, autologous blood is inexpensive and raises no risk of allergic reaction or viral infection hazard from a donor. The epidural blood patch has been well documented to be effective in patients with PDPS and SIH. The fibrin patch has been demonstrated to be particularly effective in the event of postsurgical dural tears and may obviate the need for a second surgery in a patient with a postoperative dural leak. The fibrin patch may also be effective in symptomatic patients who are unrelieved by EBP.

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18

Balloon Kyphoplasty

John M. Mathis, Wayne J. Olan, and Stephen M. Belkoff

Pain relief after percutaneous vertebroplasty (PV) has been reported by 70 to 90% of patients with vertebral compression fractures (VCFs),^{1–4} but the deformity of the vertebral body or the subsequent kyphosis (usually related to multiple compressions) has not been addressed (for a more exhaustive treatment of vertebroplasty see Chapter 14).⁵ Biomechanically, kyphosis shifts the patient's center of gravity forward, rendering the patient off-balance and at increased risk for a fall. This change in a patient's center of gravity also creates additional stress on the vertebrae, increasing the risk of fracture.⁶ The kyphosis caused by VCFs in the lumbar or thoracic region decreases vital capacity in the lungs, which in turn accentuates restrictive lung disease.⁷ Leech et al.⁸ reported a 9% average decrease in forced vital capacity per osteoporotic compression fracture in the thoracic region. In addition, these fractures can lead to gastrointestinal difficulties. Increasing kyphosis may cause the ribs to increase pressure on the abdomen, creating a sensation of bloating that may lead to early satiety, decreased appetite, and malnutrition.⁹ There is a significant decrease in the life expectancy of patients with VCFs. In a retrospective study, Cooper et al.¹⁰ found that the 5-year survival rate for patients with VCFs was lower than that for patients with hip fractures. A prospective study by Kado et al.¹¹ showed that patients with VCFs had a 23% higher mortality than agematched controls. The increased mortality was thought to result from pulmonary causes, including pneumonia and chronic obstructive pulmonary disease.

Kyphoplasty (KP) was developed in an attempt to reduce the deformity of the vertebral body (Figure 18.1A) and subsequent kyphosis while providing pain relief similar to that of PV. Kyphoplasty consists of inserting a balloonlike device (referred to as a bone tamp) percutaneously into a compressed vertebral body, inflating the device, and attempting to elevate the endplates and restore vertebral body height (Figure 18.1B). In theory, this procedure would be expected to improve vital lung capacity and gastrointestinal function by reducing the kyphosis associated with VCFs.¹²



FIGURE 18.1. (A) Osteoporotic compression fracture (T12) showing anterior and superior vertebral collapse (arrows) of about 50%. (B) Cadaver specimen with inflated kyphoplasty balloon (arrows).

Patient Selection

The selection criteria for balloon kyphoplasty are similar but not equivalent to those for PV (see Chapter 14). As with PV, the patient selection process includes obtaining a detailed history and physical examination. The patient's symptoms need to be linked to the VCF. Evaluation of the patient's films [radiographs, computed tomography (CT), magnetic resonance imaging (MRI), and bone scans] should correlate symptoms with the fracture location and image characteristics.

Balloon kyphoplasty has been used to treat osteoporotic VCFs. It may also be used in patients with vertebral body involvement from neoplastic disease such as plasmocytoma or multiple myeloma. The likelihood of restoring vertebral body height depends largely on the density of the bone and the acuity of the fracture. Fractures treated within 1 to 3 weeks of the event are much less likely to have experienced substantial healing and provide the best opportunity for height restoration.

The exclusion criteria for balloon kyphoplasty are also very similar to those used for PV and include (1) VCFs that are not painful or that

are not the primary source of pain, (2) the presence of osteomyelitis or systemic infection, (3) retropulsed bone fragments, or (4) an epidural extension of tumor. The latter two factors must be considered because balloon inflation for the KP procedure could force material into the spinal canal, causing cord compression.

