CHAPTER 77

The Lumbar Degenerative Disc

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INTRODUCTION AND EPIDEMIOLOGY

Lumbar degenerative disc disease is an ubiquitous process that occurs in most humans. In this chapter, the degenerative disc process will be outlined, discussing pathoanatomy, biochemical findings, radiographic correlations, and clinical correlations.

Low back pain is a pervasive symptom, affecting the majority of the adult population at some point in life. Despite the high prevalence of this disorder, the etiology remains controversial. The main diagnostic challenge lies in identification of the pain generator. It has been shown that the intervertebral disc is capable of acting as a pain generator, and degenerative discs are believed to be involved in the pathogenesis of low back pain. Degeneration of the intervertebral discs is common among patients with disc-related pain, and it has been suggested that degeneration of the disc is a prerequisite for disc herniation.[1] The L4–5 and L5–S1 levels are most frequently affected and usually show degenerative changes earlier than upper lumbar segments. This correlates with the higher incidence of pain in these distributions.

Intervertebral disc degeneration increases with age, and is present radiographically in nearly all spines by age 50.[2–4] In fact, the intervertebral disc shows degenerative changes earlier than other cartilaginous structures. In a radiographic study of people aged 55–64 years, 83% of men and 72% of women showed disc degeneration. Many studies have confirmed the association of age and radiographic disc degeneration. Although radiographic changes are evident, the clinical significance of these changes is unclear. Symptoms and physical examination findings frequently do not correlate with the appearance of the intervertebral disc. This complicates not only diagnosis, but also treatment. Because the distribution of the patient's pain may not correspond to the main site of radiographic pathology, targeting a particular level for intervention may be difficult. This discrepancy between the radiographic abnormality and the 'real pain generator' may account for the variable effectiveness of specific treatments directed toward degenerative discs. In addition, surgical outcomes are often less than expected, based on anatomic preoperative findings.[5] Nevertheless, the increased incidence of degenerative changes and low back pain with aging suggests an important role for disc degeneration in the pathogenesis of low back pain. The question that remains is which changes are related to normal aging and which changes represent pathologic degeneration.

THE DISC AS PAIN GENERATOR

The belief that the intervertebral disc itself could be a potential pain generator originated in 1947 when Inman showed that the disc had its own nerve supply.[6] Subsequent studies then reported that there were no nerve endings within the disc[7,8] and, consequently, a debate emerged as to whether the disc itself could be painful. This controversy was resolved with the findings published by Malinsky and others demonstrating a variety of free and complex nerve endings within the outer third of the anulus fibrosus.[9–11] Currently, it is believed that the disc is innervated and therefore can act as a source of pain.

According to Bogduk, the current data regarding the pathology of disc pain, though incomplete, leads to three distinct diagnoses. These include discitis, torsion injuries, and internal disc disruption.[12] Discitis, an infection of the disc, is associated with extreme pain. While this diagnosis is rare, its existence demonstrates that pain can arise from isolated pathology in the disc itself. Discitis can be identified with elevated serum chemistries such as sedimentation rate and C-reactive protein[13] as well as imaging including bone scan and magnetic resonance imaging (MRI) with and without contrast.[14]

The second diagnosis, torsion injury, remains a clinical diagnosis. The underlying mechanism involves forcible rotation of the intervertebral joint, resulting in disc torsion and lateral shear which together lead to painful circumferential tears in the outer anulus. Coupled with flexion which stresses the anulus, torsion can lead to even greater injury. While a patient may present with a similar mechanism of injury and exacerbation of pain with flexion and rotation, confirmation of this diagnosis cannot be made with any current imaging because the nucleus pulposus is not involved. However, with advances in imaging it may become a more concrete entity in the future.[12]

Finally, internal disc disruption (IDD), the third diagnosis accounting for discogenic pain, is believed to be the most common cause of disc-mediated chronic low back pain that can be confirmed objectively. Here, compression of the disc is hypothesized to result in vertebral endplate fracture which may alter nuclear homeostasis. Degradation of the nucleus pulposus ensues and, over time, extends peripherally to the anulus fibrosus creating radial fissures. Pain is proposed to occur via chemical and mechanical stimulation of nerve fibers in the outer third of the anulus. As opposed to the clinical diagnosis of torsion injury, IDD cannot be diagnosed by history and physical examination; however, it can be demonstrated with specific radiographic and interventional techniques. While MRI may demonstrate high-intensity signal in the anulus (see below), the current diagnostic criteria for IDD include disc stimulation reproducing pain and postdiscography CT revealing a grade 3 or greater annular fissure[12]

In summary, several studies have proven that discs are in fact innervated. The specific finding of nerve fibers within the outer third of the anulus fibrosus leads to the belief that the disc has the potential to create pain. Whether it is discitis, torsion injury, or internal disc disruption, the disc has proven to be a common cause of back pain.

THE DEGENERATIVE CASCADE: DYSFUNCTION, INSTABILITY, AND STABILITY

In order to understand the progression from an anatomically normal spine to a painful, degenerative spine, it is useful to walk through this process step by step as a person ages (Fig. 77.1). Kirkaldy-Willis coined the term 'degenerative cascade' to describe changes that occur over time consequent to recurrent compressive forces coupled with lumbar spinal flexion, extension, axial rotation, and side bending. This process can be conceptualized as occurring in three phases: the dysfunctional phase, the unstable phase, and the stabilization phase. In considering these phases, it is important to recall the notion of three-joint complex proffered by Kirkaldy-Willis, which refers to the functional unit at each spinal level comprised of the disc and the two zygapophyseal joints. Because the three joints at a given level are interconnected, forces and anatomic changes occurring in one component not only affect its function, but also affect the function of the other two components.[15]

The first phase, dysfunction, refers to the abnormal functioning of the components of the three-joint complex. A patient typically presents with an acute to subacute history of low back pain following a minor episode of trauma or unusual activity. The pain is usually localized to a specific area on one side of the low back; while the pain may refer, it rarely does so below the knee. Movement tends to make the pain worse, while rest makes it better. On examination, spinal muscles may be tender and spastic at that level. Testing of spinal range of motion may reveal painful, decreased movement in all planes, especially with extension and lateral bending. The patient's neurologic examination is usually normal[15] Radiographs are normal for the most part or reveal only very mild abnormalities, such as misaligned spinous processes, irregular facets, early disc height changes, and asymmetric decreased movement on lateral bending views. MRI findings may show early disc desiccation with decreased signal within the nucleus pulposus and annular changes. Early zygapophyseal joint synovial changes may be noted on T2-weighted imaging.[16] The mechanism underlying this phase involves minor trauma or unusual activity resulting in small tears in the zygapophyseal joint capsule and anulus; this damage leads to minor zygapophyseal joint subluxation and synovitis. In order to minimize the subluxation and protect the joint, the posterior segmental muscles contract continuously, become locally ischemic, and thereby create pain. Early on, these changes are minor and may even be reversible with simple conservative measures. However, with each traumatic episode, healing of the tears is not as complete as before. As a result, the patient is likely to progress to the second phase.[15]

