

Degenerative Disorders of the Lumbar and Cervical Spine

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The intervertebral disc is a key component in the maintenance of normal alignment and stabilization of the spine. The structure and composition of the disc support the function of the spinal segment. The intervertebral disc distributes loads and functions to promote flexibility and stability of the spine simultaneously. With normal aging, the disc becomes exposed to repetitive mechanical loads over time and eventually undergoes biochemical degeneration and dehydration. Ultimately, this process can lead to pathologic conditions.

Degenerative change in the intervertebral disc is a common and natural process in the human spine. This degeneration occurs gradually and can alter the biomechanics, stability, and neurologic function of the spine. Although these changes go largely unnoticed in most people with disc degeneration, they may manifest as back pain or neck pain and neurologic compromise in others.

The normal disc

Anatomy and composition

A thorough knowledge of vertebral and intervertebral disc anatomy is essential for understanding the pathophysiology, diagnosis, and rational treatment decisions for degenerative disc disease. A fundamental concept is the functional spinal unit, which represents the smallest segment of the spine that exhibits the biomechanical characteristics of the entire spine [1]. This segment includes two adjacent vertebrae, the intervertebral disc, and the spinal ligaments. A single motion segment is a smaller subunit that includes the paired facet joints posteriorly and the disc anteriorly. The intervertebral disc and the facet joints must support the compressive load at each level. This region has been described as a “three-joint complex” [2].

The disc itself is composed of four main components: the outer anulus fibrosus, the inner anulus fibrosus, the transition zone, and the central nucleus pulposus [3]. The outer anulus is predominantly made up of type I collagen (70%–80%) and fibrocyte/fibroblast-like cells organized in a dense concentric fashion that structurally resists tensile loads and contains the inner anulus fibrosus and nucleus pulposus [4,5]. The transition zone and the inner anulus are composed of increasing amounts of type II collagen

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and chondrocytes and decreasing amounts of type I collagen and fibrocytes [4,5]. The nucleus pulposus of a child primarily consists of notochordal cells; the nucleus pulposus of an adult consists mainly of type II collagen (80%), chondrocytes, and proteoglycans [1,3,4,6–10]. The inner anulus fibrosus and the nucleus pulposus have viscoelastic properties that help absorb compressive loads and help maintain disc heights [4,5]. In the outer anulus, the predominant cell type is the fibroblast [3] and the collagen fibers are parallel to other fibers within the same layer and oriented at an angle of 120° to the collagen fibers in the layer above or below [1,3,4,9]. The concentric lamellar organization is less distinct in the inner anulus. The outermost layers of the outer anulus fibrosus are attached to the vertebral body directly by way of Sharpey's fibers, whereas the inner fibers of the anulus are connected to the cartilaginous end plates that consist of hyaline cartilage covering thin cortical bone [4,6]. This composition and arrangement of the disc contributes to its ability to handle torsional, shear, and axial forces. The stability of the motion segment is further strengthened by the facets, the anterior longitudinal ligament, the posterior longitudinal ligament, the supraspinous ligament, and other ligamentous structures. A nondegenerated disc has limited vascularity and innervation to the outer anulus fibrosus.

Because of its limited peripheral vascularity, nutrients and waste products are transported by way of diffusion through this outer anulus and vertebral body vasculature [3,9,11–13]. Collagen fibers give the discs tensile strength, whereas proteoglycans help retain water and give the disc its stiffness and resistance to compression [2–4,8,13,14]. The combination of the inner anulus and the nucleus pulposus gives the disc viscoelastic properties. Logically, the discs change volumetrically when subjected to compression and bending forces, whereas changes in shape without volumetric changes occur with torque [5].

Nerve endings have been described surrounding intervertebral discs, within the anterior and posterior longitudinal ligaments, and within the outer one third of the anulus fibrosus [14–19]. Facet capsules and ligaments have also been shown to have nerve endings [4,18]. The presence of peripheral disc innervation may provide some evidence for an anatomic etiology of discogenic back pain. Two specific neural structures that are speculated to be involved in the development of back and neck pain are the dorsal root ganglia and the sinuvertebral nerves [5]. The dorsal root ganglia appears to have nociceptors for the calcitonin gene-related peptide substance P and has been found to have a high density of glutamate

receptors [5,18]. The source of glutamate is speculated to arise from the catabolism of intervertebral discs. The second disc-innervating neural structure of importance is the sinuvertebral nerve that arises from the ventral root and gray rami communicantes [5]. The sinuvertebral nerve innervates the anulus fibrosus and the posterior longitudinal ligament and is also thought to be responsive to painful stimuli [5].

