eXtreme Lateral Interbody Fusion (XLIF®)

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Radiology of Lumbar Degenerative Disease

H. Brad Jones, Jr.

Lumbar degenerative disease is a leading cause of disability, work loss, and medical expenses. With the increase of obesity throughout the world, especially in the United States, degeneration of the spine is increasing in prevalence and is affecting more younger patients than ever before.

An overview of imaging anatomy begins this chapter. It is important to understand normal anatomy first, because this knowledge makes it easier to highlight the progression of findings in lumbar degenerative disease, including disc degeneration, central canal stenosis, lateral encroachment, and degenerative scoliosis. However, the true objective of this chapter is to provide a review of available imaging modalities—information that allows a radiologist to help a clinician with his or her care of a patient. These imaging modalities include plain radiography, myelography, discography, computed tomography (CT), and magnetic resonance imaging (MRI); the advantages and drawbacks of each method are discussed. Also included are the findings of degenerative lumbar disease as they are obtained with both radiography and cross-sectional imaging, an area that has seen significant advancement in recent years. Imaging advances benefit patients, because clinicians can better select the appropriate treatment for each patient's specific problem.

Anatomy

The lumbar spine is made up of five vertebral bodies; an intervertebral disc exists between each. In some instances, a sixth lumbar vertebra also exists and the terms *six non–rib-bearing vertebrae* and *transitional lumbosacral vertebrae* will be used. In these cases, it is critical that the radiologist and clinician communicate clearly with one another and that they be consistent in the labeling of the disc spaces, especially if an intervention is needed.

Each lumbar vertebra is made up of a body and pedicles, and the bodies are secured by anterior and posterior longitudinal ligaments. The posterior elements include the lamina and spinous processes; an interspinous ligament anchors the spinous process at each level. Bilateral articulating facet joints stabilize the adjacent vertebrae with one another; the ligamentum flavum stabilizes the lamina with the ipsilateral articulating facet.[1]

The intervertebral discs are composed of a peripheral anulus fibrosus and a central nucleus pulposus, which is predominantly made up of water and has a homogeneous high signal on a water-sensitive (T2-weighted) MRI scan. The anulus fibrosus, however, has a low signal in water-sensitive (T2-weighted) MRI scans because of its fibrous content.[2] Because disc degeneration is typically the instigator for lumbar degeneration, it is important to know what normal and abnormal discs look like on cross-sectional imaging (Fig. 4-1).

The conus medullaris of the spinal cord can vary in its termination point. However, it is typically located at the L1 or L2 level. Nerve roots emerge from the distal cord; these travel within the spinal canal to exit through the intervertebral neural foramina at their respective levels. A disease at a specific lumbar level has the potential to affect two separate nerve roots. Because the upper nerve root at a certain level travels under the pedicle and then into the neural foramen, posterolateral and far lateral disc disease or osteophytosis typically affect this nerve root. Central and paracentral disc disease typically affect the lower nerve root.[3] A posterolateral osteophyte or diseased disc at L4-5 often impinges on the ipsilateral L4 nerve root. Central or paracentral osteophytes or a diseased disc at L4-5 often impinge on the L5 nerve root.[1]

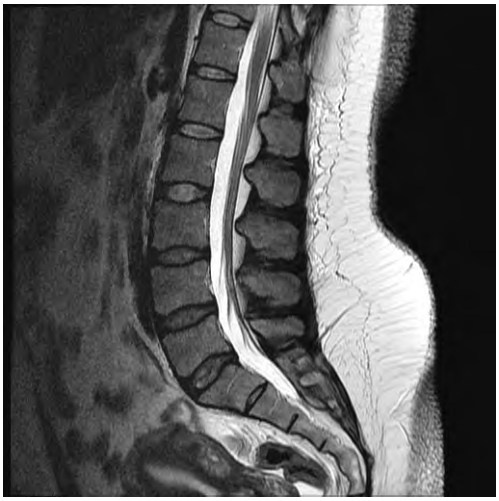

FIG. 4-1 A sagittal T2-weighted image that demonstrates a normal signal in upper lumbar intervertebral discs and water loss with loss of a signal in the lower lumbar intervertebral discs.