The unstable phase, the second phase of the degenerative cascade, is labeled as such because of the abnormal movement present in the three-joint complex. The patient presents either with or without an inciting episode of minor trauma or unusual activity. Characteristic symptoms include back pain similar to that of the severe dysfunction phase, sometimes with the sensation of giving way or 'catching' in the back upon rising from a forward flexed position. Pain may be experienced with transitional movements such as from prolonged sitting to standing transfer or from prolonged standing to the sitting position. Examination may reveal abnormal movement between adjacent spinal levels at rest or during range of motion testing. As the patient comes to a standing position after bending forward, a 'catch' or lean towards one side may be appreciated. On lateral bending radiographs, successive vertebrae may appear to be laterally shifted, rotated, or abnormally tilted. On oblique films, facets may be open and misaligned. Flexion and extension films may reveal translation, increased foraminal narrowing, abnormal disc opening, and abrupt change in interpedicular height. The mechanism in this phase involves further trauma and/or continuing stress leading to increased dysfunction in the disc and zygapophyseal joints. In the disc, small fissures will form within the anulus. As the fissures unite, concentric tears appear parallel to the circular-shaped annular lamellae. Additional concentric tears occurring at different depths of the anulus enable these concentric tears to coalesce together to form radial tears perpendicular to the annular lamellae. Depending on the location and severity of these tears, this may manifest in internal disruption, annular bulging, or loss of nucleus pulposus material into the subannular space, extra-annular but subposterior longitudinal ligament, or even beyond the posterior longitudinal ligament.[16] Rauschning's cryoplane anatomic analysis of 83 degenerated frozen human cadaver lumbar spines nicely details these degenerative findings in the disc. He found clefts through the anulus on the periphery, with the lamellae frequently detached from the apophyseal rim and the vertebral body periosteum. Sometimes these fissures were filled with granulation tissue and small blood vessels dividing the more peripheral layers of the lamellae. With internal disc disruption, a 1–2 mm thick darkened 'annular capsule' was identified in the outermost layer of the anulus. This caused circumferential bulging and occlusion of the retrodiscal space[17] Increased concentrations of inflammatory mediators and proteolytic enzymes have been found in association with annular tears. In addition, annular tears may subject the previously immunoprotected nucleus pulposus to autoimmune attack, resulting in further inflammation and chemically mediated pain.[18–20] Regarding the zygapophyseal joint, the intra-articular facet cartilage degenerates leading to attenuation and then laxity of the capsule. Recurrent inflammation and effusions occur within a weakened joint capsule. Synovial fluid-filled cysts, or outpouchings, can form, extending into the nearby neural canal causing radicular pain.[21–23] Small rents in the weakened facet capsule may represent one avenue of inflammatory synovial fluid leaking into the neural foramen, causing radicular symptoms as a result of chemical spinal nerve irritation.[17] As the zygapophyseal joint experiences this laxity, the articular processes progressively override, causing subluxation of the joint[24] and intervertebral disc narrowing accompanied with buckling or infolding of the ligamentum flavum[17] The ligamentum flavum can form cysts,[25] fray, partially rupture, and ossify. Even though it does not represent hypertrophy of tissue, this buckling or redundancy of tissue is frequently referred to as 'ligamentum flavum hypertrophy,' which is a term that may not actually reflect the pathologic process.[17]

This degeneration further compromises the three-joint complex leading to increased instability. Krismer's demonstration that fissured discs have increased axial rotation and lateral translation after torque supports this observation.[26] During this phase, microinstability occurs at a specific segment, increases stresses and loads in the zygapophyseal joint and disc complex. Further overload of these structures contributes to further annular tearing which frequently culminates in a path through the lamellae of the anulus fibrosus through which the nucleus pulposus can pass. It is at this point that a disc protrusion develops. This mass effect of the protruding anulus extends into the lumbar vertebral canal, the lateral recess, or more rarely, the foramen. Traversing nerve roots can be chemically irritated and/or mechanically compressed, causing radicular leg symptoms. As the protruding disc resorbs spontaneously or is iatrogenically removed with a surgical procedure, leg symptoms will commonly abate. The disc, however, is still left with a weakened anulus with compromised structural integrity accompanied with disc space narrowing. This newly weakened anulus in combination with laxity of the two zygapophyseal joint capsules creates a relatively unstable segment. The vertebral bodies just above and below this segment may shift and supercede the prior physiologic anterior–posterior translation, axial rotation, and/or flexion–extension bending. Thus, this superphysiologic motion creates instability at the segment in question, sometimes