There are also relative contraindications to KP. First, there must be sufficient residual height for the instruments used with kyphoplasty to be inserted into the compressed vertebral body. Thus, although PV may be performed in a severely compressed vertebral body, KP of the same vertebral body may not be technically feasible (Figure 18.2). Second, small pedicles may also be a limiting technical factor because the instruments used for KP are somewhat larger than those for PV. When the pedicles appear to be too small to accommodate the KP instruments, a parapedicular approach can be utilized. Kyphoplasty can be performed safely from L5 to T7 in most patients.¹³

Technique

The KP technique is an extension of PV and could alternatively be termed "balloon-assisted vertebroplasty."

The patient is positioned on the fluoroscopic operating table in a prone position. It is important to avoid an antecubital intravenous line. High-resolution C-arm or biplane fluoroscopy is essential when one is performing KP or PV. The patient is positioned so that the spine is located at the isocenter of the C-arm. The fracture is then identified fluoroscopically. The approach is usually bilateral transpedicular; however, a single posterolateral approach can be used for the large lower lumbar vertebrae (almost always at L5; less commonly at L2 through L4). An extrapedicular approach must be used when the pedicles are too small to accommodate the kyphoplasty instruments (usually in the mid- or upper thoracic regions).

Localization of the pedicles is performed in a manner similar to that used for PV. A posterior approach with slight ipsilateral obliquity of 10 to 25° is preferred. The medial wall of the pedicle must be well visualized.

After sterile preparation and draping of the patients, and after the fluoroscopy equipment has also been covered in sterile fashion, local anesthetic is injected into the patient's skin, subcutaneous tissue, and periosteum of the bone. Typically a 25-gauge needle is used, but a longer spinal needle can be used to reach the periosteum. Most patients require only local anesthesia and conscious sedation. As in PV, the key to local anesthesia is extension of the anesthetic to the periosteum of the pedicle. Patients who cannot lie in a prone position may be candidates for general anesthesia. Prophylactic intravenous antibiotics, typically 1 g of cefazolin, are administered.

The kyphoplasty procedure requires an 11- or 13-gauge (4–6-in.) bone entry needle, a scalpel, a kyphoplasty kit, inflatable balloon tamps, sterile barium sulfate or other opacifier, and bone cement (Figure 18.3). The procedure begins by directing the entry needle into the



FIGURE 18.2. Sagittal MRI image showing an extreme compression (arrow). There is no room left in this vertebra to insert the balloon for KP.



FIGURE 18.3. Some of the materials needed for the kyphoplasty procedure. The inflator and bone cement are not shown (for inflator, see Figure 18.8).

bone under fluoroscopic guidance. For a transpedicular approach, the needle is directed through the pedicle to the posterior aspect of the vertebral body (Figure 18.4). For very small pedicles, an extrapedicular approach can be used. The needle targets a starting point just superior and lateral to the pedicle (Figure 18.5A, B). If a single posterolateral approach is chosen, the trajectory can be established along a posterolateral path similar to that used for discography. This approach is appropriate for the larger lumbar vertebrae, especially L5. One must be cautious to avoid injuring the exiting nerve roots, and the beginning point must not be so far lateral that puncture of the bowel or kidney results. With the posterolateral approach, the drill should cross the midline of the vertebra on anteroposterior and lateral views. Oblique views should also be used to confirm proper positioning. The advantage of the single posterolateral approach is the time saved by placing one balloon instead of two; the disadvantage is a reduction of the working surface area of the inflatable balloon tamp.

After needle insertions, the trocar is removed. A Kirschner wire (K-wire) is then directed through the cannula and into the bone. The needle cannula is removed, leaving the K-wire in place. A blunt dissector is then fitted over the K-wire and, under fluoroscopic guidance,



FIGURE 18.4. (A) Slight oblique radiograph (from anteroposterior direction) shows the bone introduction needle (white arrow) penetrating the pedicle (small arrows). (B) Lateral image showing the cannula and K-wire tip just at the pedicle–posterior vertebral body junction.

FIGURE 18.5. (A) Axial drawing demonstrating the trajectory of the needle for a parapedicular approach. The needle follows the junction of the rib and transverse process of the vertebra and enters the vertebral body along the lateral margin of the pedicle. (B) Lateral view of the parapedicular approach. Note the needle has a downward angle that allows one to go over the transverse process on the way to the lateral pedicle margin.



into the bone to be situated at the level of the K-wire. In a transpedicular approach, the K-wires and blunt dissector are directed to the posterior third of the vertebral body. One should manipulate the K-wire with the same caution that one would use for a guide wire in the vascular system. The operating physician should always have control of the proximal end of the K-wire because the sharp tip could easily penetrate soft bone and breach the anterior vertebral cortex.