The degenerative process

Effects on disc composition and structure

Disc degeneration is part of the normal aging process. A key factor in intervertebral disc degeneration is a distinct alteration in its biochemical composition. In comparison to older individuals, there is a higher concentration of proteoglycans in the nucleus pulposus of younger individuals. The aggregation of proteoglycans promotes enhanced hydration that in turn accounts for the disc's resilience [5,9]. As aging progresses into the third decade, there is a decrease in the proteoglycan concentration and number of chondrocytes [3,5,7–9,13,14]. Although the mechanism for this process has not been fully elucidated, decreases in proteoglycans appear to be due to impaired synthesis and accelerated fragmentation of its structure. Loss of chondroitin sulfate glycosaminoglycan side chains leads to a proportionally higher concentration of keratan sulfate.

The amount of biomechanical loading over time appears to be responsible for changes in proteoglycans of the nucleus pulposus [20]. The net result is a decrease in the ability to maintain a hydrated nucleus, leading to alterations in disc structure and volumetric changes [3,5,7–10,13,14]. Progressing toward the periphery, the inner anulus fibrosus sustains a loss of collagen fibril organization, and the inner anulus eventually desiccates into a fibrocartilaginous material that is difficult to distinguish from the desiccated nucleus pulposus [5]. As the outer anulus fibrosus degenerates, a loss of structural organization is characterized by the appearance of cracks and fissures in the lamellae. These cracks and fissures can then coalesce into larger channels that can predispose the central disc material for herniation through the anulus [5]. Over time, the anulus becomes more histologically fibrocartilaginous and biomechanically stiff [3]. Biologically, the cells within the intervertebral disc become senescent, leading to decreased synthetic capacity and ability to replicate DNA [3].

There are several net effects on the spine that result from disc degeneration. Herniation of disc mate-

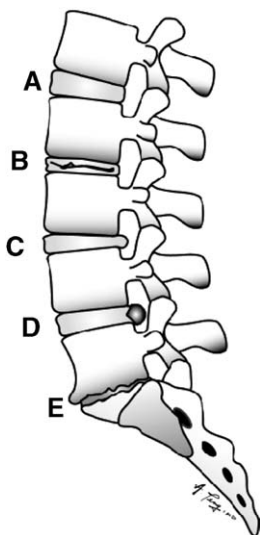


Fig. 1. Spectrum of spondylosis in the lumbar spine. (A) normal disc; (B), disc degeneration and thinning; (C), disc bulge; (D), disc herniation; (E), spondylosis with disc degeneration and osteophytic changes.

rial may result from anular degeneration. Depending on the location of the disc herniation, the pathologic signs and symptoms can range from myelopathy or neurogenic claudication associated with central canal stenosis to radiculopathy associated with lateral herniations. The classically described location is paramedian or posterolateral, at the insertion of the outer annulus into the vertebral body [14,21].

Symmetric extensions of the disc beyond the margins of the vertebral end plate are classified as disc bulges. The disc is considered herniated only if nuclear material is expelled through a discrete annular defect (Fig. 1). It is classified as a disc protrusion if the fragment herniates through the annulus beyond the posterior margin of the vertebral end plate. If the fragment is expelled further and the fragment is in continuity with the central disc (often by a pedicle), then it is classified as a disc extrusion [14,22]. A sequestered disc fragment has no direct contact with the disc and, by definition, migrated from its source.

Vascular and nutritional changes

With the exception of the outer annulus fibrosus, the intervertebral disc is relatively avascular. As a result, the central portion of the disc receives most of its nutrition passively by diffusion [3]. The vertebral end plates contain capillaries that support diffusion of nutrients and waste products. Studies have verified the presence of muscarinic cholinergic receptors

on these end plates that may help regulate blood flow [23].

With normal aging, there is often a decrease in the peripheral blood supply; however, there are several reports that suggest that as degeneration progresses, proliferation of vessels in the end plate region adjacent to degenerated discs occurs [5]. Degenerative end plate changes can lead to sclerosis, which can further impede nutrient and waste diffusion [3]. The proliferation of vessels adjacent to degenerative discs may be the body's attempt to overcome the sclerotic barrier to diffusion in the aging end plate.

Pain generation

Pain from motion segment degeneration

Axial back or neck pain may be multifactorial and often difficult to treat. Discogenic pain, or pain originating from the intervertebral disc, is caused by derangement of the nucleus pulposus or annulus fibrosus. Degeneration of the annulus itself may lead to loss of structural integrity and eventual tearing. Painful stimuli from annular tears are thought to occur by way of stimulation of the surrounding sinuvertebral nerves.