Disc Degeneration and Imaging

Because humans are upright creatures and walk on two legs instead of four, the lumbar spine degenerates as we age. The degeneration process typically begins with the intervertebral discs. The central nucleus pulposus loses its water content and becomes more fibrous. The high signal within the nucleus, seen on T2-weighted images, will start to lower, beginning centrally and then expanding within the disc toward the endplates[2] (see Fig 4-1). The peripheral anulus can also begin to develop cracks along its edge. If these cracks, also known as anular tears, can be visualized on T2-weighted MRI, they have a linear high signal. Anular tears allow nitrogen to enter the central portion of the disc, resulting in continued degeneration. The nitrogen produces air density that can be seen with plain radiography and CT, and it produces a linear low signal within the disc on MRI. These areas of air density are referred to as *vacuum discs* and are signs of advanced degeneration[1] (Fig. 4-2). Disc degeneration and anular tears place the patient at increased risk for symptomatic disc disease. Tears in the anulus, for example, allow the nucleus pulposus to extend outward from its central location.

Although disc morphology can be described in different ways, none is fully correct. The keys for accurately describing disc morphology should be consistent and clearly communicate findings with a surgeon. The location of any abnormal disc morphology is especially crucial. Disc disease can be central, paracentral, posterolateral, or far lateral. As mentioned in the previous section, posterolateral and far lateral disc disease affect the upper nerve roots, whereas central and paracentral disc disease affect the lower nerve roots.[3]

Disc bulges are typically broad-based and extend at least 2 mm beyond the margin of the vertebral body.[2] In addition, they are almost always present with acquired lumbar degenerative disease. Focal disc protrusions or herniations typically occur in central or paracentral

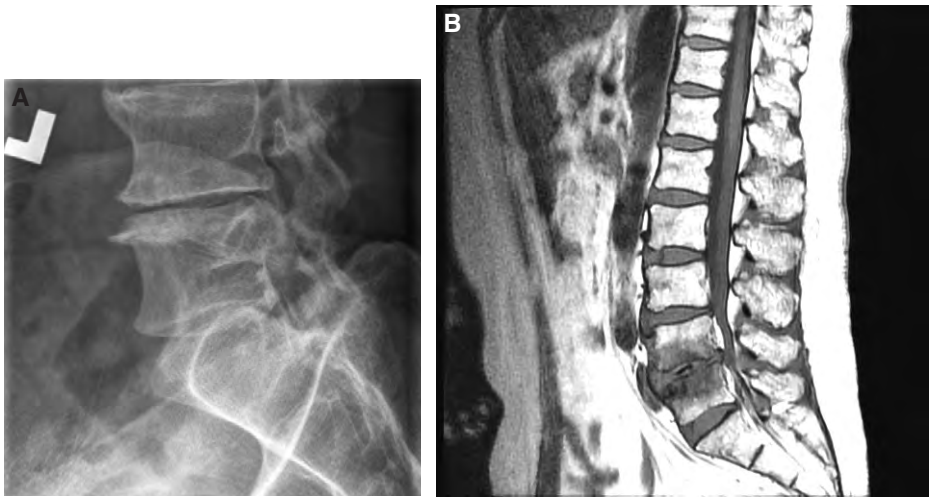

FIG. 4-2 Vacuum discs on **A,** a conventional lateral radiograph and **B,** a sagittal T1 MRI.

locations. Although not always symptomatic, these discs can be quite symptomatic if they occur in certain positions. Posterolateral and foraminal disc protrusions commonly produce root compression and symptoms correlating with the affected level. Far lateral protrusions most commonly affect nerve roots that exit proximal to the disk level involved. Disc extrusions, another type of spinal ailment, have larger anteroposterior dimensions than mediolateral dimensions in axial cross-sectional imaging[2] (Fig. 4-3). Because of the size of these disc extrusions, they often migrate either superiorly or inferiorly behind the adjacent vertebral body. In addition, they are often symptomatic. Another spinal disorder occurs when sequestered disc fragments break away from their parent disc (Fig. 4-4). A sequestered disc fragment shows rim enhancement in postgadolinium MRI scans, and the size and location of a disc fragment determine its clinical significance.

