

Lumbar decompression

Anatomy & Pathophysiology

BONY AND LIGAMENTOUS ANATOMY

- Lumbar vertebral bodies are large, with a transverse diameter greater than the anterior-posterior diameter [27].
- Lumbar pedicles arise from the superior aspect of the vertebral bodies and project more horizontally than thoracic pedicles [27].
- L1 pedicles are minimally medially angled, while the orientation becomes more medial as one progresses down the lumbar spine, particularly at L5 [27].
- Lumbar transverse processes project more perpendicular relative to the vertebral body and are large and flat in the upper lumbar spine [27].
- L4 and L5 transverse processes are often smaller than those in the upper lumbar spine [27].
- Lumbar spinous processes are thick and project straight dorsally [27].
- The superior articular facet arises at the junction of the pedicle and lamina and is oriented such that the articular surface faces dorsomedially [27].
- The inferior facet extends down from the lamina and nestles snugly on the medial side of the superior facet [27].
- The sagittal orientation of lumbar facet joints allows flexion and extension while providing resistance to axial rotation and translation [27].
- Each spinal segment consists of three joints: the intervertebral disk and two facet joints [12].
- The central spinal canal is defined as the space posterior to the posterior longitudinal ligament, anterior to the ligamentum flavum and laminae, and bordered laterally by the medial border of the superior articular process [12].
- The lateral recess is defined by the superior articular facet posteriorly, the thecal sac medially, the pedicle laterally, and the posterolateral vertebral body anteriorly [12].
- The intervertebral foramen is bordered superiorly and inferiorly by the adjacent level pedicles, posteriorly by the facet joint and lateral extensions of the ligamentum flavum, and anteriorly by the adjacent vertebral bodies and disk [12].

- Normal foraminal height is 20 to 30 mm [12].
- Normal superior foraminal width is 8 to 10 mm [12].
- The lateral recess, also known as “Lee’s entrance zone,” begins at the medial border of the superior articular process and extends to the medial border of the pedicle [23].
- The borders of the lateral recess are the pedicle laterally, the superior articular facet dorsally, the posterior ligamentous complex to disc and floor of the canal, and the central canal medially [23].
- “Lee’s midzone” describes the foraminal region, which lies ventral to the pars [23].
- The borders of the foraminal region are the lateral recess medially, the posterior vertebral body and disc ventrally, the pars and intertransverse ligament dorsally, and the lateral border of the pedicle laterally [23].
- The dorsal root ganglion and ventral motor root occupy 30% of the foraminal space [23].
- The exit zone is identified as the area lateral to the facet joint [23].
- The human spine possesses 23 intervertebral disks that separate the vertebrae and provide flexibility [30].
- Intervertebral disks account for about 20% to 30% of the length of the spine [30].
- Intervertebral disks increase in size from the cervical to the lumbar regions [30].
- The intervertebral disk contains a central gelatinous nucleus pulposus (NP) surrounded by a fibrous ring, the annulus fibrosus (AF) [30].
- Each vertebral body has cartilage end plates, which are a thin layer of hyaline cartilage tissue that separate the adjacent vertebrae [30].
- The nucleus pulposus consists mainly of a high concentration of proteoglycans and water surrounded by a loose type II collagen network [30].
- In the nucleus pulposus, collagen fibrils assume a random orientation and are interspersed in the matrix [30].
- The annulus fibrosus has a low proteoglycan and water content and a high concentration of type I collagens as well as a small concentration of type II collagens [30].
- The annulus fibrosus is described as possessing 20 to 25 lamellae rich in collagen fibrils arranged in a parallel fashion [30].
- In each adjacent lamella of the annulus fibrosus, the collagen fibrils along the axis are fashioned in the opposite direction to create an alternating pattern between the lamellae [30].
- The content of water and proteoglycan concentration within the disk increases when progressing from the annulus fibrosus to the nucleus pulposus [30].
- The content of collagen within the disk decreases from the outer annulus to the nucleus [30].
- With increasing age, the proteoglycan and water content of the nucleus decrease [30].
- The collagen content of the nucleus is highest in cervical disks and lowest in lumbar disks [30].
- The proteoglycan content of the disk shows an opposite trend to collagen content when evaluating spinal levels [30].

NEURAL ELEMENTS AND INNERVATION

- The organization of neural elements is strictly maintained throughout the entire neural system, including within the conus medullaris and cauda equina [24].
- The most cephalad nerve roots lie lateral and the most caudad lie medial within the dural sac and at the conus medullaris [24].
- Motor roots are ventral to the sensory roots at all levels [24].
- The arachnoid mater holds the nerve roots in their specific positions [24].
- In the thoracic and lumbar spine, the named nerve root exits below the named pedicle [24].
- Discs are formally named for the vertebral bodies between which they lie [24].
- Lateral recess pathology, such as lateral recess stenosis or posterolateral disc herniation, typically involves the next nerve root exiting caudal to that disc [24].
- An L4-5 posterolateral disc herniation is expected to cause L5 nerve root symptoms [24].
- The dorsal root ganglion (DRG) lies within the outer confines of the intervertebral foramen [24].
- Distal to the DRG, three distinct branches arise: the ventral ramus, the sinuvertebral nerve, and the dorsal ramus [24].
- The ventral ramus supplies all structures ventral to the neural canal [24].
- The sinuvertebral nerve originates from the ventral ramus and progresses medially over the posterior aspect of the disc and vertebral bodies [24].
- The sinuvertebral nerve innervates the posterior disc, vertebral bodies, and posterior longitudinal ligament [24].
- The dorsal ramus courses dorsally, piercing the intertransverse ligament near the pars interarticularis [24].
- The dorsal ramus divides into lateral, intermediate, and medial branches [24].
- The lateral and intermediate branches of the dorsal ramus provide innervation to the posterior musculature and skin [24].
- The medial branch of the dorsal ramus separates into three branches to innervate the facet joint at that level and the adjacent levels above and below [24].
- Disc innervation is through afferent axons with cell bodies within the DRG [24].
- Animal studies have revealed two paths between the annulus and the DRG: one from the sinuvertebral nerve and another along the paravertebral sympathetic trunk [24].
- The sinuvertebral nerve is a recurrent branch of the ventral ramus that connects back to the posterior disc at each level [24].
- The paired ganglia chains of the sympathetic trunks have axons that course through the gray rami communicantes to the spinal nerve [24].
- The disc is innervated by fibers from multiple levels [24].
- In animal models, the lateral annulus was innervated by fibers coursing from the index level and two additional superior levels through the sinuvertebral nerves [24].

