

Cervical disc replacement

Anatomy & Pathophysiology

BONY 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, which consists of the lamina and spinous process [3].
- The vertebral bodies function primarily to bear weight and transfer forces to the pelvis and hips, while the posterior elements provide protection to neural structures and function as a tension band [3].
- The cervical spine is composed of seven vertebrae and assumes a lordotic curvature [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 vertebral body is composed of an inner region of cancellous bone surrounded by a thin shell of cortical bone [8].
- The cervical vertebral body is an oblong structure with a coronal diameter larger than its sagittal diameter [20].
- 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].
- The transverse process forms a half-pipe configuration that cradles the exiting spinal nerve as it projects in an anteroinferior direction [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

- Each successive vertebra is connected anteriorly via the IVD and posteriorly via the facet joints [8].
- Passive support for the spinal column is provided by 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].

VASCULAR ANATOMY

- The cervical spine derives its circulation primarily from the vertebral arteries [12].
- The vertebral arteries arise from the subclavian arteries and typically enter the transverse foramen at the C6 level [12].
- The vertebral arteries run proximally through the transverse foramina to C1, then course posteriorly over the superior aspect of the C1 ring before entering the foramen magnum [12].
- Segmental branches to each cervical vertebra arise from the vertebral artery and the deep cervical branch of the costocervical trunk [12].
- There is significant variability in vertebral artery anatomy, including entry through the C7 transverse foramen or anomalous courses looping through a cervical vertebral body [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].

- Three anterior medullary arteries typically supply the cervical region of the spinal cord [12].

BIOMECHANICS AND ALIGNMENT

- Normal cervical alignment is approximately 15° of lordosis [7].
- The curvatures of the spine function to keep the head balanced over the pelvis and to transmit axial forces through the spine to the pelvis [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 functional spinal unit consists of two vertebrae, the disk between them, and the facet joints (and their capsules) [7].
- The functional spinal unit serves to limit motion of the spine within the confines of protecting the neural structures contained therein [7].
- 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 annulus fibrosus [7].

PATHOPHYSIOLOGY OF DEGENERATION

- Cervical degenerative disc disease (DDD) is a pathophysiologic process that incorporates a spectrum of disease states ranging from neck pain and headache to cervical radiculopathy and/or myelopathy [30].
- Disc degeneration does not always cause pain, but it can lead to internal disc derangement or disc herniation [30].
- The degenerative process of the spine has been divided into three stages: dysfunction, instability, and stabilization [28].
- The dysfunction stage of spinal degeneration 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 [28].
- The instability stage of spinal degeneration is found in 35- to 70-year-old patients and is characterized by internal disruption of the disc, progressive disc resorption, degeneration of the facet joints with capsular laxity, subluxation, and joint erosion [28].
- The stabilization stage of spinal degeneration is present in patients 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 [28].
- Disc herniation is considered a complication of disc degeneration in the dysfunction and instability stages [28].

- Spinal stenosis from degenerative arthritis is a complication of bony overgrowth compromising neural tissue in the late instability and early stabilization stages [28].
- Degenerative cervical myelopathy results from static compression, spinal malalignment leading to altered cord tension and vascular supply, and dynamic injury mechanisms [27].
- The cascade of events after compression of the spinal cord in degenerative cervical myelopathy includes ischemia, destruction of the blood–spinal cord barrier, demyelination, and neuronal apoptosis [27].
- Potential genetic factors for degenerative disc disease include those related to MMP-2 and collagen IX [27].
- Potential genetic factors for ossification of the posterior longitudinal ligament include collagen VI and XI [27].
- Congenital anomalies including spinal stenosis, Down syndrome, and Klippel-Feil syndrome may predispose to the development of cervical disc degeneration [27].
- The incidence of significant abnormalities shown by imaging studies in asymptomatic matched controls is 76% [30].
- Approximately 80% of individuals are affected by nonspecific axial pain at some time in their lives [30].