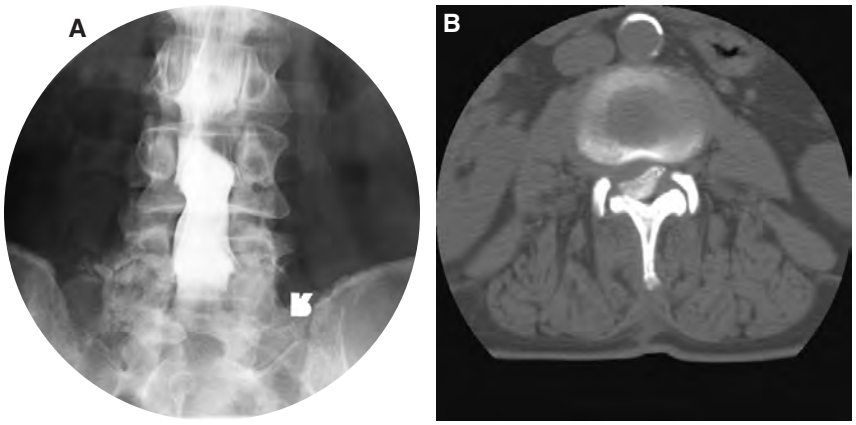

FIG. 4-3 These **A,** myelogram and **B,** postmyelogram CT images both demonstrate a large right paracentral disc extrusion with secondary nerve root impingement.

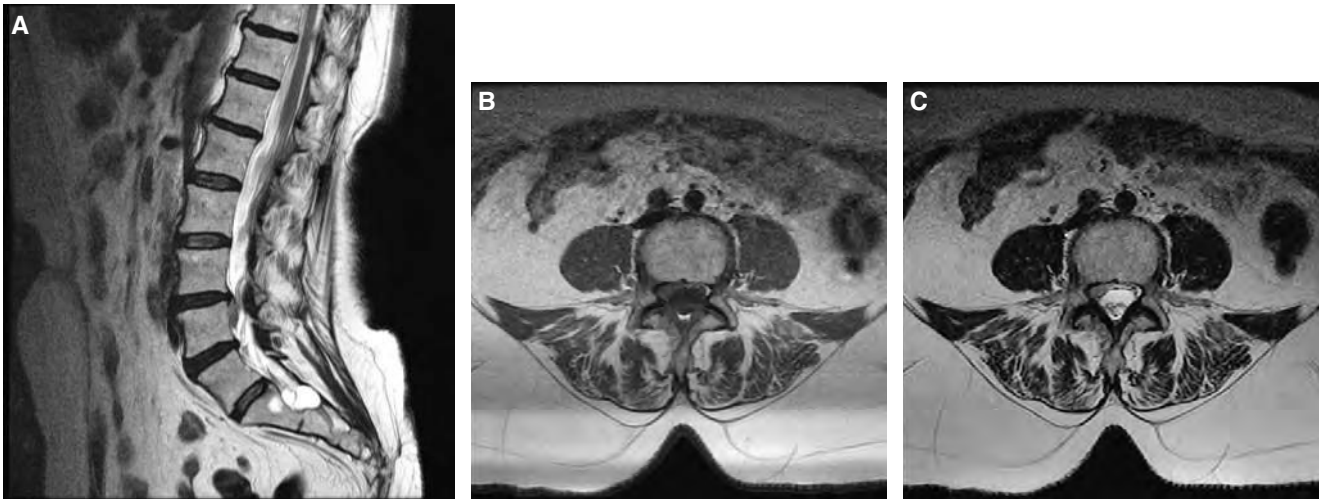

FIG. 4-4 **A,** Sagittal T2, **B,** axial T1, and **C,** axial T2 images demonstrate a right paracentral sequestered disc fragment that originates from the L3-4 disc space and extends inferiorly behind the L4 vertebral body.

CONVENTIONAL RADIOGRAPHY AND DISC DISEASE

Radiographs allow the radiologist and clinician to see preservation of disc height. With progressing disc degeneration, the disc height begins to decrease and endplate degenerative changes occur. This is discussed in more detail in the osseous degeneration section.

