

Vertebroplasty and kyphoplasty

Anatomy & Pathophysiology

OSSEOUS ANATOMY

- The bony anatomy of the spine consists of 7 cervical vertebrae, 12 thoracic vertebrae, 5 lumbar vertebrae, 5 fused sacral vertebrae, and 4 or 5 fused coccygeal vertebrae [3].
- The vertebral body consists of a fairly cylindrical mass of bone connected by the pedicles to the posterior arch of the vertebra, which consists of the lamina and spinous process [3].
- The spinal canal is created by the vertebral body anteriorly, the lamina posteriorly, and the pedicles laterally [3].
- The vertebral bodies function primarily to bear weight and transfer forces to the pelvis and hips [3].
- The posterior elements provide protection to the neural structures and function as a tension band [3].
- The thoracic spine represents two transitional zones: from the highly mobile cervical spine into the more rigid thoracic region, and then back to the more mobile lumbar spine [5].
- The thoracic spine, in conjunction with the ribs and sternum, forms a bony “cube” that is an inherently stable structure providing protection to the heart and lungs [5].
- Thoracic vertebral bodies are larger than cervical vertebrae but smaller than lumbar vertebrae [5].
- Thoracic pedicles arise more superiorly from the posterior vertebral body than in the cervical or lumbar spine and project obliquely from superodorsal to inferoventral [5].
- The spinal canal is narrowest in the thoracic region of the spine [5].
- The spinous processes of the midthoracic spine project sharply obliquely, overlapping the lamina and spinous processes inferiorly [5].
- The superior articular facets of the thoracic spine project cranially from the junction of the laminae and pedicles and are oriented coronally [5].
- The rib heads articulate with the lateral aspect of the vertebral bodies, with a shared articulation at the level of the disk space referred to as a demifacet [5].
- The transverse processes of the thoracic spine project obliquely superolaterally, with the costotransverse joint located along their ventral aspect [5].

- There is no costovertebral articulation at T11 or T12 [5].
- The vertebral body is composed of an inner region of cancellous bone surrounded by a thin shell of cortical bone [8].
- Each vertebra is composed of an anterior portion (vertebral body) and a posterior arch formed by the pedicle, facet, lamina, and spinous process [8].
- The cervical spine is composed of seven vertebrae and assumes a lordotic curvature [8].
- The thoracic spine is composed of 12 vertebrae and assumes a kyphotic curvature [8].
- The lumbar spine is composed of five vertebrae and assumes a lordotic curvature [8].
- The five fused sacral vertebrae form a portion of the pelvis [8].
- Four small, fused vertebrae form the coccyx at the most caudal extent of the spinal column [8].
- The vertebral column comprises 33 vertebrae divided into five sections: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal [11].
- The sacral and coccygeal vertebrae are fused, which typically allows for 24 mobile segments [11].
- The length of the vertebral column averages 72 cm in men and 7 to 10 cm less in women [11].
- The vertebral canal extends throughout the length of the column and provides protection for the spinal cord, conus medullaris, and cauda equina [11].
- The cervical endplates have a cup-in-saucer configuration, distinct from the normally flat endplates of the thoracic and lumbar vertebrae [20].
- The posterior aspect of the cervical transverse process guides the cervical spinal nerves as they exit the spinal canal, with the spinal nerves lying posterior to the vertebral artery [20].

INTERVERTEBRAL DISC ANATOMY

- The intervertebral disc (IVD) separates each successive vertebral body except between the atlas (C1) and the axis (C2) [8].
- The IVD is composed of an inner nucleus pulposus (NP) and an outer ring termed the annulus fibrosus (AF) [8].
- The nucleus pulposus serves as an osmotic pump to attract water and generate hydraulic pressure when subjected to significant loads [8].
- The annulus fibrosus encapsulates the gelatinous nucleus pulposus and provides mechanical support to contain NP pressure and constrain intervertebral rotations [8].
- The outer annulus fibrosus is integrated with the vertebral rim via a fibrocartilage enthesis that consists of a thin layer of calcified cartilage, or “tidemark” [8].
- The end plate is a bilayer of cartilage and bone that separates the disk from adjacent vertebrae [8].
- The cartilage end plate integrates with the inner annulus fibrosus to fully encapsulate the nucleus pulposus [8].
- The end plate must be strong and thick to resist significant loads but also permeable to favor chemical transport and disk cellular vitality [8].

LIGAMENTS AND SOFT TISSUE

- Additional soft-tissue structures providing passive support include the anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, facet joint capsule, interspinous ligament, and supraspinous ligaments [8].
- The erector spinae muscle runs longitudinally on the dorsal surface of the spinal column and functions to extend the spine [8].
- The psoas muscle runs longitudinally on the ventrolateral surface of the spinal column and serves to flex the hip or laterally bend the trunk [8].
- The multifidus muscle connects intersegmentally to stabilize the spine by acting like a bowstring to maintain lordosis [8].