A skin incision is then made to accommodate the working cannula, which is advanced through the soft tissues over the blunt dissector and through the pedicle to rest along the posterior aspect of the vertebral body. A plastic handle can be placed on the hub of the cannula to advance it manually into the vertebral body, or a mallet can be used to tap the plastic handle, driving the cannula into the vertebral body. If there is considerable resistance to placing the working cannula, the cannula's handle can be rotated in an alternating clockwise, counterclockwise (screwing) motion to help breach the cortex and facilitate advancement. If using the mallet, one must be careful to direct the blows onto the handle; inadvertently striking the K-wire or blunt dissector might drive the object deeper into the vertebra.

Next, the K-wire and blunt dissector are removed, leaving the working cannula in place. A 3 mm drill is advanced through the cannula, and multiplanar fluoroscopy is used to recheck the orientation of the working cannula. Then the drill is directed ideally along a slightly posterolateral to anteromedial trajectory into the vertebra until the tip of the drill is 3 to 4 mm posterior to the anterior margin of the vertebral body, or at least within the anterior third of the vertebral body (Figure 18.6). If the fracture involves the superior aspect of the vertebral body, the drill must be directed somewhat inferiorly to the midline of the vertebral body. If the fracture is along the inferior aspect of the vertebra. Extreme caution should be used to avoid breaching the anterior cortex of the vertebral body with the drill. For bilateral transpedicular or extrapedicular approaches, the sequence of events is repeated on the contralateral side.

The inflatable balloon tamp is available in different sizes. Each balloon has markers to delineate its distal and proximal extents (Figure 18.7). These markers are also radiopaque and easily visualized under fluoroscopy. The bone tamps are then prepared for inflation. Air is purged from the balloons, and the reservoir of an angioplasty injection



FIGURE 18.6. The bone drill (arrow) in the vertebral body (introduced through the bone cannula).

FIGURE 18.7. Lateral radiograph, with black markers pointing to the distal and proximal markers of the balloon (bone tamp).



device (incorporating a pressure monitor) is filled with 10 mL of diluted iodine contrast material (Figure 18.8). If the patient has an allergy to iodine, gadolinium can be substituted. The drill is then removed. (If there is a question of underlying malignancy, a biopsy can be performed by pushing the drill bit back and forth in the cavity to collect bone fragments before the drill is removed from the working cannula.)

The uninflated balloon tamps are inserted through the working cannulas under fluoroscopy and directed to the most anterior extent of the vertebral body. If the clinician feels resistance in the passageway of the drilled hole, perhaps secondary to small shards of bone, the drill or bone filler device can be inserted and withdrawn once or twice along the path to clear it of debris, whereupon the balloon tamp can be inserted without difficulty.

Balloon inflation should be performed slowly. Inflation via the injection device is begun under continuous fluoroscopy, increasing balloon pressure to approximately 50 psi to secure the balloon in position. The stiffening wire is withdrawn from the shaft of the bone tamps, and the volume of contrast media in the reservoir is recorded. The balloons



FIGURE 18.8. The inflator, which is connected to the bone tamp by high-pressure tubing.

are progressively inflated by half-milliliter increments (Figure 18.9), with frequent pauses to check for pressure decay, which occurs as the adjacent cancellous bone yields and compacts. If the bone is osteoporotic, pressure decay may be immediate. If the bone is quite dense, there may be little or no pressure decay, even at pressures up to 180 psi. The balloon system is rated to 180 psi, with a practical maximum of 220 psi. Even with slow inflation, pressures higher than 220 psi have been achieved in dense bone.¹⁴ If a balloon ruptures, it is simply withdrawn through the working cannula and replaced.