- Innervation of the lateral annulus also occurs through the sympathetic trunk by the DRG from three levels superior to the sinuvertebral innervations [24].
- Contralateral DRG involvement occurs through both sinuvertebral and sympathetic pathways [24].
- Nonsegmental, multilevel innervation patterns have been reported for the ventral disc surface [24].
- Innervation of the disc from the vertebral endplate has been shown [24].
- Intraosseous nerves follow the osseous vasculature for endplate innervation [24].
- Endplate innervation occurs through the sinuvertebral nerve and the basivertebral nerve [24].
- The basivertebral nerve enters the foramen, and its nerve fibers enter the vertebral margin with the vessels [24].
- The density of innervation at the vertebral endplate is similar to that seen in the outer annulus [24].

PATHOPHYSIOLOGY OF DEGENERATION AND STENOSIS

- Lumbar spondylosis is due to a degenerative cascade associated with intervertebral disk degeneration [25].
- Mechanical progression and associated disk space narrowing leads to adjacent level pedicle approximation with narrowing of the superior-inferior dimensions of the intervertebral foraminal canal [25].
- Laxity of associated ligaments and vertebral column translates into altered loading mechanics and an altered pressure relationship on vertebral bone and joint surfaces [25].
- Altered loading mechanics and pressure relationships influence osteophyte formation and facet joint hypertrophy [25].
- Intervertebral disk degeneration is a complicated multifactorial process characterized by altered biomechanics of loading [25].
- Intervertebral disk degeneration involves an imbalance of extracellular matrix synthesis and degradation [25].
- Intervertebral disk degeneration involves increased secretion of proinflammatory cytokines [25].
- Intervertebral disk degeneration involves increased apoptosis and senescence in nucleus pulposus cells [25].
- Altered biomechanics of the disk lead to further degenerative changes and osteophyte formation [25].
- Degenerative changes and osteophyte formation have the potential to cause lumbar central and foraminal stenosis leading to symptomatic nerve compression and radiculopathy [25].
- The degenerative process of the spine has been divided into three separate stages: dysfunction, instability, and stabilization [17].
- The dysfunction stage is seen in individuals 15 to 45 years old and is characterized by circumferential and radial tears in the disc annulus and localized synovitis of the facet joints [17].
- The instability stage is found in 35- to 70-year-old individuals and is characterized by internal disruption of the disc, progressive disc resorption, and degeneration of the facet joints with capsular laxity, subluxation, and joint erosion [17].

- The stabilization stage is present in individuals older than 60 years and is characterized by progressive development of hypertrophic bone around the disc and facet joints leading to segmental stiffening or frank ankylosis [17].
- Each spinal segment degenerates at a different rate [17].
- Disc herniation is considered a complication of disc degeneration in the dysfunction and instability stages [17].
- Spinal stenosis from degenerative arthritis is a complication of bony overgrowth compromising neural tissue in the late instability and early stabilization stages [17].
- Lumbar spinal stenosis is the final stage of a cascade of events [12].
- Disk degeneration is thought to be the event that begins the process resulting in lumbar spinal stenosis [12].
- As disk height decreases, the loading characteristics of the facets are altered [12].
- Facet joint capsules become incompetent, leading to capsular, ligamentum flavum, and facet hypertrophy [12].
- The ligamentum flavum becomes less pliable with age [12].
- The final stage of the degenerative continuum is a decrease in the diameter of the spinal canal [12].
- When the spine is in extension, the spinal canal diameter diminishes resulting in buckling of the shortened, hypertrophied ligamentum flavum [12].
- In flexion, there is a relative increase in the spinal canal diameter [12].
- Most authors support a multifactorial etiology of low back pain and leg pain associated with lumbar spinal stenosis [12].
- Mechanical compression, nutritive insufficiency, heredity, structural decompression, individual pain perception, and chemical insult likely play a role in lumbar spinal stenosis symptoms [12].
- Degeneration of the disc occurs with disc narrowing and subsequent ligamentous redundancy, which compromises the spinal canal area [23].
- Instability may ensue from disc degeneration and ligamentous redundancy [23].
- Relative hypermobility precipitates the formation of facet overgrowth and ligamentous hypertrophy [23].
- The ligamentum flavum may be markedly thickened into the lateral recess where it attaches to the facet capsule, causing nerve root compression [23].
- Central spinal stenosis denotes involvement of the area between the facet joints, which is occupied by the dura and its contents [23].
- Stenosis in the central region is usually caused by protrusion of a disc, bulging annulus, osteophyte formation, or buckled or thickened ligamentum flavum [23].
- Symptomatic central spinal stenosis results in neurogenic claudication with generalized leg pain [23].
- Compression in the lateral canal region results in radiculopathy [23].
- Facet arthritis most frequently causes stenosis in the lateral recess zone, along with vertebral body spurring and disc or annulus pathology [23].