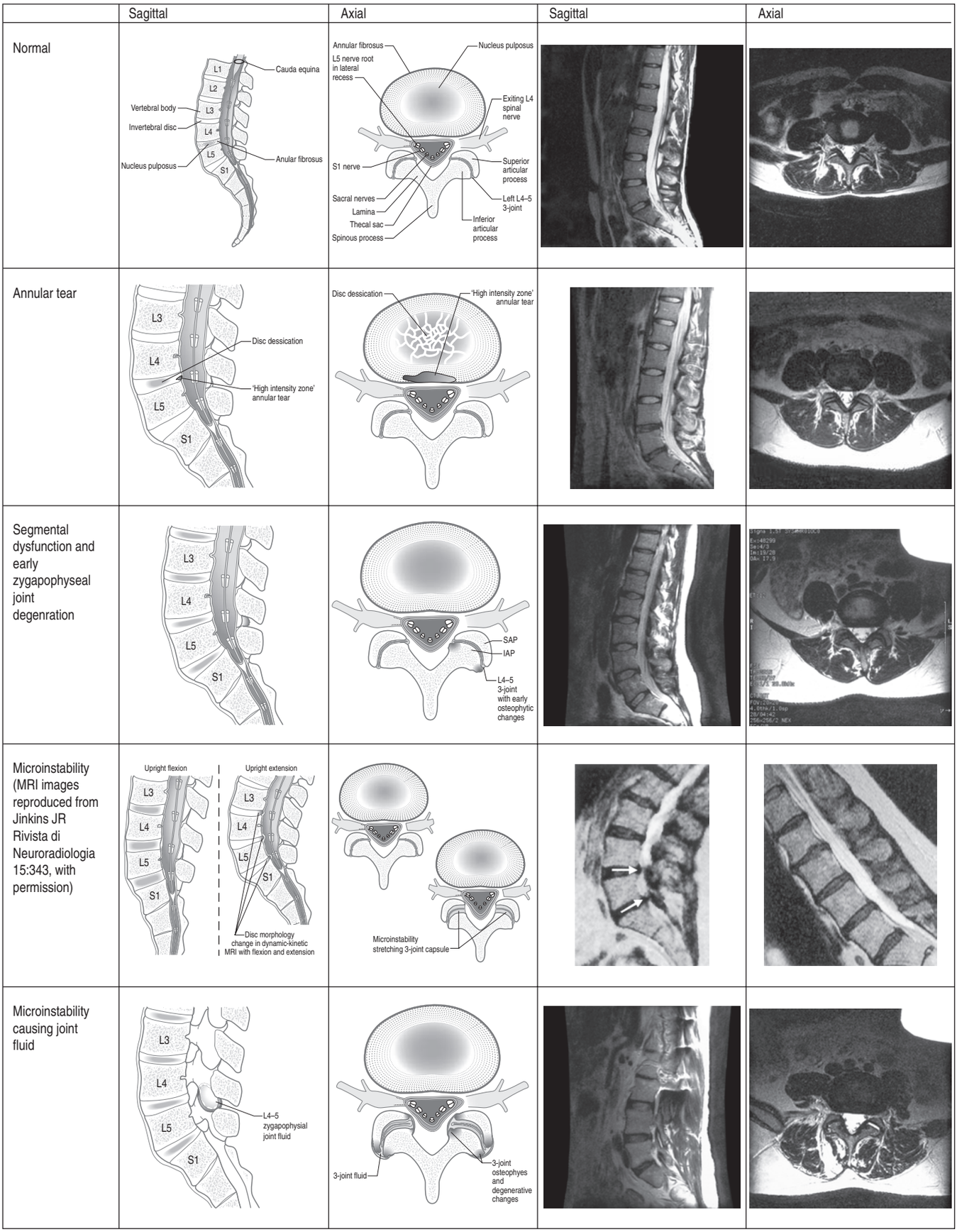
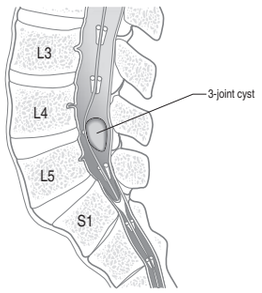
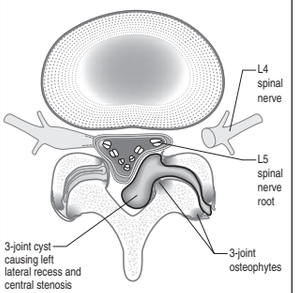
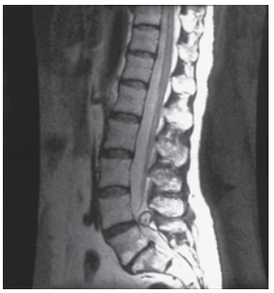
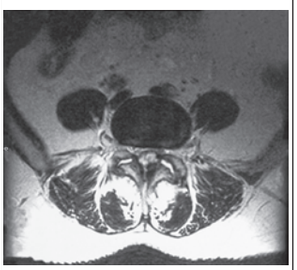
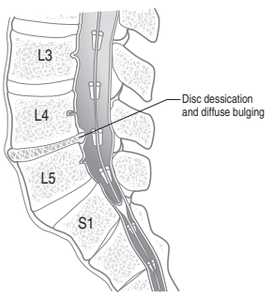
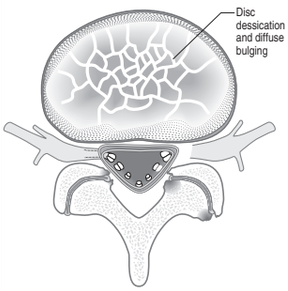
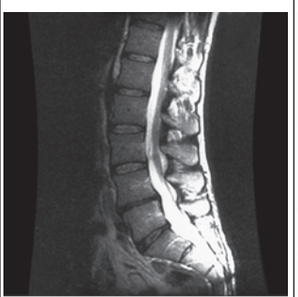
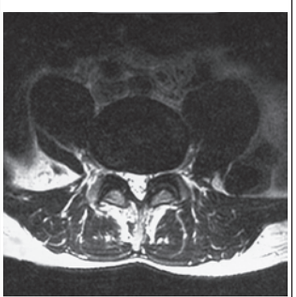
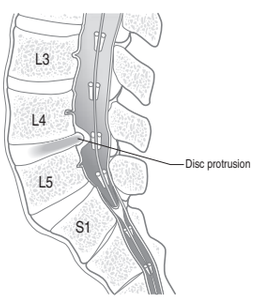
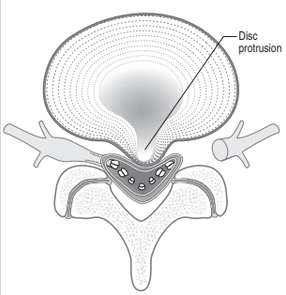
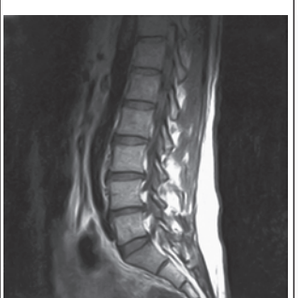
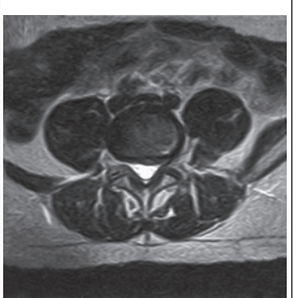
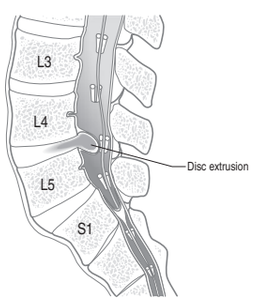
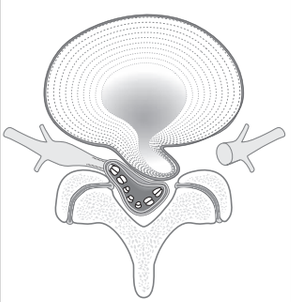
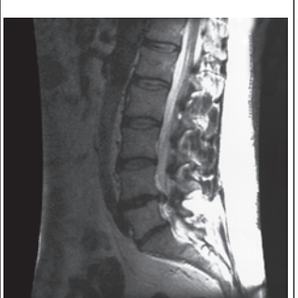
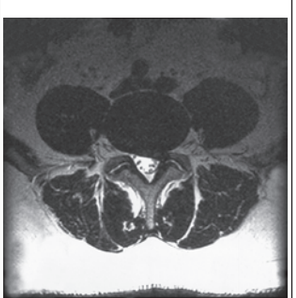
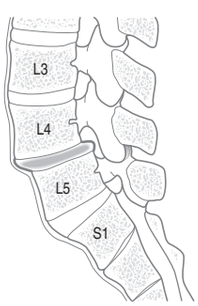
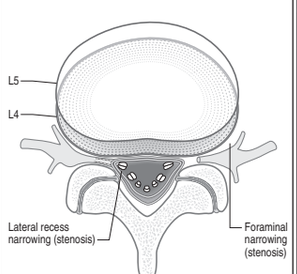
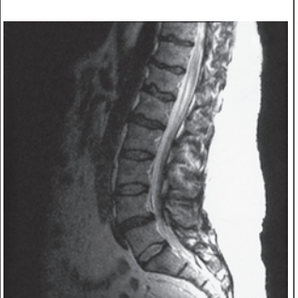
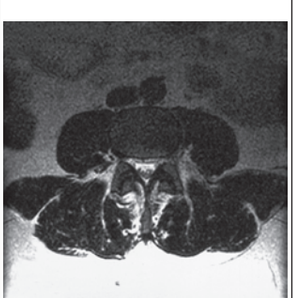


Fig. 77.1 The degeneration of the L4–5 segment (Part d [MRI scans]. From Jinkins JR, Rivista di Neuroradiologia 2002; 15:343 figures d and c.[139])