The possible end points of inflation are (1) restoration of the vertebral body height to normal, (2) flattening of the balloon against an endplate without accompanying height restoration, (3) contact with a lateral cortical margin, (4) inflation without further pressure decay, and (5) reaching the maximum volume of the balloon or maximum pressure. The operating physician must maintain both visual and manual control throughout the entire inflation process and should record the amount of fluid used to inflate the balloon when the end point has been achieved. This volume indicates the size of the cavity that has been created, and it will serve as an estimate of the amount of cement to be delivered. If substantial height restoration has not been achieved, careful repositioning of the bone tamps and reinflation may be helpful.

Once adequate inflation has been achieved, the cement is mixed in a manner similar to that for PV. The cement mixture is transferred to a 10 mL syringe that is used to fill a series of 1.5 mL bone filler devices. The volume of cement for injection is approximately 1 mL more than the volume of the cavity created by each inflatable balloon tamp.¹⁵ If a quantity of cement is equal to or less than the volume of the cavity, the vertebra will not be reinforced and will recollapse quickly.

Once the bone cement has undergone transition from a liquid to a cohesive, doughy consistency (about 3–4 minutes after mixing), the





В

FIGURE 18.9. (A) Anteroposterior image reveals two inflated balloons (arrows) during kyphoplasty. (B) Lateral image shows the two inflated balloons (arrows).

bone filler devices are passed through the working cannula and into the anterior aspect of the vertebral cavities. The cavity is then filled with cement, proceeding from the anterior to the posterior aspect of the vertebra. Continuous fluoroscopic monitoring is maintained to identify leakage of cement into the spinal canal, paraspinous veins, inferior vena cava, or disc space. One hypothetical advantage of KP over PV is that the former affords a low-pressure cement delivery into the cavity created by the inflatable balloon tamp. However, there are no reports of measurements of intravertebral pressure during cement injection. Recent pressure measurements taken in our laboratory during cement injection in ex vivo vertebral bodies suggest that the pressure increase is minimal and not likely to be of clinical consequence (unpublished data). Some operating physicians prefer to fill one cavity first, leaving the contralateral balloon inflated as a supporting strut. This maneuver may be effective at maintaining any height elevation that has been achieved.

When cement filling of the cavity has been confirmed fluoroscopically from both lateral (Figure 18.10A) and anteroposterior views, the bone filler devices are withdrawn partially to allow complete filling of the cavity; then they are used to tamp the bone cement in place before being withdrawn completely. The cannulas are then rotated (so they are not cemented in the bone) and removed, and hemostasis is obtained at the incision site by using manual pressure. Steri-Strips are usually sufficient for wound closure. The patient remains prone on the table and is not moved until the remaining cement in the mixing bowl has hardened completely. The usual time frame for KP is 35 to 45 minutes, which compares favorably with the 20 to 25 minutes per level required



FIGURE 18.10. (A) Lateral radiograph shows the pretreatment appearance of the compression fracture. (B) Postkyphoplasty image. A small cement leak occurred anteriorly but was asymptomic. There is mild height restoration of between 3 and 4 mm.

for PV. In denser bone, the balloons may take longer to respond to small incremental increases in pressure.

The follow-up and postoperative procedures for KP are identical to those for PV. At some institutions, KP and PV are performed on an outpatient basis unless the patient is extremely frail, or unless the procedure is performed at the end of the day and staffing issues make it easier to keep the patient overnight for discharge the next morning. Outpatients are observed for 3 to 4 hours after the procedure.

Kyphoplasty is a technically demanding procedure. Safe performance requires a high level of skill and high-quality imaging equipment. One should not perform this procedure without being an expert in clinical and radiographic spinal anatomy, without having completed a kyphoplasty course with expert instructors, and without imaging equipment that is capable of clearly delineating key bony landmarks, particularly the pedicles, the cortices, and the spinous processes.

Results

The case demonstrated in Figure 18.10 is an average result. The patient had good pain relief (similar to PV) and a modest amount of height was restored (approximately 3–4 mm; Figure 18.10B). The clinical significance of this amount of height restoration still needs review. PV may also be associated with mild height restoration and is excellent at relieving pain. With pain relief following both PV and KP, patients get reduction in kyphosis and are able to support their body weight without pain (allowing them to stand straighter). Reproducible outcome analysis is needed to understand the significance (or lack thereof) of the differences between PV and KP.