- Causes of stenosis in the foraminal region include pars fracture with proliferative fibrocartilage or a lateral disc herniation [23].
- Thickening of the ligamentum flavum sometimes extends into the foramen and can be associated with a spur from the undersurface of the pars [23].
- Foraminal stenosis is associated with foraminal height less than 15 mm and posterior intervertebral disc height less than 4 mm [23].
- The nerve root in the exit zone can be compressed by a “far lateral” disc, spondylolisthesis and associated subluxation, or facet arthritis [23].
- The most common type of spinal stenosis is caused by degenerative arthritis of the spine, including Forestier disease [23].
- Degenerative spinal stenosis is characterized by hyperostosis and spinal rigidity in elderly patients [23].
- Acquired forms of spinal stenosis are usually degenerative and most commonly localized to the facet joints and ligamentum flavum [23].
- The L4-5 level is the most commonly involved in degenerative spinal stenosis, followed by L5-S1 and L3-4 [23].
- Disc herniation and spondylolisthesis may exacerbate the narrowing of the spinal canal further [23].
- Congenital spinal stenosis usually is central and is evident on imaging studies [23].
- Idiopathic congenital narrowing usually involves the anteroposterior dimension of the canal due to short pedicles [23].
- In achondroplasia, the canal is narrowed in the anteroposterior plane owing to shortened pedicles and in lateral diameter because of diminished interpedicular distance [23].
- Degenerative spondylolisthesis is differentiated from isthmic spondylolisthesis by the presence of an intact pars [40].
- In degenerative spondylolisthesis, the arch is intact and moves forward with the L4 vertebral body, causing progressive spinal stenosis in addition to facet degenerative changes [40].
- The true deformity of degenerative spondylolisthesis is a rotary deformity that may distort the dura and its contents and exaggerate the appearance of spinal stenosis [40].
- The sagittal facet theory suggests a predilection for slippage because of facet orientation that does not resist anterior translocation forces [40].
- The disc degenerative theory proposes that the disc narrows first, and subsequent overloading of the facets results in accelerated arthritic changes, secondary remodeling, and anterolisthesis [40].
- Facet arthritic changes seem to be more severe than disc space narrowing, with the most advanced anterolisthesis present when disc narrowing is more pronounced [40].
- Facets that are aligned in a more sagittal orientation provide less stability at the involved level [40].
- Boden et al. showed that sagittal facet angles of more than 45 degrees at L4-L5 predicted a 25 times greater likelihood of degenerative spondylolisthesis [40].

- There seems to be no sex-specific difference in facet orientation, despite the increased frequency of degenerative spondylolisthesis in women [40].
- Sagittal facet orientation has been correlated with disc space narrowing, suggesting that disc narrowing increases loading of the facet, resulting in secondary facet changes [40].
- Instability from degenerative spondylolisthesis causes facet arthritis, disc degeneration, and ligamentous hypertrophy, which all contribute to produce symptoms [40].

Classification

HISTORICAL CONTEXT AND CHALLENGES

- The classification of thoracic and lumbar spine injuries remains difficult because goals, anatomic structures to consider, and definitions have not been agreed upon by the community of spine surgeons [9].
- Terminology relating to “stability” of the spine does not have a universally agreed-upon definition, which introduces conflicting meanings in different schemes [9].
- The concept of “instability” has progressed to include immediate instability and delayed instability [9].
- Nicoll et al. were the first to focus on patient outcomes and found that anatomic reduction was not crucial to good outcomes in a population of miners [9].
- Some classification systems use “instability” as a surrogate term for neurologic injury, considering injuries unstable if a neurologic injury is present without considering the fracture pattern [9].
- CT is now the modality of choice in most centers for imaging the spine to classify fractures [9].
- The use of MRI remains controversial and has a limited role in the thoracic and lumbar regions [9].
- Khoury et al. found that MRI added very little to the management of patients with CT-proven thoracic and lumbar injuries, being helpful only in a small group of patients with planned surgery based on CT [9].
- Recent studies have shown that CT findings can be well correlated with MRI findings, negating the need for MRI in most thoracolumbar injuries [9].
- Classification systems have evolved to accommodate diverse treatment options including posterior segmental fixation, anterior reconstruction and fixation, intraosseous techniques, and minimally invasive systems [9].

FACTORS RELATED TO SPINAL INSTABILITY

- Factors related to spinal instability include neurologic function, specifically the degree of neurologic deficit and potential for additional neurologic injury [9].
- Structural disruption factors include severity of overall structural damage, comminution of the vertebral body, degree of canal compromise, and disruption of spinal ligaments [9].
- Structural disruption factors also include disruption of the facet joints, lamina, and pedicles, disruption of the intervertebral disc, presence of multiple contiguous injuries, and the effect of previous destabilizing procedures [9].

- Deformity factors include severity of deformity (kyphosis or scoliosis), buckling of the spinal column (loss of height), potential for progression of deformity, redisplacement after reduction, and potential for late collapse [9].
- Anticipated function factors include loss of stiffness, expected future physical exertion, potential for developing chronic pain, and potential impact on future employment [9].