	Sagittal	Axial	Sagittal	Axial
Joint cyst causing left L5 lateral recess stenosis, central stenosis and left radiolar symptoms				
Diffuse disc bulging and disc dessication				
Disc protrusion				
Disc Extension				
L5 degenerative spondylolisthesis				

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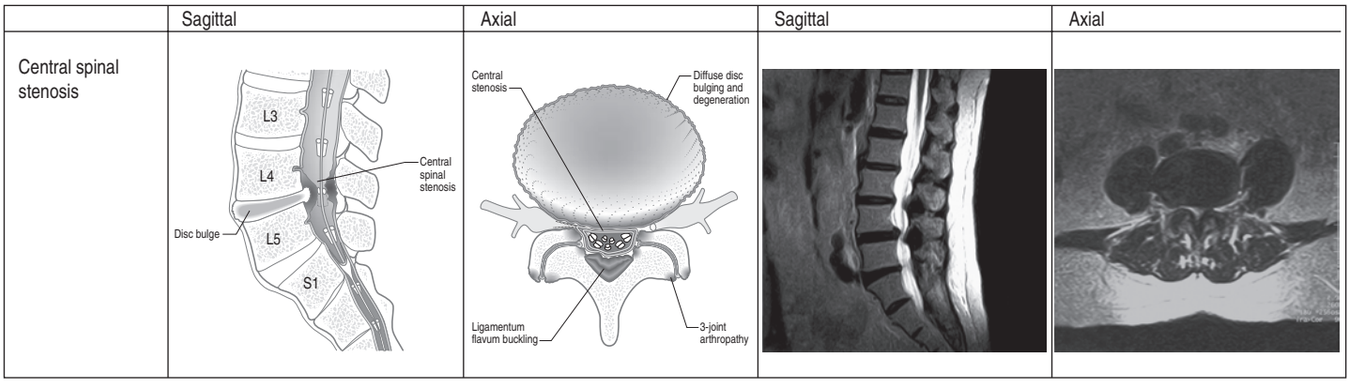

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causing degenerative spondylolisthesis. Degenerative spondylolisthesis most frequently occurs at the L4–5 segment, commonly accompanied with vertebral canal, lateral recess, and foraminal narrowing with the shifted vertebral bodies[16] Over time, with repetitive loading and progression of laxity and instability, the bone responds with osteophyte formation and may ultimately reach the third phase of the degenerative cascade as described below.

The previously unstable spine becomes increasingly stiff in the stabilization phase, the third stage of the degenerative cascade. A patient may present with a long history of axial low back pain now with predominating leg pain. During the examination, range of motion is typically reduced in all directions, particularly with extension. There may also be tenderness over the paraspinal musculature as well as scoliotic curves. Notably, sustained lumbar extension may elicit radicular signs. Radiographs typically show uni- or multilevel spondylosis including hypertrophic osteophytic zygapophyseal joints, significant loss of disc height, extensive vertebral body osteophytes, narrowed foramina, and degenerative scoliosis. Reduced movement may also be present on lateral bending or flexion and extension films. During the mechanism of 'stabilization' further changes in the zygapophyseal joint and the disc are observed. In the zygapophyseal joint, cartilage destruction leads to joint fibrosis and enlargement, locking facets, and finally periarticular fibrosis. Concurrently, in the disc, nuclear loss leads to vertebral body approximation, endplate destruction, disc fibrosis, and finally osteophyte formation identified at the vertebral body ring apophysis. Circumferential osteophytic ridges form posterolaterally around extending laterally and anteriorly. These vertebral body rims consistently appear sclerotic, peaking posteriorly and lipping up superiorly at the tip, thus creating deep, oblique grooves.[17] Osteophyte formation from the inferior articular process contributes to vertebral canal stenosis and osteophyte formation extending from the superior articular process can contribute to narrowing of the neural foramen.[27] The combination of disc height loss and bulging, ligamentum flavum buckling, and zygapophyseal joint osteophytic changes all combine to narrow the central spinal canal,[28] the lateral recesses,[29,30] and the neural foramina, compressing the traversing nerve and creating dynamic radicular leg pain. The end result of all of these changes is increased stiffness of the spine, eventually culminating in near-complete spondylosis and 'autofusion.'

While it is tempting to make clear separations between each of the three phases of the degenerative cascade, the lines of distinction are in fact blurred. Thus, over a person's lifetime, the spine transitions from excellent flexibility and disc hydration and pliability as a teenager moving to intermittent episodes of low back pain and muscle spasm as a young adult. This reflects the initial phase of the degenerative cascade, the dysfunctional phase. The patient usually experiences the instability phase next. These intermittent flares of axial low back pain lasting several days start to become more frequent, with episodes lasting for longer periods of time, reflecting progressive intervertebral disc annular tears. As the intervertebral disc anulus weakens and disc protrusions and extrusions develop, the patient has episodes of axial low back pain and/or leg pain usually lasting several weeks to months. With progression of osteophyte formation, the patient transitions from middle adulthood into late adulthood with the stability phase. Constant axial low back pain may become less constant as the spine autofuses, with some patients noting that their back pain has just melted away. If significant stenosis has developed as a result of this stabilizing spondylotic process, intermittent episodes of radicular pain may occur. In addition, while a patient has a tendency over time to sequentially pass from dysfunction to the unstable phase and then to stabilization, this might not always be the case. For example, one patient may bypass the second phase and pass directly from dysfunction to stabilization, while another may pass back from the unstable phase to dysfunction, perhaps as a result of treatment. Finally, one must keep in mind that different levels may predominate at adjacent spinal levels.

In summary, people of all ages may present with low back pain and spine pathology; an individual assessment at each episode will help guide noninterventional and interventional treatment algorithms to maintain patient function. Frequently, by communicating the natural history of spinal aging, the clinician can allay some of the patient's fears and provide hope for maintained age-appropriate function.

PREDISPOSING ANATOMY AND ACTIVITIES

The intervertebral disc is subjected to significant load during normal daily activities. Standing erect places approximately 500 N of compressive force on the spine, with an additional 1500 N caused by bending forward to lift 10 kg.[31] Loading of the spine results in decreased disc height. Similarly, with enough force applied, traction has reproducibly been shown to increase the intervertebral height; however, consistent clinical effectiveness of lumbar traction has not been shown. Approximately 1.13% of body height is lost through normal daily activity, and this difference increases with advancing age and increasing body weight. The ability of the nucleus to displace under asymmetrical loading decreases with age,[32] and traction can cause more intervertebral height in younger individuals. It appears that compressive forces contribute to disc degeneration, and the altered physical response of the aged disc may facilitate this response.