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 identifying infections, tumors, and degenerative changes within the discs [23].
- MRI is superior to CT for imaging the disc and directly imaging neural structures [23].
- MRI typically shows the entire region of the spine (cervical, thoracic, or lumbar) [23].
- MRI allows for imaging of the nerve root in the foramen, which is difficult with postmyelography CT because the subarachnoid space and contrast agent do not extend fully through the foramen [23].
- MRI evidence of disc degeneration has been reported in the cervical spine in 25% of patients younger than 40 years [23].
- MRI evidence of disc degeneration has been reported in the cervical spine in 60% of patients 60 years and older [23].
- The most common indication for MRI of the spine is evaluation of intervertebral disc disease [22].
- After routine radiography, MRI is the procedure of choice for screening patients with low back or sciatic pain [22].
- 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].

- Sagittal images provide an initial evaluation of the intervertebral discs and posterior longitudinal ligament [22].
- A normal disc exhibits signal hyperintensity on T2-weighted images due to its high water content [22].
- The aging process results in gradual desiccation of the disc material and 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, usually of intermediate T1-weighted signal in contrast to the hypointense cerebrospinal fluid [22].
- MRI can detect significant spinal cord compromise in the cervical and thoracic spine [22].
- Edema within the spinal cord is readily demonstrated as hyperintensity with T2 weighting [22].
- A bulge is defined as a circumferential, symmetric extension of the disc beyond the interspace around the endplates [22].
- A protrusion is defined as a focal or asymmetric extension of the disc beyond the interspace, with the base against the disc of origin broader than any other dimension of the protrusion [22].
- An extrusion is defined as a more extreme extension of the disc beyond the interspace, with the base against the disc of origin narrower than the diameter of the extruding material itself or with no connection between the material and the disc of origin [22].
- A sequestration specifically refers to a disc fragment that has completely separated from the disc of origin [22].
- 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].
- Information from diffusion tensor imaging can be helpful in early identification of patients in whom operative treatment is indicated [26].

COMPUTED TOMOGRAPHY (CT)

- CT has largely supplanted plain radiographs as the initial screening study of choice due to its combination of high sensitivity and specificity [24].
- CT of the spine should be obtained in the setting of a high-risk mechanism, in the presence of acute thoracic or lumbar pain after a trauma, when fractures have been identified on plain radiographs, and in

situations where there are other reasons to suspect a spine injury such as the presence of a neurologic deficit [24].

- A dedicated spine CT consists of 2- to 3-mm wide axial slices of the thoracic and lumbar spine, typically reformatted into sagittal and coronal images [24].
- Compared to plain radiographs, CT allows for identification of subtler fractures that might have remained undiagnosed on plain radiographs [24].
- CT provides additional three-dimensional detail, even for more severe and easily recognized injuries, such as the degree of canal compromise and the amount of fracture comminution [24].
- CT is particularly useful in differentiating compression fractures from burst fractures [24].
- CT is useful in identifying subtle yet important features of an 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 magnetic resonance imaging (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].

CLINICAL CORRELATION AND INTERPRETATION

- One of the difficulties with MRI is showing anatomy that is abnormal but may be asymptomatic [23].
- MRI findings must be carefully correlated with the clinical impression [23].
- The best way to obtain meaningful clinical information from MRI is to have a specific question before the study derived from the patient's history and careful physical examination [23].
- The specific question for MRI interpretation is posed using the parameters of (1) neural compression, (2) instability, and (3) deformity [23].
- In each case, the specific location of the abnormality should be suspected before MRI and confirmed with the study [23].
- Only abnormalities in one or a combination of the categories of neural compression, instability, and deformity are important because operative techniques can treat only these problems [23].
- Failure to interpret an imaging study in this way, especially MRI, would inevitably lead to poor clinical choices and outcomes [23].
- Ideally, an advanced imaging study should be used for confirmation, not reevaluation [26].

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