DENIS THREE-COLUMN MODEL

- The Denis classification is based on a three-column model of the spine and is an example of a mechanistic system that remains in widespread use [9].
- Denis developed the three-column model as an extension of the work of several other authors based on his review of 412 thoracolumbar injuries, only 53 of which had CT scans [9].
- The goal of the Denis system was to highlight injury patterns resulting from specific injury mechanisms [9].
- The Denis system did not consider treatment or functional outcomes [9].

AO CLASSIFICATION SYSTEM

- The AO system is based on fracture morphology with more severe injuries progressing from type A to type C [9].
- The AO system includes subtypes 1 to 3 within each type of injury, which are further subdivided into 53 possible patterns [9].
- The original AO thoracolumbar spine fracture classification divided fractures into broad categories corresponding to compression injuries (type A), bending injuries (type B), and rotational injuries (type C) [56].
- The revised AO Spine thoracolumbar fracture classification stratifies injuries into three types in ascending order of instability [56].
- Type A in the revised AO classification includes minor, nonstructural fractures (A0), wedge compression (A1), split (A2), incomplete burst (A3), and complete burst (A4) [56].
- Type B in the revised AO classification includes transosseous tension band disruption/chance fracture (B1), posterior tension band disruption (B2), and hyperextension (B3) [56].
- Type C in the revised AO classification includes displacement/dislocation [56].

THORACOLUMBAR INJURY CLASSIFICATION AND SEVERITY SCORE (TLICS)

- The Thoracolumbar Injury Severity Score (TLISS) system was produced in 2005 by a collaborative effort of the Spine Trauma Study Group [9].
- The TLISS system incorporates the neurologic examination of the patient in a more direct way than previous systems [9].
- The TLISS system uses neurologic information, fracture morphology, and the integrity of the posterior ligamentous complex to derive a numeric score for a given injury [9].

- The numeric value from the TLISS system is used to guide treatment options based on consensus opinions [9].
- The TLISS system was subsequently modified to become the Thoracolumbar Injury Classification and Severity Score (TLICS) by the original author to improve the reliability of classifying injuries [9].
- The TLICS is a scoring system that assigns a numerical score to any given thoracolumbar injury based on fracture morphology, neurologic status, and integrity of the posterior ligamentous complex (PLC) [56].
- In the TLICS, compression and burst fracture morphologies are assigned 1 point each [56].
- In the TLICS, translational/rotational fracture morphology is assigned 3 points [56].
- In the TLICS, distraction fracture morphology is assigned 4 points [56].
- In the TLICS, an intact posterior ligamentous complex is assigned 0 points [56].
- In the TLICS, a suspected or indeterminate posterior ligamentous complex is assigned 2 points [56].
- In the TLICS, an injured posterior ligamentous complex is assigned 3 points [56].
- In the TLICS, intact neurologic status is assigned 0 points [56].
- In the TLICS, nerve root injury is assigned 2 points [56].
- In the TLICS, complete spinal cord or conus medullaris injury is assigned 2 points [56].
- In the TLICS, incomplete spinal cord or conus medullaris injury is assigned 3 points [56].
- In the TLICS, cauda equina injury is assigned 3 points [56].
- According to the TLICS, a fracture with a cumulative score of 3 or less is deemed stable and amenable to nonoperative treatment [56].
- According to the TLICS, a score of 4 is indeterminate and should be left to the surgeon's discretion [56].
- According to the TLICS, a score of 5 or more designates an unstable injury that should be treated operatively [56].
- The TLICS has shortcomings because a reliable neurologic examination cannot be obtained in a significant percentage of multiply injured patients, often rendering the scoring system unusable [56].
- The TLICS fails to assist in decision-making for controversial injuries such as burst fractures with a question of PLC injury, which invariably end up with an "indeterminate" score of 4 [56].
- The TLICS was adapted primarily based on the "North American" approach to fracture treatment, which has prevented it from being accepted globally in places where surgical treatment of burst fractures without PLC injury or neurologic deficit is standard practice [56].

RELIABILITY AND VALIDITY

- Studies evaluating the reliability of various classification systems have generally not shown one classification system to be superior to another [9].
- The TLICS system is appealing because it incorporates the neurologic function of the patient, which is the single most important determinant of functional outcome for a patient with spine injury [9].
- The reliability of the TLICS system has been found to be equivalent to other systems [9].

- The validity of the criteria for the TLICS system has not been demonstrated, which is also the case for other classifications [9].
- The treatment recommendations associated with the TLICS system are level IV evidence as consensus opinion [9].
- Interobserver and intraobserver reliability for previous classification systems, including the original AO classification, have generally been suboptimal [56].

Clinical Presentation

LUMBAR DISC HERNIATION

- The peak incidence of lumbar disc herniation is in the fourth and fifth decades of life [51].
- Men are three times more likely to sustain a lumbar disc herniation than women [51].
- Only 4% to 6% of lumbar disc herniations become symptomatic [51].
- Caudal segments are affected more commonly in lumbar disc herniation, with L5-S1 more commonly affected than L4-L5 [51].
- Patients with lumbar disc herniation typically present with varying degrees of back and leg pain [51].
- Leg pain in lumbar disc herniation usually follows the dermatomal path of the affected root(s) [51].
- Radicular pain in lumbar disc herniation may be accompanied by motor, sensory, and/or reflex disturbances [51].
- The presence of sciatica is the most sensitive and specific finding for lumbar disc herniation [51].
- Cauda equina syndrome secondary to large central lumbar disc herniations is rare [51].
- Within 3 months of symptom onset, approximately 90% of patients with lumbar disc herniation will experience symptomatic improvement without surgery [51].
- Most lumbar disc herniations, particularly contained ones, resorb and diminish in size over time [51].
- In the physical examination for lumbar disc herniation, the ipsilateral hip and knee may be flexed and externally rotated to relieve root tension [51].
- Pain with straight leg raise testing in lumbar disc herniation results from increased nerve root tension and a lack of normal excursion of the root at the herniation site [51].
- A positive crossed straight leg raise test has a higher specificity than a positive ipsilateral test for lumbar disc herniation, but the sensitivity varies [51].
- The diagnosis of recurrent disc herniation is significantly more difficult than that of primary disc herniation [10].
- The clinical presentation of recurrent disc herniation may be identical to that of primary herniation but usually has a larger component of axial pain [10].
- Most recurrences of lumbar disc herniation happen in the relatively early postoperative period, primarily the first 6 months after surgery [10].