The clinical correlate to these observed changes resulting from load lies in the findings of increased incidence of disc degeneration among persons involved in heavy physical work.[33–35] It has been shown that benign spine pathology is associated with moderate work levels, while painful spine pathology correlated to the highest and lowest degrees of physical activity.[36] Other studies have shown earlier onset of disc degeneration in men than women, possibly a result of men being more commonly involved in occupations involving heavy manual labor. Because compressive forces applied to the disc cause biomechanical changes, it would be expected that obesity, with the resulting increased load, would be involved in the acceleration of degenerative discs. However, studies on the effects of obesity on the prevalence and severity of degenerative discs have yielded conflicting results.[34–38]

Further evidence for excessive load as causative of disc degeneration is found in examination of persons involved in athletics. A small study of elite athletes demonstrated more severe disc degeneration than nonathletes, which was most commonly observed at the L5–S1 level. However, evaluation of elite athletes revealed no increased incidence of low back pain,[39] again raising the question of the clinical significance of radiographic findings. The extreme physical loading experienced with weight lifting has been shown to correlate with only about 10% of the disc degeneration found.[40] A study of elite gymnasts showed an increased incidence of radiographic disc degeneration (75%) compared to nonathletes (31%), and was able to demonstrate a correlation with back pain.[41] At the opposite end of the spectrum, a sedentary life style and occupations such as motor vehicle driving have shown an increased incidence of disc degeneration.[42] There is evidence to show that exercise can be beneficial in the treatment of low back pain.[43–49] It is believed that this beneficial effect is primarily through early activation after onset of pain, maintenance of aerobic exercise, directional preference exercises, and possibly increased strength of the muscular corset surrounding the spine. The types of forces that are destructive and result in pathology versus those which facilitate repair and protection of the disc from further damage remain unknown.

Altered forces may also be created by the spinal anatomy. Spinal disorders such as spondylolisthesis and scoliosis have been associated with an increased incidence of degenerative disc disease.[50] This effect is most likely a result of abnormal forces imposed on the disc by the altered anatomy. In addition, excessive motion of an unstable bony framework results in internal disc disruption, tears, and annular bulging. This corresponds to the instability phase, the second phase of the degenerative cascade.[15] Spine anomalies such as 'transitional vertebra' can lead to a similar alteration in biomechanical forces in the spine, thus affecting disc degeneration. To keep nomenclature consistent, especially for interventional procedures, effort should be made to label transitional vertebra as a sacralized lumbar segment or a lumbarized first sacral segment. In order to do this, the spinal segments should be labeled by counting down from the cranium and/or the ribs. The prevalence of transitional vertebra has been noted to be 7–30%, depending on the groups sampled and the criteria and methods used. Luoma studied a group of men without active complaints of low back pain. There were 138 working men (age range of 40–45) and 25 others aged 18–20 years. On MRI, transitional vertebrae were found 30% of the time with increased frequency of degenerative changes in the disc above the transitional segment among the younger men. In the middle-aged men there was decreased risk of degenerative changes in the disc below the transitional vertebra, presumably lending a protective effect on the lower disc. Interestingly, in this group of volunteers, when questioned about their low back pain history over the previous 4 years, there was no association of increased low back pain in those individuals with a transitional vertebra.[51] Bertolotti's syndrome depicts low back pain in association with an anomalous transitional lumbosacral segment. Elster revisited Bertolotti's syndrome in a study of radiographic findings in 2000 patients with back pain who had lumbar spine X-rays and computed tomography (CT) or MRI scans. Transitional segments were found in 7% of subjects, who had disc pathology at the level immediately above the transitional segment nine times more often. Stenosis was also noted at an increased rate at the level above. Again, disc preservation at the level immediately below was observed.[52] The hypothesized reason that early disc degeneration occurs at the segment above the transitional level is that the more motion is forced in the segment immediately adjacent to the fixed segment, concentrating torsional biomechanical stresses. By the same token, postsurgical fusion is frequently associated with hastened adjacent level disc degeneration.[53]

In addition to the mechanical effects of load, compressive, torsional, and strain forces have been demonstrated to alter the biosynthetic activity of intervertebral discs.[54] This may contribute to early degenerative changes through alterations in the supporting matrix. Clinically, flexion and torsional stress have been identified as risk factors for degenerative disc disease.[42,55]

Torsional stresses on the lumbar discs can be magnified by relative inflexibilities or weakness of parts of the body above and below the lumbar spine. If a hip joint capsule is relatively tight and restricts internal rotation during a functional activity such as walking, this requires segments above to accommodate the need for the pelvis to rotate in the transverse plane. If the pelvis cannot get the necessary axial motion to get proper pelvic rotation from the hip, the next joint complex to be asked for rotational motion will be the lumbar spine. Thus, increased rotational forces could develop in the lumbar discs and zygapophyseal joints. By the same token, it is easy to see how a transverse plane dominant activity such as golf and racket sports can introduce increased forces in the lumbar spine. If the hip joint and/or the thoracic spine/shoulder complex do not have the available range of motion, forces are quickly transmitted into the lumbar spine structures. Although lower limb flexibility is not a predictor of low back pain, hamstring flexibility is strongly correlated to motion in subjects with a history of low back pain.[56]

Hip joint restriction can be a contributing factor that predisposes an individual to advanced lumbar disc degeneration. Hip inflexibility can increase forces seen in the lumbar spine zygapophyseal joints and thereby be associated with lumbar disc degeneration.[57] If the iliopsoas muscle, tendon, and anterior hip joint capsule unit are restricted, this puts the pelvis in an anterior pelvic tilt. In other words, the anterior superior iliac spines are more inferior relative to the posterior superior iliac spines. In an individual with such restriction in the anterior hip structures, compensatory spinal extension must occur for a person to remain fully erect in the sagittal plane. Without this compensatory spinal extension motion, the person would have to walk looking toward the ground. These extension-type forces can increase the biomechanical stress in the zygapophyseal joints,[12] creating inflammation and laxity, and thereby creating abnormal strain forces and degeneration in the lumbar discs. Iliopsoas and anterior hip capsule flexibility again becomes an important factor in later stages of the lumbar degenerative disc cascade as the spine matures developing osteophytes that narrow the vertebral canal, lateral recesses, and the foramina. This frequently becomes problematic during spine extension as the spinal canal narrows and the traversing nerve structures are constricted.[27,58,59] When the spinal canal is already narrowed by degenerative changes, activities requiring relative lumbar extension such as walking are associated with compression on these neural structures, causing neuropathic-type radicular symptoms in one or both legs. To reduce the symptoms and the degree of flexion in the spine, the compensatory postural change is frequently to bend forward at

the waist. This compensatory posture puts the iliopsoas muscles in a shortened position. After a period of time, the hip flexors become shortened, weakened, and tight. This hip flexor tightness adds to the lumbar extension moment forces, leading to further compression of neural structures as they pass through a tightened neural canal. Therefore, assessing iliopsoas flexibility and hip joint capsule mobility is clinically important whether the patient is in the earliest or the latest stages of the lumbar degenerative cascade. Vad et al. found a significant correlation between low back pain and decreased hip internal rotation in the lead hip in professional tennis players (mean age of 25.4 years old)[60] and golfers (mean age of 30.7 years old).[61] This important kinetic chain link between the hip and the spine has also been clinically demonstrated in small case series of hip osteoarthritis and lumbar spinal stenosis. Surin reported 5 of 15 subjects who had severe spinal stenosis also had severe hip osteoarthritis; excellent results were noted in 4 patients who underwent a decompressive laminectomy followed by a total hip replacement.[62] Similarly, lumbar spinal stenosis has been associated with patients whom have undergone a hip joint replacement, but have continued leg pain. Six of 8 patients with disabling posterior buttock pain after hip arthroplasty underwent a lumbar decompressive procedure with complete relief of their symptoms.[63] McNamara reported on 14 patients with both symptomatic lumbar spinal stenosis and lower limb degenerative joint disease. Nine of the patients had persistent symptoms attributed to spinal stenosis over 9 months after joint arthroplasty, seven of whom subsequently required lumbar decompressive surgery.[64] Therefore, because of the relationship between the hip and the lumbar spine, it is important to address hip inflexibility in the rehabilitation program. Specifically, manual mobilization and functional flexibility exercises of the hip joint have been shown to decrease pain and disability in a series of patients with lumbar spinal stenosis.[65]