Other possible anatomic sources of pain include the facet joints, vertebral bodies, spinal ligaments, and paraspinal musculature. Alterations in any one of these structures may adversely affect adjacent (or nonadjacent) structures of the functional spine unit, ultimately resulting in generation of pain. As the disc continues to degenerate by fragmentation and herniation, bone-on-bone apposition may result in pain with loading and motion. In addition, a collapsed disc space may lead to altered biomechanics of the functional spine unit, thereby increasing the loads on the posterior facet joints. Abnormally high loads placed on the posterior elements over time can then lead to premature facet joint arthropathy, which further perpetuates the cycle of spinal degeneration. This spectrum of degenerative changes is termed *spondylosis* (see Fig. 1). Failure of normal biomechanics or cellular structures may lead to further degeneration of the intervertebral disc [24].

Pain from neural compression

Compression of nerve roots can occur as a result of soft tissue or bony impingement. Herniation of soft disc material can generate pain by direct mechanical compression and by biochemical inflammation of neural elements. With worsening spondylosis, alter-

ations in the biomechanics of the vertebral body and facets occur with loss in disc height. The body's response to these structural changes may result in the formation of facet joint osteophytes and osteophytes adjacent to the vertebral end plates. Although osteophytes are thought to have a stabilizing effect on the spinal segment, they can ultimately interfere with adjacent neural structures. As the disc space collapses, the neural foramen can narrow and impinge nerve roots, resulting clinically in radicular symptoms. The facets can hypertrophy and the ligamentum flavum can thicken in response to degenerative changes. With further collapse of the disc space, the ligamentum can buckle on itself and exert pressure on the dural sac. Central compression of neural elements can lead to debilitating myelopathy in the cervical spine and neurogenic claudication in the lumbar spine.

Lumbar spine degeneration

A multitude of factors such as repetitive mechanical stresses, micro- or macrotrauma, and changes in metabolism, cellular nutrition, and biochemical composition lead to alterations in the integrity of the intervertebral disc. The intervertebral discs in the lumbar spine are particularly susceptible to the process of disc degeneration (Fig. 2).

An investigation of 600 lumbar intervertebral discs found a correlation between degeneration and disc levels subjected to higher mechanical stresses [25]. Intervertebral discs in male subjects were found to have more degenerative changes than interverte-

bral discs in female subjects at corresponding ages. The investigators suggested that a longer avascular pathway for nutrition could contribute to this finding [25]. Degeneration of the lumbar intervertebral disc can manifest as loss of disc height, alterations in segmental biomechanics, and neural compromise.

The innervation of the lumbar intervertebral disc appears to be anatomically limited to the outer anulus fibrosus. Immunohistochemical studies have shown that nerve endings in the normal human lumbar intervertebral disc are found to penetrate only a few millimeters into the outer anulus [16,18]. With progressive degeneration, however, increased numbers of nerve fibers are found in the inner portions of the intervertebral discs [16]. These nerve fibers have been shown to be positive for immunohistochemical staining for the pain neurotransmitter known as substance P [16,18]. Inflammation and the subsequent cascade of cytokines can lead to stimulation of pain fibers in the disc and in other components of the functional spine unit [26].

Changes in the anulus can alter its structural integrity and eventually lead to herniation of the nucleus pulposus. Abnormalities in disc composition and structure, however, are common incidental findings and do not necessarily result in symptoms such as low back pain and sciatica. An MRI lumbar study of 98 asymptomatic subjects revealed that 52% of individuals had a one-level disc bulge, 27% of individuals had a disc protrusion, and 1% of individuals had a disc extrusion [22]. Similarly, other reports have suggested that positive findings on MRI do not necessarily correlate with low back pain and that degenerative changes may indeed be present in MRI scans of asymptomatic individuals [27–31].

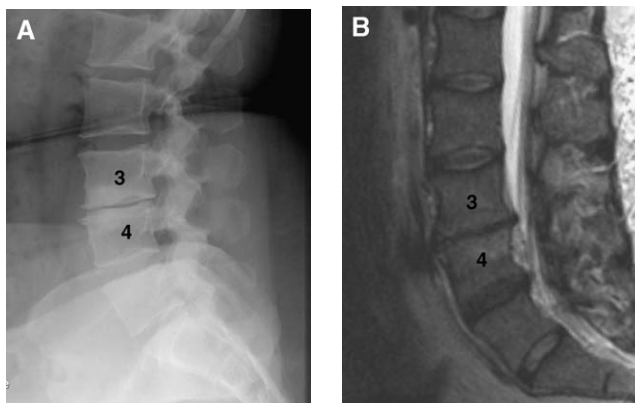


Fig. 2. Lateral radiograph (A) and T2-weighted MRI (B) of an individual with intervertebral disc space collapse, end plate sclerosis, and osteophytes between the third and fourth lumbar vertebrae.