- The incidence of recurrent lumbar disc herniation is reported in 3% to 7% of patients [10].

LUMBAR SPINAL STENOSIS

- Physical examination is often normal in patients with lumbar spinal stenosis [55].
- In the SPORT trial, only 50% of patients with lumbar spinal stenosis had physical examination findings including depressed reflexes, sensory or motor deficits, or positive nerve tension signs [55].
- Over 20% of asymptomatic individuals older than 60 years have MRI evidence of lumbar spinal stenosis [55].
- Predominant leg pain is associated with better surgical outcomes in degenerative spondylolisthesis and spinal stenosis [4, 6].
- The natural history of degenerative disc disease is one of recurrent episodes of pain followed by periods of significant or complete relief [17, 18].
- Nonprogressive neurologic deficits originating from the lumbar spine, except cauda equina syndrome, can be treated nonoperatively with expected clinical improvement [17].
- If surgery is necessary for nonprogressive neurologic deficits from the lumbar spine, it usually can be delayed 6 to 12 weeks to allow adequate opportunity for improvement [17, 18].
- The frequency and intensity of symptoms helps determine the aggressiveness of intervention for degenerative disc disease [18].
- Other pathologies that can mimic or overlap the signs and symptoms of degenerative spondylolisthesis and associated spinal stenosis include vascular claudication, degenerative hip arthritis, and peripheral neuropathy [54].
- A facet joint effusion more than 2 mm in width is highly suggestive of instability at that level [54].
- For each 1 mm of facet joint effusion, there is a 42% probability of dynamic instability [54].

GENERAL CLINICAL ASSESSMENT

- The history and physical examination are crucial to the diagnosis of lumbar spinal stenosis because physical examination is often normal [55].
- An examination of the lower extremities is crucial to rule out alternative causes for pain, as lumbar spine pathology and lower extremity joint dysfunction, especially the hip, are common [55].
- At a minimum, hip range of motion and irritability should be evaluated as well as peripheral pulses in the feet and proprioception when evaluating for degenerative spondylolisthesis [54].
- The history, physical examination, and imaging studies must all confirm the same pathologic process as the source of symptoms if surgical intervention is to be reproducibly successful [17].
- Many patients with pain have absent neurologic findings other than sensory changes and have normal imaging studies or studies that do not support the clinical complaints and findings [17, 18].
- Careful assessment of patients to determine if they have problems that can be orthopaedically treated is imperative to avoid both overtreatment and undertreatment [17, 18].

- Low back pain in young, active patients is most often a self-limiting episode without underlying etiology [53].
- Nonsurgical treatment is usually first for thoracic and lumbar disk herniation, spondylolysis, and spondylolisthesis unless substantial or worsening neurologic involvement, infection, or spine instability is present [53].

Investigations

IMAGING MODALITIES

- MRI is the standard for advanced imaging of the spine and is superior to CT in most circumstances, particularly for identifying infections, tumors, and degenerative changes within discs [33].
- MRI is superior to CT for directly imaging neural structures and the intervertebral disc [33].
- MRI allows imaging of the nerve root within the foramen, a capability that is difficult to achieve with postmyelography CT because contrast agent does not fully extend through the foramen [33].
- MRI evidence of lumbar disc degeneration has been found in 35% of patients aged 20 to 39 years and in 100% of patients older than 50 years [33].
- MRI findings must be carefully correlated with the clinical impression because the modality frequently demonstrates asymptomatic anatomic abnormalities [33].
- The most effective method for obtaining meaningful clinical information from MRI is to pose a specific question derived from history and physical examination, focusing on neural compression, instability, or deformity [33].
- CT is the diagnostic imaging modality of choice for injuries involving the thoracic, lumbar, or sacral regions of the spine [36].
- In thoracolumbar trauma, MRI has a limited role and adds very little to the management of patients with CT-proven injuries, being helpful only in a small group of patients with planned surgery based on CT findings [9].
- Recent studies indicate that CT findings can be well correlated with MRI findings, negating the need for MRI in most thoracolumbar injuries [9].
- In patients who do not respond to nonsurgical treatment or deteriorate neurologically, plain radiographs, MRI, and/or myelogram with CT are indicated to delineate the pattern and degree of lumbar spinal stenosis [12].
- For operative planning in lumbar degenerative disease, standing lateral and posteroanterior scoliosis radiographs are required to assess global balance and pelvic parameters [13].
- High-resolution CT scans are obtained to evaluate pedicle morphology, adequacy of the L5 transverse process, sacral morphology, facet arthritis at adjacent levels, and bony foraminal dimensions when thorough anatomic evaluation is needed [13].
- MRI is typically obtained to determine the specific location and etiology of nerve root symptoms in patients with significant radicular complaints [13].