Not only proper flexibility of the lower limb is required to normalize lumbar spine forces, but also strength of the 'core musculature.' These core muscles include the abdominals (rectus abdominus, obliques, transversus abdominus),[66] lumbar paraspinal muscles (erector spinae, multifidi), quadratus lumborum,[67] pelvic floor muscles,[68] the diaphragm,[69] and the hip girdle musculature.[70] If these core muscles exhibit weak muscular control, this may cause excessive external loads on the disc.[57] The strength and firing patterns of the quadratus lumborum[67] and the transversus abdominis,[66] gluteus maximus, gluteus medius,[70,71] have received particular attention as important spine stabilizers in low back pain. Multifidi muscle atrophy has been associated with low back pain.[72] Pelvic floor muscles have been observed to be co-activated with the contraction of the transversus abdominis.[68] It also seems that endurance of the core muscles is even more important than strength.[73] It remains to be seen if improving core muscle strength and endurance will prevent symptomatic degenerative discs, but early data do suggest that a core muscle strengthening program trends toward decreasing the incidence of low back pain.[74,75] Core stabilization exercises for treatment of low back pain have seen some success.[47,76,77] More randomized controlled studies need be performed to further document the utility of core strengthening programs in the prevention and treatment of lumbar degenerative discs.

HISTOLOGY

The biomechanical function of the disc is determined by the structure. The histology of normal and degenerative discs has been extensively examined in attempt to provide a more thorough understanding of the structural changes which predispose the disc to mechanical failure. Changes have been observed in the anulus, nucleus, cellular layout, and protein composition of the matrix.

A normal young anulus fibrosus consists of a complex system of fibers in a circular course, with lamellae of differing thickness. The lamellae of collagen fibers run obliquely, separated by layers of ground substance. By the fifth decade, gaps and fissures are observed between the collagen fiber bundles. Fragmentation and loss of individual collagen fibers is observed by age 65, and increased appearance of chondroid tissue is present by 70 years of age.[78] Clinically, three different types of annular tears have been described. Rim lesions are tears in the periphery of the anulus, which occur more predominantly anteriorly. Concentric tears represent rupture between the collagen lamellae in a circumferential pattern. Radial tears divide the lamellae and are perpendicular to the endplate. Radial tears occur more commonly in the posterior aspect of the anulus. These annular tears may be sufficient to cause low back symptoms and certainly predispose the disc to herniation. Unfortunately, a uniform classification system has not been universally accepted for disc herniation. Disc bulging typically refers to appearance of diffuse bulging without focal prominence associated with loss of disc space. An isolated disc bulge is generally not sufficient to cause canal or foraminal stenosis unless accompanied by hypertrophic degenerative changes of the vertebral body endplates and superior articular processes or from congenitally short pedicles. Protrusion represents a focal lesion of the nucleus through a defect in the internal annular fibers. However, the nucleus remains contained within the anulus. Extrusion represents a full disruption of annular fibers through which the nucleus migrates, but communication is maintained with the parent disc. Sequestration represents complete separation of a nuclear fragment from the disc, which may migrate cranially or caudally. This fragment has separated from the disc of origin. Although it would be preferred that all clinicians follow the same 'rules' to describe disc pathology, it is even more important for a clinician to be internally consistent in the way in which he or she describes the anatomic abnormalities on MRI scan. As such, with all clinicians not adhering to the same terminology,[80] it is essential to view the actual images of each patient for whom the clinician is providing care. In the end, only the healthcare provider that has obtained a careful history and physical examination can clinically correlate properly the findings on radiographic imaging with the patient's symptoms.

Not only does the histology of the anulus change, but so do the biomechanical properties. Healthy intervertebral discs show decreasing tensile strain of the anulus fibrosus from inner to outer layers when placed under compressive loads. Compression alone, as described above, is not sufficient to cause herniation. Disc degenerative changes coupled with sagittal and transverse plane motions lead to annular tears, which allow the nucleus to herniate under load. The integrity of the annular fibers is critical to maintaining normal disc structure. In healthy discs, annular fibers are responsible for restricting axial rotation to a greater degree than facet joints.[81] However, a change in loading pattern appears to exist in degenerative disc anulus fibrosus,[82] and the mechanical properties of the anulus have been shown to change with age. The tensile behavior is related to the composition of the tissue. Therefore, increased degeneration results in altered biomechanics, which predisposes the disc to further degeneration. Further evidence for this cycle can be found in modeling studies which have demonstrated that annular tears may have a role in further accelerating degenerative changes.[83] In fact, in animal models, degenerative discs can be created which closely mimic human histology by introducing an annular laceration.[84] Further evidence for a pivotal role of the anulus is the finding that disc degeneration appears to occur before facet osteoarthritis.[85]

Changes are also observed in the character of the nucleus. The homogenous, gelatinous central disc changes to dry, fibrous tissue with advancing age. The water content of the nucleus decreases from

90% to 74% throughout the first eight decades.[32] However, this loss of water appears to be related to aging and not degeneration as it has been shown that degenerative and normal discs from the same spine have the same water content.[86] This again raises the concern over distinguishing between normal aging changes seen radiographically and true symptomatic pathology. Severely degenerative discs have also been found to contain granulation tissue and the boundary between the nucleus pulposus and anulus fibrosus becomes more diffuse, with the two tissues becoming less distinguishable. These changes are associated with loss of endplate cartilage and osteophyte formation, as well as formation of fissures and cavities in the nnulus and nucleus. A morphologic grading system has been proposed by Thompson et al. which scores degenerative discs on the basis of changes in the nucleus, anulus, endplate, and vertebral body. This system is based on the gross appearance of pathologic sections. Grade I represents a bulging nucleus, an anulus with discrete fibrous lamellae, uniformly thickened endplates, and vertebral bodies with rounded margins. Grade II has white fibrous tissue on the periphery of the nucleus, mucinous material between lamellae of the anulus, irregular endplates, and pointed margins of the vertebral body. Grade III describes a nucleus with consolidated fibrous tissue, extensive mucinous infiltration of the anulus with loss of the annular–nuclear demarcation, focal defects in endplate cartilage, and early osteophytes. Grade IV represents a nucleus with horizontal clefts, focal disruption of the anulus, irregularity and focal sclerosis of subchondral bone, and osteophytes of less than 2 mm. Finally, grade V represents clefts extending through the nucleus and anulus, diffuse sclerosis, and large osteophytes.[87]