BIOMECHANICS AND ALIGNMENT

- Normal cervical alignment is approximately 15° of lordosis [7].
- The thoracic spine generally ranges from 20° to 40° of kyphosis [7].
- The lumbar spine has approximately 40° to 50° of lordosis [7].
- Kyphotic segments (thoracic, sacral) are considered “primary” curvatures as they are present in utero and at birth [7].
- The lordotic curvatures of the cervical and lumbar spine develop secondarily later in life to allow the growing child to develop an upright posture [7].
- The center of gravity of the spinal column runs from the odontoid process proximally through the sacral promontory caudally [7].
- Changes in sagittal balance that shift the center of gravity too far ventrally can result in significant pain and disability [7].
- The functional spinal unit consists of two vertebrae, the disk between them, and the facet joints (and their capsules) [7].
- The vertebral bodies bear 70% to 90% of the static axial load of the spine [7].
- The facet joints support 10% to 20% of axial load in a standing, neutral alignment [7].
- In extension, the facet joints may bear up to 30% of the axial load [7].
- In flexion, the facet joints may be burdened with up to 50% of the anterior shear load [7].
- As compressive forces are applied to the disk, the nucleus pulposus deforms, redistributing axial forces radially [7].
- The radial pressure generated by the nucleus pulposus is resisted by the tensile properties of the alternating bands of fibers within the anulus fibrosus [7].
- The spinous processes and transverse processes act as lever arms, providing mechanical advantage for the muscles that insert along their surfaces [7].

VASCULAR ANATOMY

- The thoracic and lumbar levels are supplied by paired segmental arteries which originate directly from the aorta along its posterior surface [12].
- Branches of the segmental arteries supply the vertebral body, the paraspinal musculature, and the spinal cord [12].
- The cervical spine derives its circulation primarily from the vertebral arteries [12].
- The vertebral arteries typically enter the transverse foramen at the C6 level and run proximally through the transverse foramina to C1 [12].
- The vertebral arteries course posteriorly over the superior aspect of the C1 ring before turning proximally again and entering the foramen magnum [12].
- The vertebral arteries merge to form the basilar artery at the foramen magnum [12].
- The vascular supply of the spinal cord is primarily from the medullary branches of the segmental spinal arteries [12].
- The anterior spinal artery is responsible for supplying approximately 80% of the vascular supply to the spinal cord [12].
- The arteria medullaris magna (AMM), also known as the arteria radicularis magna or artery of Adamkiewicz, is the largest anterior segmental artery [12].
- The AMM typically arises on the left side anywhere between the T8 and L1 level [12].

NEURAL ANATOMY

- A typical mixed spinal nerve has three distinct components: motor, sensory, and sympathetic [13].
- Motor rootlets leave the anterolateral sulcus of the spinal cord and unite to form each motor root, with fibers arising from anterior horn cells to innervate skeletal muscles [13].
- Sensory fibers arise from pain, thermal, tactile, and stretch receptors, with cell bodies located within the dorsal root ganglia [13].
- The sympathetic component of all 31 mixed spinal nerves leaves the spinal cord along only 14 motor roots [13].
- The cells of origin for the sympathetic component are in the intermediolateral cell column that extends throughout the thoracic and upper lumbar cord segments [13].
- Mixed spinal nerves, having left the intervertebral foramina, receive their sympathetic component and promptly branch into anterior and posterior primary rami [13].
- The posterior primary rami are directed posteriorly and supply the paraspinal musculature and the skin along the posterior aspect of the trunk, neck, and head [13].
- The anterior primary rami of all the cervical, the first thoracic, and all the lumbosacral nerves join in the formation of plexuses [13].
- The upper four cervical anterior rami form the cervical plexus [13].
- The lower four cervical and first thoracic anterior rami form the brachial plexus [13].

- The first three and a part of the fourth lumbar anterior rami form the lumbar plexus [13].
- The sacral anterior rami along with the fifth lumbar and a part of the fourth join to form the lumbosacral plexus [13].
- The area of skin supplied by the fibers of a single spinal root is called a dermatome [13].
- Segmental dermatomal patterns are well preserved in the thoracic region but not in the limbs [13].