- Myelography is indicated when MRI cannot be obtained, when there is suspicion of an intraspinal lesion, in patients with spinal instrumentation causing artifact, or when diagnosis is questionable due to conflicting clinical findings [37].
- Myelography is valuable in evaluating previously operated spines and in patients with marked bony degenerative change that may be underestimated on MRI [37].
- The use of postmyelography CT improves the diagnostic value of myelography, particularly in evaluating spinal stenosis [37].
- Flexion and extension radiographs can reveal the presence of instability in the lumbar spine [37].
- Oblique radiographic views are used to visualize the spinal foramen [37].

ELECTRODIAGNOSTIC AND PROVOCATIVE TESTING

- Needle EMG has a lower false positive rate than MRI in asymptomatic older adults being evaluated for lumbar spinal stenosis [2].
- EMG may be helpful to distinguish peripheral neuropathy from lumbar spinal stenosis [12].
- Provocative discography is not considered a reliable diagnostic tool for evaluating adjacent levels in patients with isthmic spondylolisthesis [13].
- Pars injection with a small volume of long-acting local anesthetic is a helpful diagnostic tool when evaluating patients with extensive degenerative changes at multiple levels in addition to isthmic spondylolisthesis [13].
- MRI with intravascular contrast material is helpful in identifying recurrent lumbar disc herniations [10].
- It is difficult to distinguish peridural scar from a small recurrent disc herniation on MRI [10].

CLINICAL EVALUATION AND HISTORY

- The incidence of lumbar spinal stenosis is 1.7% to 8.0% in the general population, increasing in the fifth decade of life [12].
- Lumbar spinal stenosis is the most common diagnosis requiring spine surgery in patients older than 65 years [12].
- The natural history of lumbar spinal stenosis is typically favorable, with approximately 15% of patients deteriorating clinically and 30% to 50% improving [12].
- Patients with lumbar spinal stenosis typically present with pain, paresthesias, subjective weakness, or heaviness in the back, buttocks, and lower extremities that occurs with walking, prolonged standing, or descending stairs [12].
- Symptoms of lumbar spinal stenosis usually start proximally and progress distally, which is the opposite pattern of vascular disease [12].
- Patients with lumbar spinal stenosis usually gain relief by sitting down, unlike vascular insufficiency where stopping walking alleviates symptoms [12].
- Common symptoms of lumbar spinal stenosis include pseudoclaudication and standing discomfort (94%), numbness (63%), and subjective weakness (43%) [12].

- The differential diagnosis for lumbar spinal stenosis must include peripheral vascular disease, hip arthritis, and peripheral neuropathy [12].
- A positive lumbar extension test is highly predictive of lumbar spinal stenosis [12].
- A vascular examination must be performed in all patients with suspected lumbar spinal stenosis [12].
- The clinical presentation of recurrent disc herniation may be identical to primary herniation but usually includes a larger component of axial pain [10].
- Most recurrent disc herniations occur in the first 6 months after surgery [10].
- The incidence of recurrent disc herniation is reported in 3% to 7% of patients [10].
- For internal disc derangement, pain that is constant with little variation in intensity or only random fluctuations is probably not caused by the condition [15].
- In internal disc derangement, straight-leg raising typically causes back and buttock pain but no pain distal to the knee [15].
- The presence of three or more Waddell signs suggests an alternative diagnosis to internal disc derangement [15].

Treatment

NONOPERATIVE MANAGEMENT

- Epidural steroid injections are a treatment option for lumbar spinal stenosis [2].
- Interspinous distraction devices, such as the X-STOP, have been used for the treatment of lumbar spinal stenosis [2].
- Nonoperative treatment for lumbar spinal stenosis has been evaluated in clinical studies regarding clinical and outcome results [2].
- Surgery reduced pain and disability in lumbar spinal stenosis better than nonoperative treatment [2].
- A randomized controlled trial compared surgical versus nonoperative treatment for lumbar spinal stenosis [2].
- Conservative management of lumbar disc herniation with associated radiculopathy has been systematically reviewed [4].
- The cost and use of conservative management of lumbar disc herniation before surgical discectomy have been analyzed [4].
- Outcomes of conservative treatment for ruptured lumbar disc herniation have been reported [4].
- Two-year comprehensive medical management of degenerative lumbar spine disease, including stenosis, has been analyzed for cost, pain, disability, and quality of life [6].

OPERATIVE DECOMPRESSION

- Lumbar decompression remains the benchmark for patients with lumbar spinal stenosis [19].

- There is no benefit to routinely performing fusion with lumbar decompression for lumbar spinal stenosis [19].
- Additional studies are required to determine which patients with degenerative spondylolisthesis can undergo decompression only versus those requiring fusion [19].
- The preferred procedure for treating degenerative spondylolisthesis is posterolateral fusion combined with transforaminal lumbar interbody fusion [50].
- A fusion should be added if a complete facetectomy or extensive bone removal is necessary to adequately decompress the nerve root during lumbar decompression [38].
- If more than one facet is removed during additional exposure for disc herniation, a fusion should be considered [48].
- Spinal fusion is not performed during repeat lumbar disc excision unless an unstable spine is created by the dissection or was identified preoperatively as a correctable and symptomatic problem [10].
- Minimally invasive decompression techniques allow preservation of paraspinal muscles, spinous processes, and intervening ligaments [16].
- Results with full-endoscopic decompression techniques have been shown to be equal to those of conventional procedures, with advantages of fewer complications [16].
- Patients with scoliosis, especially with listhesis, have a significantly higher revision rate after minimally invasive decompression [16].
- Complete laminectomy may be necessary if adequate decompression is impossible through a limited laminotomy in patients with severe involvement [16].
- Spinous process osteotomy for decompression resulted in a 47% improvement in the Low Back Outcome Score and a 66% improvement in average pain level in 46 of 50 patients evaluated 9 months after surgery [16].
- The only complications reported for spinous process osteotomy decompression were dural tears in four patients [16].
- In lumbar decompression surgery, keeping the hips relatively extended is important to simulate the anatomy in the standing position to allow adequate assessment of the decompression [38].
- If a frame is used that flexes the lumbar spine to open the interlaminar space, this must be taken into account to avoid an inadequate decompression [38].
- For a complete laminectomy, the entire spinous process of the laminectomy level and the caudal one third of the cephalad level are removed [38].
- The decompression is carried up to the caudal margin of the L3 lamina, focusing initially on central canal stenosis [38].
- Once central decompression is complete, attention is turned to lateral recess and foraminal stenosis as demonstrated by imaging studies [38].
- The foraminotomy is completed such that a Murphy ball hook can pass easily between the root and the inferior aspect of the pedicle and posterior to the root ventral to the pars [38].
- Careful attention is paid to the amount of bony removal from the pars to avoid risk of fracture [38].