MYELOGRAPHY AND COMPUTED TOMOGRAPHY

Although MRI has become the standard, myelography and follow-up CT remain valid and important imaging modalities for disc disease and lumbar degeneration (see Fig. 4-3). These tests are often performed in patients who are unable to undergo MRI, including those individuals with extreme claustrophobia, pacemakers, or spinal stimulators. The obvious disadvantage of myelography is the invasive nature of the procedure—the patient must undergo a lumbar puncture and an injection of contrast into the thecal sac. However, one advantage is that it allows visualization of the individual nerve roots. By visualizing the individual nerve roots, one is able to see their course, as well as specific points of impingement and effacement. Lateral radiographs following myelogram injection allow assessment of central canal preservation or stenosis.

A postmyelogram CT is crucial, because it defines whether a nerve root impingement is related to isolated disc abnormalities and/or osseous degeneration. A CT examination also helps assess the central canal dimensions, as well as lateral recess stenosis and far lateral neuroforaminal stenosis. The facet joints and ligamentum flavum can be well evaluated on CT examinations, and their contributions to acquired central canal, lateral recess, and neuroforanimal stenosis are easily discerned. Today's 16-slice and 64-slice CT scanners allow quick imaging and easy access to three-dimensional reconstructed images. These reconstructed images allow visualization of the individual nerve roots in a coronal plane, as well as easy assessment of degenerative scoliosis in the coronal plane.

MAGNETIC RESONANCE IMAGING

MRI has become the gold standard for evaluating degenerative disc disease. The test has a number of advantages: it is noninvasive, provides results that have great spatial resolution, and avoids any exposure to radiation. In addition, MRI gives exact assessments of the size and locations of disc abnormalities. Broad-based disc bulges, focal disc protrusions or herniations, disc extrusions, and sequestered disc fragments are all easily seen using MRI (see Fig. 4-4). Because of the anatomic detail seen with MRI, an impingement on a specific nerve root can be determined easily. It is also useful for disc degeneration. When a disc loses water or becomes dehydrated, there is a loss of signal on T2-weighted (water-sensitive) images.[2] With further progression, the disc loses height and eventually develops abnormal peripheral morphology.

DISCOGRAPHY

Discography is a provocative procedure that is used to determine the sources and levels of pain in patients with disc degeneration. This invasive procedure is often performed on patients who have not responded to conservative treatments. Needles are placed into multiple discs, then contrast is injected into the disc space. The patient is kept awake throughout the procedure so that he or she can describe the intensity of pain at each disc space level of the spine, thereby confirming a level-specific diagnosis of pain generators.

Osseous Degeneration

The preceding sections of this chapter discuss the progression of disc degeneration as it leads to the final stage of lumbar disease—osseous degeneration. With progressive disc degeneration and loss of height, the vertebral endplates come closer to one another, and other changes in the endplates also develop, which are are best seen using MRI. As the endplates change, the facet joints simultaneously begin to lose their articular cartilage. With the loss of these stabilizing elements, abnormal movement occurs in the lumbar spine. Vertebral osteophytes can also form as the disease progresses; these secondarily narrow the central canal and exiting foramina. With loss of cartilage, the facet joints also begin to hypertrophy and become arthropathic. At the same time, the stabilizing ligamentum flavum begins to hypertrophy and bow inward. These factors contribute to progressive central canal, lateral recess, and neuroforaminal stenosis. [2]

Progressive loss of stabilizing elements around the lumbar spine allows continual abnormal motion, which in turn leads to degenerative spondylolisthesis, in the form of either anterolisthesis or retrolisthesis. When an anterolisthesis occurs, the superior vertebral body moves *anterior* to the inferior vertebral body, whereas the superior vertebral body moves *posterior* to the inferior vertebral body in retrolisthesis. Spondylolisthesis in general can be graded in terms of the degree of abnormal movement. A simplistic approach is to divide the vertebral body into quarters. With grade I anterolisthesis, the superior vertebral body moves forward 0% to 25% over the inferior vertebral body. Grade II occurs when the vertebral body moves 25% to 50%, grade III is at 50% to 75%, and grade IV is at more than 75%.[3]

The term *degenerative spondylolisthesis* is used in this section because spondylolisthesis can also be seen with pars interarticularis defects (spondylolysis).[3] Spondylolysis can be recognized with plain radiography or with cross-sectional imaging. It is important for the image interpreter to look for this not-uncommon entity. Degenerative spondylolisthesis can be differentiated from spondylolisthesis secondary to spondylolysis by the central canal diameter. With spondylolysis, the central canal remains patent or widened, whereas degenerative spondylolisthesis leads to a narrowing of the central canal. Both conditions lead to lateral recess and neuroforaminal stenoses (Fig. 4-5).