Kyphoplasty is a relatively new procedure and, as such, peerreviewed reports of clinical results are few. One early outcome study of 70 vertebral bodies treated in 30 patients reported average restoration of 2.9 mm of height.¹³ When the treated vertebrae were separated into two groups, 70% gained an average of 4.1 mm (46.8% height restoration), whereas 30% regained no height. Asymptomatic cement extravasations occurred in 8.6% of the levels treated, a rate similar to that reported for PV used for osteoporotic VCFs. Perioperative complications for KP include one myocardial infarction (3.3%) and two patients who sustained rib fracture during positioning (6.7%).

In another small report, the average vertebral body height restoration obtained in 24 procedures was as follows: anterior, 3.7 mm; middle, 4.7 mm; and posterior, 1.5 mm.¹⁶ The findings were similar to the amount of height restoration in the clinical series reported by Lieberman et al.¹³

Reporting on preliminary results from 340 patients from a multicenter registry, Garfin et al.¹⁷ indicated a height restoration similar to that reported earlier.¹³ There was a serious complication rate of 1.2% that included permanent cord damage associated with cement leakage.¹⁷ It should be noted, however, that these results were anecdotally reported in a literature review regarding KP and PV.
These early clinical reports do not offer substantial data for complete evaluation of the procedure's efficacy. Although KP appears to be able to restore height in some cases (Figure 18.10), it is unknown whether the typically 3 to 4 m of height restoration results in clinically significant benefit. Furthermore, it is unknown whether height restoration results in kyphosis reduction and subsequently in increased lung capacity. A long-term follow-up study determining the benefits of KP versus PV is needed but in reality will be a difficult task. Both procedures provide similar pain relief and, in experienced hands, similar risk. In the presence of pain relief, the benefits of height restoration will most likely remain empirical. Although the exact mechanism of pain relief is unknown, it is believed that both procedures provide pain relief secondary to fracture stabilization via cement injection.

Biomechanical Investigations

Reports indicate that height restoration has the potential benefit of reducing postfracture kyphosis and its associated sequelae.^{7–9,18,19} The magnitude of height restoration mentioned in the preliminary clinical reports discussed earlier is similar to that measured ex vivo.¹⁴ In the ex vivo study by Belkoff et al.,¹⁴ average actual height restoration (average of six height measurements made circumferentially about the vertebral body) was 2.5 ± 0.7 mm.^{7–9,18} It is important to note that this ex-vivo study of osteoporotic vertebral bodies that were compressed to create simulated fractures and repaired with PV suggested that half of the compressed height recovers elastically,¹⁴ a phenomenon similar to that reported in vivo.²⁰ In addition, PV restored 30% of the height that was not elastically recovered in ex vivo specimens, whereas kyphoplasty restored 97%.¹⁴ The actual height restoration seems to range from 2.5 to 3.5 mm, values similar to those reported clinically.¹³

One of the theoretical advantages of kyphoplasty over standard PV is that the former may permit the injection of cement under lower pressures, a factor that could be important for the use of calcium phosphate and hydroxyapatite cements, which are bioresorbable but difficult to inject.^{21–25} A recent ex vivo study comparing a hydroxyapatite-forming cement and a poly(methyl methacrylate) cement found that height restorations were similar and that they were qualitatively as easy to inject, but the former produced a weaker and less stiff repair.¹⁵ It was found that osteoporotic vertebral bodies are similarly easy to inject when the same hydroxyapatite cement is directly injected into them.¹⁵ Thus, it appears that the ease of injection of the hydroxyapatite cement may have more to do with its composition than with the environment into which it is injected. Injection pressure was not measured in either study, but it seemed to be similarly low in both situations.

Conclusion

Both PV and KP seem to provide the same pain relief from vertebral compression fractures and, in experienced hands, approximately the

same risk. However, kyphoplasty may provide an opportunity for restoring vertebral body height before stabilization and reduction of a fracture in the clinical setting. Because the pain relief from both procedures appears to be similar and because variables such as pulmonary function, gastrointestinal issues, and even kyphosis change in the presence of pain relief, it will be difficult to compare or distinguish the two procedures based on clinical outcomes. Any benefits of KP over PV remain to be proven, but the prospect of height restoration is compelling. A trial with patients randomly assigned to KP and PV treatment groups is needed. Separate randomized clinical trials are being considered to compare KP and PV with the conventional medical management of vertebral compression fractures.