- An alternative technique for lumbar decompression is a laminoforaminotomy, which can be unilateral or bilateral [38].
- Achieving an adequate decompression is the primary goal of laminoforaminotomy, and it can usually be accomplished without a complete laminectomy [38].
- The fascia is closed to the spinous process where possible to better restore the normal resting length of the paraspinal musculature after lumbar decompression [38].
- Patients are started on oral analgesics and scheduled muscle relaxers after lumbar decompression [38].
- Mobilization is started either the evening of surgery or the next morning after lumbar decompression [38].
- Most patients are independent with mobility and can be discharged home the same day or at least by the second postoperative day after lumbar decompression [38].

ENDOSCOPIC AND MINIMALLY INVASIVE TECHNIQUES

- The transforaminal endoscopic approach is an advantage for the treatment of recurrent disc herniation [10].
- The transforaminal endoscopic approach can be used for recurrence after a traditional microdiscectomy [10].
- If both the primary and recurrence approaches are transforaminal, the total level of invasiveness is typically less than a primary microscopic approach because there is no violation of the facet joint [10].
- The interlaminar endoscopic lumbar discectomy technique is typically used for posterolateral herniations at L5-S1 [45].
- The interlaminar endoscopic technique can be used at higher levels if the interlaminar window is wide enough to accommodate the operative cannula [45].
- The interlaminar endoscopic technique is a facet-sparing technique used when there is no need for lateral recess decompression [45].
- The operative cannula for interlaminar endoscopic discectomy should be no larger than 8 mm to prevent undue tension on the nerve root while retracting [45].
- The fenestration in the ligamentum flavum for interlaminar endoscopic discectomy needs to be only 3 to 4 mm in length [45].
- The facet joint must not be violated during the interlaminar endoscopic discectomy technique [45].
- Decompression is complete in transforaminal endoscopic thoracic discectomy when the undersurface of the thoracic dura is seen pulsating to heartbeat and the patient notes resolution of typical thoracic radicular pain [41].
- The awake transforaminal endoscopic approach to the thoracic spine typically can reach herniations from T4 to L4 in most people [41].
- The transforaminal endoscopic thoracic approach does not require violation of the chest cavity, usually does not require fusion, and does not require general anesthesia [41].
- A diagnostic transforaminal epidural injection at the site of a thoracic herniation that provides profound relief is a good predictor of surgical outcome for endoscopic surgery [41].

- Complications associated with minimally invasive decompression for lumbar spinal stenosis have been reported [2].
- Micro-decompression for lumbar spinal stenosis has been evaluated using a modified surgical technique [6].
- Extent of decompression and incidence of postoperative epidural hematoma vary among different techniques of spinal decompression in degenerative lumbar spinal stenosis [6].

RECURRENT DISC HERNIATION

- No operative technique has been shown to reduce the incidence of recurrent disc herniations [10].
- More aggressive disc removal does not reduce the incidence of recurrent disc herniations [10].
- Most recurrences of disc herniation happen in the relatively early postoperative period, primarily the first 6 months after surgery [10].
- MRI with intravascular contrast material has been helpful in identifying recurrent herniations [10].
- It is difficult to distinguish a peridural scar from a small recurrent herniation on MRI [10].
- The principles of identifying and protecting the nerve root and then removing the herniation are the same for recurrent herniation as for primary discectomy [10].
- The area of exposure for recurrent herniation surgery generally should be larger than for primary surgery [10].
- Recurrent disc excision can usually be done on an outpatient basis [10].
- If the initial procedure was done using the tubular retractor technique, a tubular retractor is used for recurrent disc herniations [10].

FUSION AND INSTRUMENTATION

- The interbody device is placed from the side with the most severe nerve root compression and patient complaints [50].
- The goals of interbody spacer device placement are to restore disc height and improve alignment with sufficient lordosis through the segment [50].
- Biomechanically, coverage of 35% of the endplate is desirable for stability of the interbody device [50].
- A single cage device packed with local autograft is preferred and placed just anterior to the midbody [50].
- The subchondral bone is strongest around the perimeter of the endplate and weakest centrally, increasing the risk of cage subsidence if the device is too small or only centrally located [50].
- Pedicle screws are inserted at each level after the bone graft is placed to avoid making decortication and graft placement more difficult [50].
- The rods are secured with set screws which are tightened to the manufacturer's recommended torque [50].
- Care is taken to ensure the rods do not impinge on the cephalad joint [50].
- A second dose of tranexamic acid is administered as wound closure is begun after lumbar decompression and fusion [50].