Cervical spine degeneration

Although degeneration of the cervical spine occurs as normal age-related changes, notable differences in the anatomy and loading characteristics between cervical and lumbar spines result in differences in the pattern of involvement, rate of degeneration, and clinical presentation. Similar to its function in the lumbar spine, the intervertebral discs in the cervical spine function to provide stability, facilitate movement, absorb shock, and separate the vertebral bodies and intervertebral foramen of the cervical spine. Unlike the lumbar spine, however, the cervical intervertebral discs experience significantly less axial loads over time. Whereas the lumbar spine supports the loads produced by an individual's head, neck, arms, and trunk, the cervical spine is responsible only for supporting the load of an individual's head.

Anatomically, the cervical spine is also characterized by the presence of uncovertebral joints [32]. The joints of Luschka contain fibrocartilage that can narrow and form osteophytes during the course of degeneration (Fig. 3). Although the uncovertebral joints are less than one third of the normal disc height, they are able to bear some of the axial loads imparted to the cervical spine, thereby decreasing the overall loads placed on the intervertebral discs [33]. These factors help to make the clinical entity of cervical disc herniations rare in individuals younger than 30 years and more common later, during the fifth and sixth decades of life.

Although the presence of cervical spondylosis can manifest symptomatically as neck pain, upper extremity radiculopathy, or myelopathy, most age-related degenerative changes remain asymptomatic [34]. Similar to lumbar spine MRI studies in asymptomatic individuals, a prospective investigation of

cervical spine MRI scans revealed abnormalities in 19% of asymptomatic subjects [34]. These findings suggest that MRI changes normally considered signs of cervical spondylosis (eg, degenerative discs, osteophytes, disc-space narrowing, foraminal stenosis, and cord impingement) can occur in individuals who are symptom-free. Furthermore, the prevalence of abnormalities in individuals who were older than 40 years (28%) was twice the prevalence of abnormalities in individuals less than 40 years old (14%), indicating that these abnormal changes become more prevalent with increasing age, even in asymptomatic individuals.

The clinical presentation of symptomatic cervical spondylosis is largely dependent on the anatomic location of the pathology. Cervical degeneration without nerve root or cord impingement may result in neck pain without radicular or myelopathic involvement. Anatomic studies have confirmed that the intervertebral disc in the cervical spine is innervated by the sinuvertebral nerve, a branch of the ventral nerve root [35]. Branches of the nerve innervate the outer layers of the annulus fibrosus, the posterior longitudinal ligament, the vertebral periosteum, and even the cervical pedicle.

Impingement or inflammation of the cervical nerve roots from a soft tissue or bony source usually manifests as occipital, posterior neck, shoulder, or upper-extremity radicular symptoms. Radicular manifestation of pain in a dermatomal or myotomal pattern can be provoked by direct mechanical compression or radiculitis in which proteoglycans and phospholipases from a herniated nucleus pulposus mediate a biochemical inflammation. Reproducible patterns of pain have been generated by performing cervical discography at different cervical intervertebral levels [36]. Similar studies that investigated the pain patterns produced by zygapophyseal joint injections also suggest that reproducible patterns of pain can be elicited and then blocked by selectively injecting facet joints and dorsal primary rami at different cervical levels [37–39].

Cervical myelopathy with associated lower-extremity gait disturbances, loss of upper-extremity fine motor control, and bowel/bladder dysfunction usually results from direct spinal cord compression [40]. Degenerative changes in the intervertebral disc space that can result in cord compromise most commonly occur at the C5-6 level, followed by the C6-7 and C4-5 levels (Fig. 4). Anteriorly, the cord is most often compromised by soft disc herniations, end plate osteophytes, and ossification of the posterior longitudinal ligaments. Posteriorly, cord compression typically occurs as a result of facet joint hypertrophy



Fig. 3. Oblique cervical spine radiograph demonstrates C3-4 foraminal stenosis resulting from uncovertebral osteophyte impingement.