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19

Intradiscal Oxygen–Ozone in the Treatment of Herniated Lumbar Disc

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Low back pain and nerve root pain are among the most common conditions affecting the lumbar spine. Approximately 80% of the population in western countries will experience one or more episodes of low back pain in their lifetime, and 55% will suffer from low back pain associated with a radicular component.¹

Back pain is commonly caused by disc disease; however, other factors may be responsible for nerve root syndromes, and these should be considered when clinical symptoms fail to match computed tomography (CT) findings.²

We know from the natural history of a herniated disc that clinical symptoms tend to resolve in up to 50% of patients and the disc herniation can shrink on follow-up CT or magnetic resonance (MR) scans within 8 or 9 months of the start of back pain.^{1–3}

The short-term success rate after surgery for lumbosacral disc herniation is estimated at 95%, with a 2 to 6% incidence of true recurrence of herniation. The success rate drops to 80% over time owing to the onset of symptoms linked to failed back surgery syndrome (FBSS), a condition characterized by recurrence of disc herniation and/or hypertrophic scarring with severe symptoms in 20% of patients.^{4–5}

The failures after back surgery have stimulated research into new techniques to improve patient outcome. At the same time, advances in percutaneous techniques by interventional procedures [chemodiscolysis with chymopapain, aspiration of the nucleus according to Onik (see Chapter 8), intradiscal electrothermal annuloplasty (IDET), discectomy laser, nucleoplasty, etc.) have minimized the invasive nature of surgery and have avoided complications such as scarring and infection associated with open surgery.

Reducing intervertebral disc size by mechanical aspiration of disc fragments, by chemical dissolution, or by drying can reduce the conic pressure on the torn annulus and create the space necessary for disc retraction.

All percutaneous procedures are mildly invasive, requiring only a short hospital stay. By avoiding the spinal canal, these techniques also eliminate the risk of postoperative scarring that has been associated with surgery. Scarring is often responsible for recurrence of pain. Percutaneous techniques can also be repeated in the same patient without eliminating the option of traditional surgery. The success rates reported with chemonucleolysis and aspiration vary from 65 to 80% with excellent or good results.⁴

Epidural steroid injections under CT or fluoroscopic guidance may also be used to minimize radicular pain.^{6–11}

Oxygen–Ozone Therapy

Chemodiscolysis with "nucleoptesis" produces drying of the nucleus by an oxygen–ozone (O_2 – O_3) mixture. The unstable, colorless irritant gas has a pungent odor and has strong oxidizing power as well as good antiseptic, disinfectant, and antiviral properties. Ozone is prepared and administered by using a special generator to transform a small percentage of oxygen into the heavier gas. The O_2 – O_3 gas mixture produced can be injected into either the intervertebral disc or a root foramen: 3 to 4 mL into the disc and 15 to 20 mL into the neural foramen and root canal. The concentration of the mixture is adjusted by the equipment.

The dose administered to treat disc disease is 30 to 40 μ /mL, a concentration arrived at from experimental studies resulting in the concentration best suited to dry out the nucleus and minimize inflammation.

A number of studies have been reported in the literature on the O_2 - O_3 treatment of disc herniation with satisfactory results in appropriately selected cases.^{12–18}

The etiology of back pain has been the topic of many scientific investigations. Such pain has been attributed to mechanical and/or inflammatory irritation of the nerve endings.^{19–23}

How the O₂–O₃ Mixture Works

The nucleus pulposus can set off an immune-mediated inflammatory process. The proteoglycan component of the nucleus is largely isolated from the immune system after birth. Herniation of a fragment of the nucleus pulposus may trigger an autoimmune reaction and generate an inflammatory process whose cellular component is mainly supported by macrophages. A non-immune-mediated mechanism of inflammation may be created by the nucleus, which reacts with surrounding histiocytes, fibroblasts, and chondrocytes to produce cytokines (interleukin 1 α , interleukin-6, and tumor necrosis factor α) with an increase in phospholipase A₂ leading to the release of prostaglandin E₂, leukotrienes, and thromboxanes. In small amounts, prostaglandins enhance sensitivity of the nerve roots and other painproducing substances like bradykinin. Experimental studies have shown that an oxygen–ozone gas mixture at the concentrations used for intradiscal treatment has the same effect as steroids on inhibiting cytokine production and hence the pain induced by the same.²⁴