- Patients are mobilized without a brace beginning the morning after surgery for posterolateral instrumented fusion [44].
- Patients are generally independent with activity and can be discharged the second or third postoperative day after posterolateral instrumented fusion [44].
- Percutaneous anterior lumbar arthrodesis via a lateral approach requires supplementary posterior instrumentation to maintain stability [49].
- Complications, primarily related to nerve root injury or irritation, have been reported in 22% of patients after a minimally invasive direct lateral anterior lumbar fusion and extreme lateral interbody fusion [49].
- Knowledge of “safe zones” for the direct lateral approach and familiarity with dilating retractor systems are essential for avoiding complications [49].
- Patients are encouraged to walk as much as possible immediately after surgery for percutaneous anterior lumbar arthrodesis [46].
- Bending, lifting, and twisting are restricted for a period of 3 months after percutaneous anterior lumbar arthrodesis [46].
- All restrictions are lifted at 3 months if radiographs show appropriate progression of fusion after percutaneous anterior lumbar arthrodesis [46].
- Hospital stay for percutaneous anterior lumbar arthrodesis is seldom longer than 24 hours [46].
- Supplementation with calcium and vitamin D is suggested for 2 weeks before and 3 months after fusion surgery to encourage bone healing when there is no contraindication [46].

COMPLICATIONS AND OUTCOMES

- The complication rate for patients undergoing adult spinal deformity surgery is high [19].
- Patients undergoing adult spinal deformity surgery should be counseled on their risk for short- and long-term complications and need for potential revision surgery [19].
- Long-term reoperation rates, health care cost, and impact of instrumentation have been evaluated for surgery for spinal stenosis [6].
- Preoperative pain pattern predicts surgical outcome in lumbar spinal stenosis [6].
- The effect of duration of symptoms on standard outcome measures in the surgical treatment of spinal stenosis has been evaluated [2].
- Five-year follow-up by an independent observer has been conducted for surgically treated lumbar spinal stenosis [2].
- The rate of revision surgery after stand-alone lateral lumbar interbody fusion for lumbar spinal stenosis has been evaluated [6].
- Failed anterior lumbar interbody fusion due to incomplete foraminal decompression has been reported [6].
- Revision surgery for lumbar pseudarthrosis has been evaluated [6].
- Smoking is associated with increased blood loss and transfusion use after lumbar spinal surgery [6].

Complications

OPERATIVE COMPLICATIONS

- Dural tears occurred in four patients undergoing spinous process osteotomy for decompression [16].
- Cauda equina syndrome is a complication of lumbar discectomy [5].
- Retained surgical swab debris can lead to arachnoiditis and peridural fibrosis following laminectomy [5].
- Peridural scar formation is associated with activity-related pain after lumbar discectomy [5].
- Incidental durotomy during lumbar spine surgery can be complicated by long-term issues [5].
- Sexual complications have been reported following anterior fusion of the lumbar spine [5].
- The extent of decompression influences the incidence of postoperative epidural hematoma in degenerative lumbar spinal stenosis [6].
- Complications associated with minimally invasive decompression for lumbar spinal stenosis have been documented [2].
- Perioperative surgical complications occur in transforaminal lumbar interbody fusion [6].
- Complications of anterior lumbar surgery have been reviewed [6].
- Hospital and surgeon volume affect postoperative complications after lumbar spine surgery [6].
- Patients with scoliosis, especially with listhesis, have a significantly higher revision rate following minimally invasive decompression [16].
- Denervation of the paraspinal musculature occurs with wide exposures during decompression, resulting in altered muscle function [16].
- Nonunion of spinous processes after short decompressions did not correlate with poor results [16].

NON-OPERATIVE COMPLICATIONS

- Dural puncture is estimated to occur in 0.5% to 5% of patients having cervical or lumbar epidural steroid injections [58].
- Epidural abscess, epidural hematoma, durocutaneous fistula, and Cushing syndrome have been reported as individual case reports following epidural corticosteroid injections [58].
- Vasovagal reactions are the most adverse events imputed during an epidural injection [58].
- Nonpositional headaches, facial flushing, insomnia, low-grade fever, and transient increased back or lower extremity pain are minor complaints caused by corticosteroid injected into the epidural space [58].
- Needle misplacement occurs in 40% of caudal and 30% of lumbar epidural injections when done without fluoroscopic guidance [58].
- Accidental intravascular injections can occur during epidural injections [58].
- The most frequent sequela of transforaminal lumbar epidural injections is increased leg or back pain, which occurs in less than 1% of patients [58].

- Postinjection headache incidence is less than 1% in large series of transforaminal lumbar epidural injections [58].

LONG-TERM AND REVISION OUTCOMES

- Pseudarthrosis can occur after spinal fusion [1].
- Pseudarthrosis after lumbar pedicle subtraction osteotomy in adult spinal deformity has specific risk factors and assessment methods [6].
- Revision surgery is required for lumbar pseudarthrosis [6].
- Anterior lumbar interbody fusion can be used as a salvage technique for pseudarthrosis following posterior lumbar fusion surgery [6].
- Failed back surgery syndrome is a recognized outcome following spine surgery [6].
- Epidural fibrosis is associated with failed back syndrome [6].
- Recurrent lumbar disc herniation may require microendoscopic discectomy [6].
- Long-term reoperation rates for surgery for spinal stenosis are influenced by instrumentation [6].
- The complication rate for patients undergoing adult spinal deformity surgery is high, necessitating counseling on short- and long-term complications and potential revision surgery [19].

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