Degeneration and aging also affect the cellular layout. Young human discs show cells within small lacunar spaces within the matrix, whereas degenerative disc specimens show cells clustered amidst decreased or architecturally modified matrix.[88] In addition, fibroblasts are the predominant cell type in young annulus, with increasing populations of chondrocytic phenotypes with advancing age.[78]

Changes have been observed at the molecular level, which helps explain the altered matrix arrangement and water content. The biochemical composition of the disc is crucial to the osmotic balance and therefore mechanical behavior of the disc.[89] The major structural proteoglycan in the intervertebral disc is aggrecan, which acts to attract water into the disc. Nucleus pulposus cells from degenerative discs show decreased expression of aggrecan, and a similar decrease in water content.[90] The collagen network creates the matrix of the disc, within which fibroblasts or chondrocytes are imbedded. Degenerative discs have a low proteoglycan to collagen ratio. Cells of the anulus fibrosus exhibit decreased collagen expression following degeneration. Whereas the growth and development phase shows active synthesis of aggrecan and procollagen type I and II, the degeneration phase is associated with increase in the denaturation of type II collagen without an increase in type II procollagen or aggrecan synthesis. Specifically, type II procollagen synthesis is decreased, and type II collagen denaturation is increased. Type I collagen expression has also been shown to increase and contribute to abnormal matrix synthesis.[91]

In addition to the changes in structural protein synthesis that occur with degeneration, the degenerative disc is also characterized by an increase in catabolic activity. Proteases capable of producing degradation of extracellular matrix are normally kept in check by tissue inhibitors. However, this balance is altered in disc degeneration, with cytokines, in particular interleukin (IL)-1, implicated in activating the active degradation process. In addition, there is a net increase in matrix degrading enzyme activity, such as matrix metalloproteinases, which act to cleave aggrecan.[92]

Compounded on the changes observed with age, the physical environment of the disc may alter the balance between matrix synthesis and breakdown. Altered metabolism of disc cells has been shown to occur in response to mechanical loads. This response may be due to changes in systemic factors, disc fluid shifts, and resultant changes in osmolality, blood flow, altered nutrition, mechanosignaling, or a combination of these factors.[93] Compressive forces in vivo in animal models have demonstrated an increase in collagen type I and decrease in proteoglycans, chondroitin sulfate, and collagen type II in the nucleus.[54] This may contribute to early degenerative changes through alteration in the supporting matrix.

In turn, these changes at the biochemical level appear to have profound impact on the mechanical behavior of the disc. The decrease in aggrecan parallels the decreased water content observed in disc degeneration, which leads to increased deformation under compressive and torsional loads. The deformation results in increased strain experienced by disc fibrochondrocytes, and may alter the synthesis and homeostasis of reparative and degenerative enzymes, leading to further disruption of the matrix. The clinical importance of changes in the matrix is underscored by the finding that the components of the matrix from discs of the same degenerative grade do not differ with lumbar level, age, or sex, suggesting that the differences are in fact a result of degeneration.[87]

The net effect of all of these changes is a cascade of degeneration. Age and degeneration result in an altered histological composition of the disc. In addition, altered biomechanics of the disc, which also occur with aging and degeneration, lead to abnormal distribution of forces and result in altered biosynthesis. In turn, these changes at the molecular level result in a decreased ability of the disc to accept normal physiologic loads and motion, further contributing to the degenerative cascade. As a result, a cycle of degeneration and maladaptive responses to stress occurs.

CHEMICAL INFLAMMATORY PROPERTIES OF THE DEGENERATIVE DISC

Mechanically compressive disc protrusions are not the only causes of radicular pain. For this reason, chemical markers from the disc have been implicated in the inflammatory response. Saal found phospholipase A_2 in human disc samples resected for lumbar degenerative disc-related radiculopathy.[94] IL-1 has been implicated in chemical radiculitis in rats.[95] Matrix metalloproteinases, nitric oxide, IL-6, and prostaglandin E_2 have also been implicated in intervertebral disc protrusions.[96,97] Glutamate has been detected in higher levels in herniated discs compared to nonherniated discs.[98] In addition, different types of disc herniations seem to have different biochemical traits. Leukotriene B_4 and thromboxane B_2 are seen in higher levels in noncontained disc herniations compared to contained disc herniations.[99] Higher concentrations of prostaglandin E_2 have been found in sequestered disc fragments and in those individuals with a positive straight leg raise.[100] Furthermore, prostaglandin E_2 seems to be upregulated by IL-1α and decreased by tumor necrosis factor-alpha and betamethasone.[101] Please see Chapter XXX by Edward Vresilovic on further details on the biology of the disc.

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MEDICAL AND GENETIC RISK FACTORS

As persons with similar anatomy and predisposing activities have differing incidence of degenerative disc disease, a number of environmental, medical, and genetic factors have been investigated as potential risk factors. In addition, there is evidence for familial trends in degenerative disc disease.[102,103] In particular, two collagen IX alleles have been associated with lumbar disc herniation,[104] as

well as aggrecan, vitamin D receptor, and matrix metalloproteinase-3 gene polymorphisms.[42] Specific vitamin D receptor alleles have also been associated with radiographic disc degeneration.[105] In a study of metalloproteinase polymorphisms, the 5A/6A polymorphism was associated with radiographically identified degenerative changes in elderly subjects, suggesting this as a possible risk factor. The study did not show any evidence of accelerated degenerative changes in young persons carrying this genotype.[106] However, a case-control study of radiographic changes did demonstrate an association of degenerative changes associated with an aggrecan allele subtype in young subjects.[107]

There is also evidence for synergistic effects of genetic and environmental factors. A cross-sectional study of the COL9A3 gene polymorphism, obesity, and the incidence of radiographic degenerative disease demonstrated that the effect of obesity on lumbar disc degeneration was modified by this polymorphism.[108] This may help to explain the inconsistencies found in studying the effect of obesity on disc degeneration as discussed above. However, most of the studies investigating genetic predispositions focused on radiographic criteria for the definition of degenerative disease, and did not assess clinical symptoms. Future studies are needed to evaluate the incidence of clinically significant, symptomatic disease among patients believed to be at increased risk.

Ischemia is believed to play an important pathogenic role in initiating disc degeneration. Decreased oxygen tension with resulting decrease in synthesis of proteoglycans and collagen may be responsible for this effect. The association of several medical conditions with increased incidence of degenerative disease further supports the role of ischemia. Calcific deposits on the posterior aortic wall, indicative of advanced aortic atherosclerosis, have been associated with increased incidence of radiographic disc degeneration as well as low back pain.[109,110] The rationale for this association comes from the fact that the feeding arteries of the lumbar spine originate from the posterior aorta, and atherosclerosis would cause decreased blood flow and ischemia of the lumbar spine. Further evidence of the deleterious effect from ischemia comes from identical twin studies that have demonstrated that smoking is associated with an 18% increased incidence of disc degeneration in the lumbar spine.[111] It has also been established that smokers are more likely to complain of back pain.[112]

Infection may also act as a precipitating factor and has clinically been associated with discogenic radiculitis. A study of 36 disc samples from patients undergoing discectomy demonstrated positive isolates of *Proprionibacterium acnes*, coagulase negative staphylococcus, or corynebacterium in 53% of samples. No isolates were recovered from control samples taken at the time of surgical fusion.[113] Therefore, this study links infectious bacteria to symptomatic discs but does not establish an association of infection with histological disc degeneration.