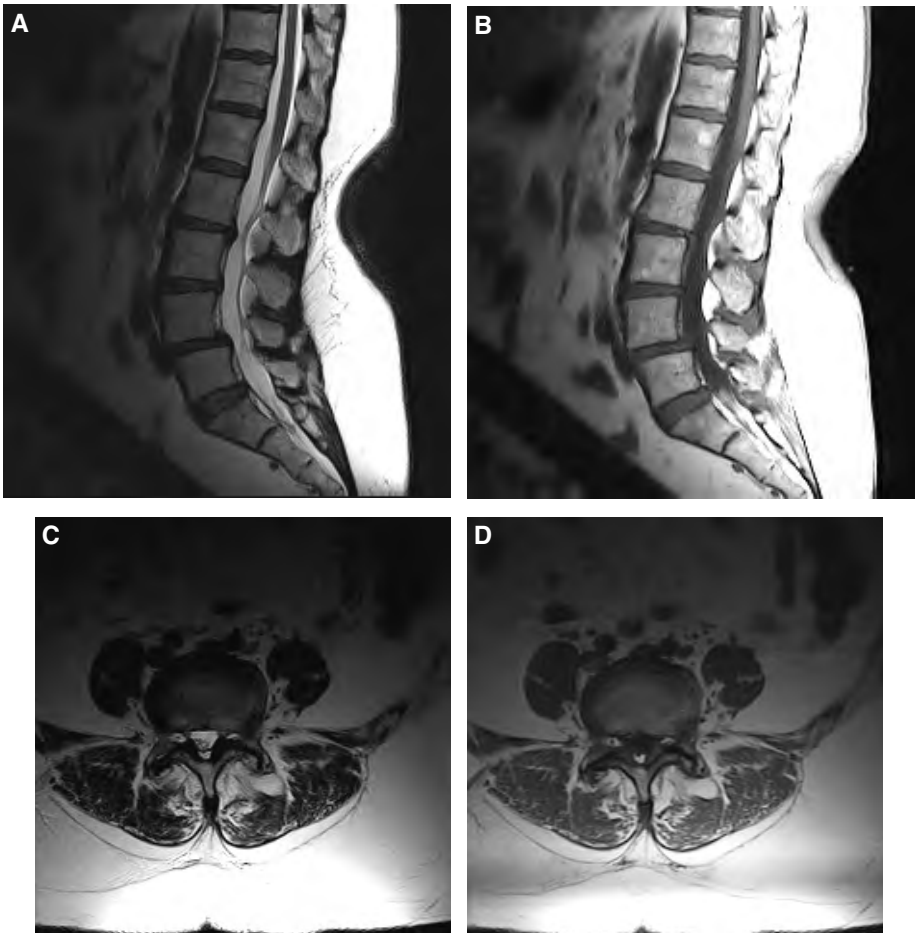

FIG. 4-5 **A,** Sagittal T2 and **B,** sagittal T1 images demonstrate grade I anterolisthesis of L4 on L5. **C,** Axial T2 and **D,** axial T1 images show the central canal stenosis secondary to the spondylolisthesis and facet arthropathy.

With the loss of disc height and facet arthropathy, the lumbar spine begins to collapse. Abnormal lateral curvature with disc and osseous degeneration is termed *degenerative scoliosis*. This condition typically occurs in older patients following years of wear. Degenerative scoliosis also contributes to central canal, lateral recess, and neuroforaminal stenoses. Neuroforaminal stenosis tends to be more severe on the ipsilateral side of the convex portion of the lateral curvature. For example, levoscoliosis centered at the L3-4 level typically causes more severe left-sided neuroforaminal stenosis. Because this contributes to bony canal compromise and progressive facet arthropathy, patients have an increased risk of developing localized pain, lumbar radiculopathy, and neurogenic claudication.