Fig. 4. Cervical T2-weighted MRI reveals herniated discs with cord impingement at C4-5 and C5-6.

and buckling of the ligamentum flavum. Perhaps the most important determinant of symptomatic manifestation of myelopathy is the space available for the spinal cord. Degenerative changes in the cervical spine can lead to an overall decrease in this space (Fig. 5). An investigation of 100 consecutive surgical patients with cervical disc herniations revealed that the spinal canal sagittal diameters and cross-sectional areas in patients with motor disturbances were significantly smaller than in asymptomatic healthy controls [41]. Progressive narrowing of the spinal canal with resultant compression of the spinal cord can eventually lead to worsening disability and deterioration of normal function [42].

Treatment of degenerative disorders

Conservative treatment remains the standard of care in the symptomatic treatment of degenerative disc disease [43]. Modalities including nonsteroidal anti-inflammatory medications, analgesics, short-term bed rest, physical therapy, heat, electrical therapy, and lifestyle modifications represent some of the mainstays in the management of lumbar and cervical spinal degeneration. Spinal injections (including epidural, selective nerve root, and facet joint injections) can serve dual diagnostic and therapeutic roles [44–47]. As diagnostic tools, selective nerve root and facet joint injections can often accurately identify the precise symptomatic level, help confirm a suspected diagnosis, and allow the clinician to design a more focused and individualized treatment approach. As therapeutic modalities, injections can provide symptomatic relief and a pain-free window to allow for more aggressive physiotherapy.

Although controversial as a diagnostic test, provocative discography is often employed as technique to identify symptomatic disc levels [48]. It is often cited as the only procedure that can determine whether a specific disc is the true generator of pain. After localization into the nucleus pulposus, contrast dye is injected to assess internal disc morphology and to provoke a pain response. Discography may be a useful diagnostic procedure in symptomatic patients who have no definitive diagnostic imaging studies or when clinical symptoms require radiologic correlation [49]. If concordant pain is elicited on discographic evaluation, the level in question may be amenable to surgical intervention.

When conservative measures fail, surgical options have traditionally included decompression of neural elements and arthrodesis of painful, diseased spinal segments or surgical excision of diseased intervertebral discs with their associated nociceptors [50]. In the lumbar spine, multiple surgical options are available in the surgeon's armamentarium, including central/foraminal decompression, posterolateral fusion, posterior lumbar interbody fusion, transforaminal lumbar interbody fusion, and anterior lumbar interbody fusion. The decision to include spinal instrumentation must be based on factors such as deformity correction and stabilization before fusion consolidation and must be made at the discretion of the operating surgeon.

In the cervical spine, anterior and posterior approaches have been successfully implemented in the treatment of degenerative disorders. The specific approach and surgical treatment must cater to the specific nature and location of each patient's own cervical pathology. Historically, however, cervical spondylotic radiculopathy and myelopathy have most commonly

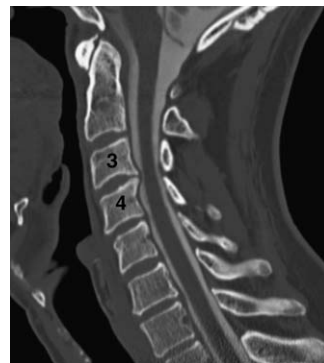


Fig. 5. Sagittal CT reconstruction of the cervical spine confirms central stenosis from end plate osteophytes with a notable decrease in the space available for the spinal cord at the C3-4 level.

been successfully treated with anterior cervical decompression and arthrodesis [51,52]. Discectomy, neural decompression, and segmental arthrodesis, with attention to careful end plate preparation, have become the mainstays in the surgical management of degenerative disc disease and spondylosis [53].

The future of degenerative disc treatment includes newly developed strategies aimed at preventing degenerative disc disease or regenerating degenerated discs [5,54]. Spinal arthroplasty (including intervertebral disc and facet joint replacement) is a novel surgical alternative with the potential benefit of relieving back and neck pain while maintaining segmental motion [50].

Summary

The etiology of symptom manifestation in lumbar and cervical spine degeneration is multifactorial and includes cellular, biochemical, and biomechanical causes. Accurate identification of pain generators in the degenerative spine can be challenging. After a diagnosis is made, however, treatment measures must address the patient's pain, neurologic function, and spinal stability. The clinician must understand that degenerative disorders in the spine are normal, age-related phenomena and largely asymptomatic in most cases. Conservative management of lumbar and cervical spondylosis is the mainstay of treatment, and most patients with symptomatic degenerative changes respond appropriately with nonsurgical management. Only when conservative measures have failed can surgical intervention be considered an appropriate and viable option. Treatment options should always be directed toward the specific nature and location of the patient's individual pathology. Although current standards in the surgical management of lumbar and cervical degenerative disorders include discectomy, neural decompression, and instrumented spinal arthrodesis, new approaches that address this often-challenging clinical entity are on the horizon.

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