The oxygen–ozone mechanisms of action are currently being investigated and include the following²⁵:

- 1. Enhanced oxygenation and reduced inflammation in the disease site due to the oxidizing effect on pain-producing chemical mediators
- 2. Direct effect of ozone on the mucopolysaccharides making up the nucleus pulposus with shrinkage of the disc herniation
- 3. Improved microcirculation and resolution of venous stasis, which results in better supply of oxygenated blood in the area of the compression

Technical Aspects

The technical approach to the disc is the same as that used for discography and for other percutaneous intervertebral disc procedures. We use an 18- to 20-gauge Chiba needle inserted with a posterior paravertebral oblique approach under CT or fluoroscopic guidance (Figures 19.1 and 19.2). The L5-S1 disc space is not always an easy target and may require a further 30° craniocaudal inclination of the needle. Once the needle has been positioned in the center of the disc, the gas mixture is injected into the disc and into the epidural and intraforaminal spaces at the concentrations and amounts described earlier (Figure 19.3). We no longer perform discography before percutaneous treatment. A CT scan is obtained before therapy to rule out the presence of a heterotopic loop of bowel that might be injured or contribute to disc infection.

Clinical Experience

Between 1997 and 2002, 1800 patients between the ages of 18 and 89 underwent percutaneous chemodiscolysis with periradicular and pariganglionic injection of the oxygen–ozone mixture. The following selection criteria were adopted:

- 1. *Clinical:* low back and/or nerve root pain that is resistant to medical treatment, physiotherapy, and homeopathic therapies (manipulation, acupuncture, etc.) for a period of not less than 2 months
- 2. *Psychological:* a firm resolve on the part of the patient to recover, with a commitment to cooperate and undergo subsequent physiotherapy with postural and motor rehabilitation
- 3. *Neurological:* paresthesia or hypoesthesia over the dermatome involved, mild muscle weakness, and signs of root–ganglion irritation
- 4. *Neuroradiological* (CT and/or MR):
 - a. Evidence of small or medium-sized herniated discs correlating with the patient's symptoms, with or without degenerative disc disease complicated by intervertebral disc changes (protrusion, herniation)
 - b. Residue of surgical (micro) discectomy with herniation recurrence and/or hypertrophic fibrous scarring



FIGURE 19.1. (A) Intradiscal positioning of the 20-gauge Chiba needle under CT guidance in a patient with median and left paramedian herniated nucleus pulposus. (B) CT axial image after intradiscal injection of 4 mL of oxygen–ozone mixture.



There were two exclusion criteria:

- 1. CT/MR evidence of a herniated disc fragment with symptoms of motor and/or sphincter disturbance
- 2. CT/MR evidence of disc herniation corresponding to clinically severe motor deficit and/or sphincter disturbance



FIGURE 19.1. *Continued*. (C) Multiplanar reconstruction with evidence of gas inside the disc.

The indications for O_2 – O_3 treatment were extended to FBSS patients when it was understood that the ozone mechanisms of action could be exploited to treat the chronic inflammation and venous stasis present in FBSS.

Because of the need for meticulous positioning of the needle within the nucleus pulposus, CT guidance was adopted instead of the welltested radiological monitoring by isocentric fluoroscopy. In addition, CT avoids the administration of intradiscal contrast material, which even in low doses reduces the discal absorption of ozone and the available space. It may also hinder visualization during the intraforaminal injection of the O_2 – O_3 mixture.

Results

There are numerous protocols to objectively analyze the clinical results in patients with low back pain and herniated nucleus pulposus (HNP).^{2–26} We evaluated our results with a modified MacNab method (Table 19.1).