PATHOPHYSIOLOGY OF DEGENERATION AND STENOSIS

- Degeneration of the disc occurs with disc narrowing and subsequent ligamentous redundancy, which compromises the spinal canal area [17].
- Instability resulting from disc degeneration may precipitate the formation of facet overgrowth and ligamentous hypertrophy [17].
- The ligamentum flavum may be markedly thickened into the lateral recess where it attaches to the facet capsule, causing nerve root compression [17].
- Central spinal stenosis denotes involvement of the area between the facet joints, which is occupied by the dura and its contents [17].
- Symptomatic central spinal stenosis results in neurogenic claudication with generalized leg pain [17].
- 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 [17].
- Facet arthritis most frequently causes stenosis in the lateral recess zone, along with vertebral body spurring and disc or anulus pathology [17].
- “Lee’s midzone” describes the foraminal region, which lies ventral to the pars [17].
- The dorsal root ganglion and ventral motor root occupy 30% of the space in the foraminal region [17].
- The exit zone is identified as the area lateral to the facet joint [17].
- The most common type of spinal stenosis is caused by degenerative arthritis of the spine, characterized by hyperostosis and spinal rigidity in elderly patients [17].
- The L4-5 level is the most commonly involved in degenerative spinal stenosis, followed by L5-S1 and L3-4 [17].
- Congenital spinal stenosis usually is central and is evident on imaging studies [17].
- In achondroplasia, the canal is narrowed in the anteroposterior plane owing to shortened pedicles and in lateral diameter because of diminished interpedicular distance [17].

Investigations

MAGNETIC RESONANCE IMAGING (MRI)

- MRI is the standard for advanced imaging of the spine and is superior to CT in most circumstances, particularly for the identification of infections, tumors, and degenerative changes within the discs [23].

- MRI is superior to CT for imaging the intervertebral disc and directly imaging neural structures [23].
- MRI typically shows the entire region of the spine (cervical, thoracic, or lumbar) [23].
- MRI allows for the imaging of the nerve root in the foramen, which is difficult even with postmyelography CT because the subarachnoid space and contrast agent do not extend fully through the foramen [23].
- In the lumbar and thoracic spine, MRI has supplanted CT myelography because it is noninvasive and less expensive [22].
- The combination of high soft-tissue contrast and high resolution in MRI allows ideal evaluation of the intervertebral discs, nerve roots, posterior longitudinal ligament, and intervertebral foramen [22].
- MRI provides excellent assessment of the spinal cord [22].
- A normal intervertebral disc exhibits signal hyperintensity on T2-weighted images due to its high water content [22].
- The aging process results in a gradual desiccation of the disc material and a loss of T2-weighted signal hyperintensity [22].
- Disc herniations or extrusions appear as convex or polypoid masses extending posteriorly into the ventral epidural space, frequently maintaining a signal intensity similar to that of the disc of origin [22].
- Sagittal T2-weighted or gradient-echo images create a “myelographic” effect useful for evaluating compromise of the subarachnoid space [22].
- Sagittal T1-weighted images should be closely examined to identify narrowing of the neuroforamina [22].
- Normal T1-weighted hyperintense perineural fat in the foramina provides excellent contrast to darker displaced disc material [22].
- Far lateral disc herniations are best seen on selected axial images localized through disc levels [22].
- Free disc fragments appear discontinuous with the intervertebral disc and usually exhibit intermediate T1-weighted signal in contrast to the hypointense cerebrospinal fluid [22].
- MRI can detect significant spinal cord compromise, with edema within the cord readily demonstrated as hyperintensity on T2-weighted images [22].
- MRI evidence of disc degeneration has been reported in the cervical spine in 25% of patients younger than 40 years and in 60% of patients 60 years and older [23].
- Lumbar disc degeneration has been found in 35% of patients aged 20 to 39 years and in 100% of patients older than 50 years [23].
- The best way to obtain meaningful clinical information from MRI is to have a specific question derived from the patient’s history and physical examination, posed using the parameters of neural compression, instability, and deformity [23].
- Only abnormalities in the categories of neural compression, instability, or deformity are important for operative treatment [23].
- Diffusion tensor imaging is an MRI technique based on the diffusion rate of water in tissue that has been reported to demonstrate spinal cord impairment in patients with early stage cervical spondylosis before it is visible on plain MRI scans [26].

COMPUTED TOMOGRAPHY (CT)

- CT has largely supplanted plain radiographs as the initial screening study of choice for spine injuries due to its combination of high sensitivity and specificity [24].
- CT allows for the identification of subtler fractures that might have remained undiagnosed on plain radiographs and provides additional three-dimensional detail [24].
- CT is particularly useful in differentiating compression fractures from burst fractures [24].
- CT identifies subtle features of injury such as the presence of facet widening [24].
- CT evaluation is essential in determining the stability of thoracic and lumbar spine fractures [24].
- The primary disadvantage of CT imaging in comparison to MRI is that it does not provide as good a visualization of the soft tissues [24].
- CT myelography is invasive and more costly than MRI and is reserved for patients who have contraindications to MRI or who have equivocal MRI examinations [22].

DIAGNOSTIC PRINCIPLES

- Proper diagnosis of a spine tumor with a biopsy is the critical first step in devising proper treatment for a patient who presents with a spine tumor [2].
- Careful identification of the tumor type by direct biopsy decreases the chance of misdiagnosis and performing unnecessary or incorrect surgery [2].
- MRI findings must be carefully correlated with the clinical impression because MRI shows anatomy that is abnormal but may be asymptomatic [23].
- The specific location of an abnormality should be suspected before MRI and confirmed with the study [23].

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