Interestingly, clinical associations have been noted with degenerative changes and osteoporosis.[114,115] and Scheuermann's disease.[116] The increased incidence of both degenerative disc disease and osteoporosis among sedentary individuals suggests that the effect may not be causative. Heithoff et al.[116] found degenerative lumbar discs in younger patients who also had findings of thoracolumbar Scheuermann's disease. In a group of 1419 patients referred for lumbar spine MRIs, there was an incidence of this interesting link in 9% of patients. Eighty-one percent of the subjects were younger than 40 years old and 9% under 21 years old. This association was hypothesized to be an expression of an intrinsic disc defect and/or cartilaginous endplates that compromises nutrition and results in structural weakness and early degeneration.[116] This association may represent a clinical subpopulation as opposed to a distinct pathologic mechanism.

RADIOGRAPHIC FINDINGS

The incidence of radiographic degenerative disc disease is known to increase with age. However, radiographic changes do not directly correlate with symptoms. Asymptomatic subjects show abnormal findings in the disc in 24% of lumbar myelograms, 36% of CT scans, and 38% of discograms.[117–119] In young, asymptomatic women aged 21–40, 33% showed MRI evidence of disc degeneration.[120] Boden et al. found that one-third of 67 asymptomatic subjects (average age 42, range 20–80 years old) had abnormalities on lumbar spine imaging. For subjects younger than 60 years old, 20% had herniated disc. In individuals over age 60, 57% were abnormal – 36% with a disc herniation and 21% with spinal stenosis.[121] Jensen et al. also studied MRI findings in asymptomatic individuals with 98 subjects of mean age of 42.3 years (range 20–80 years old). He noted 52% had a bulge at least at one level, 27% had a disc protrusion, 1% had a disc extrusion, 19% had a Schmorl's node, 14% had annular defects, and 8% had zygapophyseal joint arthropathy. Only 36% of discs were completely normal at all levels.[122] In a study of working males aged 20–58, 32% of asymptomatic subjects had abnormal imaging on MRI, and 47% of subjects with low back pain had normal MRI findings.[123] In addition, abnormal MRI findings in asymptomatic persons have not been shown to be predictive of development of low back pain in the future.[124] Therefore, the key is to use the imaging studies to complement the clinical picture. Clinical correlation is required to determine the significance of abnormalities observed on MRI. To this end, obtaining imaging studies too early could lead to inappropriate treatment if not used in the context of patient symptoms. If these aforementioned studies have clearly shown that lumbar discs degenerate both with and without symptoms, perhaps we should be challenged to reconsider the label of 'lumbar degenerative disc disease.' The term, 'disease' usually is used to describe a pathologic state of illness, and patients frequently become alarmed when they learn that they have acquired a new 'disease.' How can so many people be walking around without symptoms and have 'lumbar degenerative disc disease' on MRI? Therefore, as spine healthcare providers, it is necessary to be cautious in the word choice we use to describe our patients' intervertebral discs as well as the diagnoses with which we label them. Many patients can be relieved to know that the normal spine commonly changes with age in a similar manner to gray hair appearing on their head.

With this caveat, magnetic resonance imaging can be a useful tool for assessing disc degeneration. Annular bulging or tears and decreased signal intensity of the nucleus pulposus on T2-weighted images can be observed. In addition, these changes of the disc are frequently accompanied by adjacent marrow changes. Modic et al. defined these changes as types I–III, with type I representing decreased intensity on T1-weighted, increased intensity on T2-weighted, type II with increased intensity on T1-weighted and isointense signal on T2-weighted, and type III, with hypointense signal on both T1- and T2-weighted images.[125] Diurnal changes have been observed on T2-weighted MRI among younger individuals (age <0x003C>35), reflecting the alteration in water content throughout the day. This diurnal variation does not appear to be present radiographically in individuals over the age of 35 or among patients with degenerative discs,[126] consistent with the observed loss of water content in these populations.

As the saying goes, 'the bigger they are, the harder they fall,' so it goes for lumbar disc herniations. The larger the disc herniation, the more the disc tends to resorb.[127] Disc extrusions seem to have a better chance of 'shrinking' spontaneously.[94,128] Ahn et al. studied 36 subjects with a herniated disc (18 subligamentous, 14 transligamentous, and 4 sequestered). Overall, 25 of the 36 (69%) decreased

in size. The further the disc material traveled beyond the posterior longitudinal ligament, the more the material disappeared. Fifty-six percent of the subligamentous herniations, 79% of the transligamentous herniations, and 100% of the sequestered herniations decreased in size.[129] The mechanism of disc material resorption is presumably from immune system-mediated phagocytic response. This proposed mechanism is supported by the finding of inflammatory products, including cell infiltration, neovascularization, and granulation, which were observed in 100% of transligamentously extruded discs, 81.8% subligamentously extruded discs, and only 16.9% of contained protruded discs.[130] Antigen–antibody complexes are likely implicated as well.[131]

As mentioned, although MRI is able to demonstrate anatomic changes, these findings do not always correlate with the clinical picture and affect the patient symptomatically or functionally. High-intensity zones on MRI have frequently been associated with discogenic pain. However, there is also a high prevalence of this finding among asymptomatic persons.[132] To date, the only imaging method for symptomatic assessment of low back pain remains provocation lumbar discography. The distinction between these imaging modalities is demonstrated by the observation that among patients with discography-proven discogenic pain, no specific abnormality found on MRI can be used as a predictor of pain. Discography may be superior to MRI for the identification of annular tears,[133] and discography has the ability to provoke the patient's symptoms. Reproduction of a patient's typical back pain upon injection, with a negative pain response in at least one control level, represents a positive discogram. Discography findings in disc degeneration include loss of disc height with complex or multiple annular fissures with or without leakage of contrast agent. A bulging anulus is also often observed. A diffuse pattern of annular tearing suggests the chronic nature of degeneration. The modified Dallas scale, introduced by Bogduk and April, grades discs at 0–4. Grade 0 represents contrast remaining entirely within a normal nucleus pulposus. Grade I represents contrast extending radially along a fissure involving the inner third of the anulus. Grade 2 lesions show contrast extending into the middle third, and grade 3 extending into the outer third. Grade 4 represents a grade 3 tear dissecting radially to involve more than 30° of the disc circumference.[134] Other authors have added grade 5 (full-thickness tear), grade 6 (disc sequestration), and grade 7 (diffuse annular tear).[135,136] Please refer to Chapter XXX on the clinical utility of lumbar discography and how it is used in the algorithmic assessment of a low back pain.

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Investigations are currently underway with ultrasound to locate specific pathologic defects in intervertebral discs. Previous studies have shown utility in screening for disc degeneration,[137] and the use of a vibrating probe for pain provocation has been suggested as a useful screen prior to discography.[138]

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