In patients with degenerative disease complicated by herniation, results were:

Excellent in 40% Good or fair in 40% Mediocre or bad in 20%

In patients with L4-L5 or L5-S1 herniated discs results were:

Excellent in 64% Good or fair in 13% Mediocre or bad in 23%

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А



В

FIGURE 19.2. This patient with median herniated nucleus pulposus received (A) 4 mL of intradiscal O_2 - O_3 (CT axial scan) and (B) 15 mL of epidural O_2 - O_3 (sagittal multiplanar reconstruction).

In patients with multiple disc herniations results were:

Excellent in 58% Good or fair in 11% Mediocre or bad in 31%

In FBSS patients results were:

Excellent in 50% Good or fair in 25% Mediocre or bad in 25%



А



В

FIGURE 19.3. (A) Intradiscal positioning and (B) intradiscal and epidural oxygen–ozone diffusion in a patient with a right paramedian HNP.

In patients with calcified disc herniations results were:

Excellent in 35% Good or fair in 20% Mediocre or bad in 45%

In patients with herniated disc associated with stenosis results were:

Excellent in 25% Good or fair in 25% Mediocre or bad in 50%

Success	Failure
Excellent	Mediocre
Disappearance of symptoms	Insufficient improvement of symptoms
Complete recovery in working and	Periodic administration of drug
Sport activities	Limitations of physical activity
Good	No results
Occasional episodes of low back pain or sciatica	No improvement
	Surgery required
Fair	Bad
Improvement of symptoms	Worsening of clinical situation
Limitation of heavy physical	Surgery required

TABLE 19.1. Results as measured by a modified MacNab Method

We analyzed the failures reported herein, focusing on possible technical errors to establish whether indications for treatment had been too broad or whether correlations exist between certain types of herniated disc, site of herniation, type of intervention, and treatment failure.

Clinical follow-up for up to 18 months in 835 patients confirmed persistently good outcome in 72% of the cases. CT or MR follow-up was done in 382 patients, documenting a reduction in herniated disc size only in 67% of cases.

Retrospective analysis of our failures disclosed that an unsuccessful outcome was much more unlikely in the presence of calcified herniated discs, herniations associated with stenosis of the spinal canal, and large extruded herniations.



FIGURE 19.4. Pathological analysis of tissue of surgically herniated disk removed after unsuccessful treatment with oxygen–ozone shows dehydration of the fibrillary matrix without evidence of the chondroid metaplasia.

Tissue Structure Alterations

In vivo experimental studies on swine intervertebral discs and in vitro tests on human discs with intradiscal administration of an O_2 – O_3 mixture (at a concentration of 27 μ g/mL) demonstrated dehydration of the fibrillary matrix of the nucleus pulposus that disclosed the collagen mesh/ network and regressive events of fragmentation and vacuole formation. Neuroangiogenesis was sometimes present, with mild hyperplasia of the chondrocytes in the matrix periphery. Such changes are thought to be due to the decomposition of ozone accompanied by the release of free radicals that act directly on the disc matrix or indirectly via proteolytic enzymes (Figure 19.4).

Complications and Risks

No early or late neurological or infectious complications have been reported following O_2 – O_3 injection. The results are virtually the same as those of other percutaneous techniques (75–80% success rate). Injections can be repeated if necessary. The similar success rate and the low costs of the O_2 – O_3 therapy make it our method of choice in the percutaneous treatment of small herniated lumbar disc.

Conclusion

In our experience, intradiscal O_2 – O_3 treatment of selected herniated lumbar disc has revolutionized the percutaneous approach to nerve root disease by making it safer, cheaper, and easier than treatments currently in use. In addition, O_2 – O_3 therapy does not exclude subsequent surgery, should patients fail to respond.

Oxygen–ozone treatment has the advantage of being feasible in virtually all patients with root syndromes. The contraindications of chemonucleolysis or nucleoaspiration, which are determined by discography, are a less critical issue with ozone.

On the basis of our results and the assessment of our failures, we recommend careful selection of patients. We avoid broad indications for treatment, thereby ensuring a high success rate.

Accurate diagnosis of the lesion and the spinal level to be treated, along with accurate technical execution under CT, are key factors in ensuring the successful outcome of percutaneous treatment for this common condition.

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