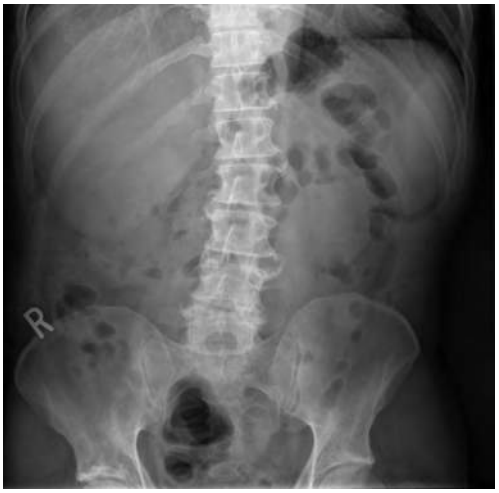

FIG. 4-6 A frontal radiograph displays degenerative levoscoliosis.

CONVENTIONAL RADIOGRAPHY IN OSSEOUS DEGENERATION

Conventional radiographs are often the first imaging modality used when a patient complains of back pain—they are easy to obtain, inexpensive, and provide useful information. Lateral radiographs allow the imager to assess for disc space preservation, vacuum discs, and posterior osteophytes. Lateral radiographs are also excellent for assessing spondylolisthesis. Oblique radiographs are used to exclude spondylolysis as the cause of spondylolisthesis.[4] Frontal radiographs give a quick assessment of disc space preservation. These radiographs are crucial for assessing lateral osteophytosis. Although the lateral recess and neuroforamen cannot be well evaluated with radiographs of the lumbar spine, the presence of lateral osteophytes is usually indicative of foraminal stenosis and encroachment on the exiting nerve roots. Frontal radiographs are also excellent for assessing degenerative scoliosis of the lumbar spine (Fig. 4-6). Large 32-inch cassettes can be used to evaluate the scoliotic curvature of the spine. Anteroposterior and lateral bending radiographs allow the radiologist and clinician to assess the stiffness of a patient's scoliotic curve. The lateral curvature and the presence of lateral osteophytes are seen easily with lumbar radiographs.

COMPUTED TOMOGRAPHY AND MYELOGRAPHY

CT gives an excellent, quick assessment of central canal diameter and neuroforaminal stenoses. Unfortunately, its benefits are limited if an intrathecal contrast medium is not

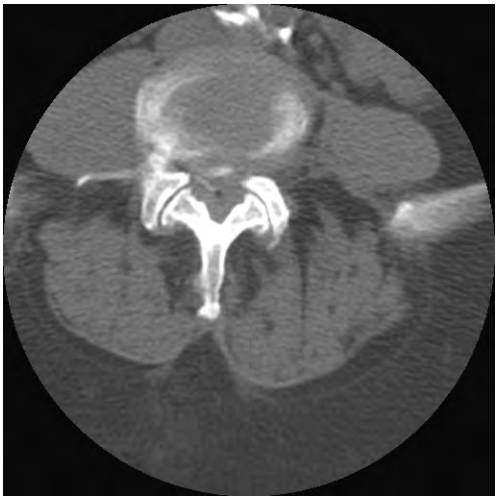

FIG. 4-7 This postmyelogram CT image demonstrates high-grade central canal stenosis and impingement on the thecal sac secondary to posterior spondylosis, facet arthropathy, and ligamentum flavum hypertrophy.

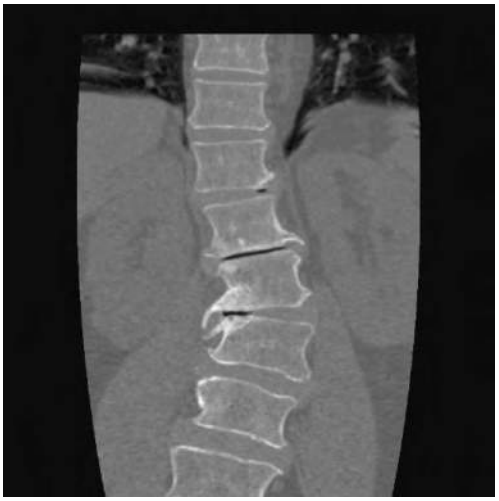

FIG. 4-8 This coronal reformatted CT image demonstrates multilevel disc degeneration, lumbar spondylosis, and secondary degenerative scoliosis.

used. Even though myelography is an invasive procedure, it does allow direct viewing of nerve root effacement. Flexion and extension postmyelogram radiographs also allow assessment of abnormal motion of the lumbar spine. Postmyelogram CT images provide impressive views of the central canal, lateral recess, and neuroforamen. The combination of these studies allows the imager to differentiate nerve root compromise secondary to disc disease from osseous degeneration.

As mentioned in the previous section, posterior osteophytes, facet arthropathy, and ligamentum flavum hypertrophy can all be clearly evaluated with a postmyelogram CT examination (Fig. 4-7). Postprocessing also allows the development of three-dimensional sequences. Sagittal sequences allow excellent assessment of degenerative spondylolisthesis, whereas coronal sequences allow assessment of degenerative scoliosis (Fig. 4-8) and secondary lateral recess and neuroforaminal compromise. With intrathecal contrast, the nerve roots are directly visualized. Therefore impingement of the nerves secondary to osseous degeneration is easily assessed.

MAGNETIC RESONANCE IMAGING

MRI is also the standard for assessing osseous degeneration. Vertebral body endplate changes following disc degeneration are visualized earlier with MRI than they are with any other modality. These changes, first described by Modic et al,[5] are as follows: type 1 changes produce a low signal along the endplates on T1-weighted images and a high signal on T2-

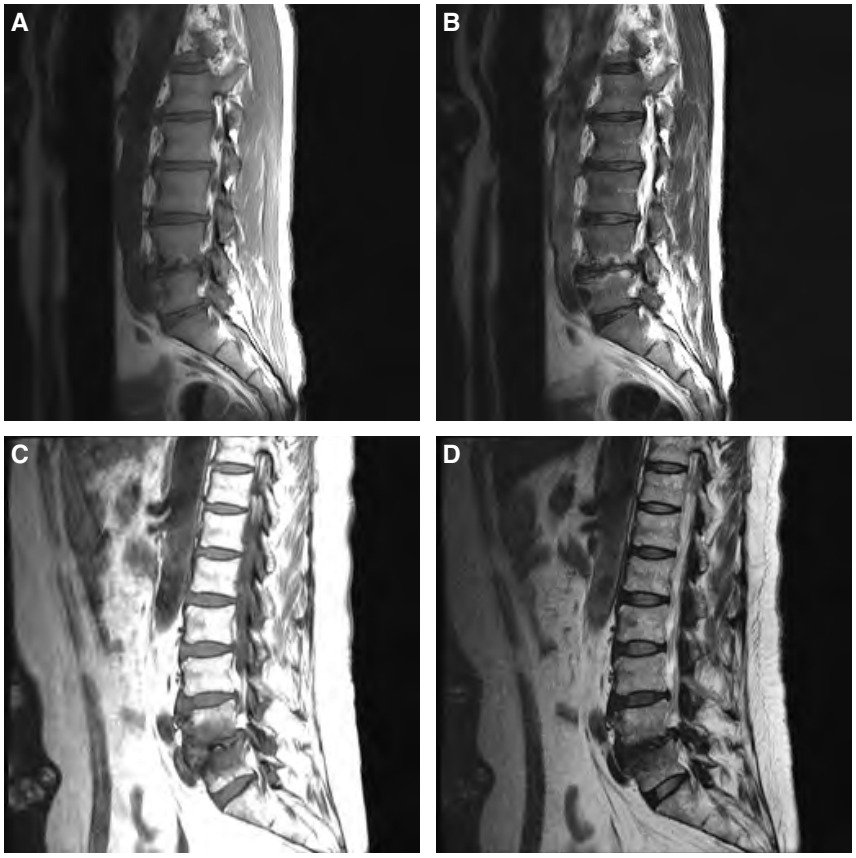

FIG. 4-9 **A** and **B,** Type 2 Modic changes. **C** and **D,** Type 3 Modic changes.

weighted images, type 2 changes produce a high signal along the endplates on both T1- and T2-weighted images, and type 3 changes produce a low signal along the endplates on both T1- and T2-weighted images. Conventional radiographs allow visualization of only the type 3 changes because of the sclerosis along the endplates. Sclerosis produces a low signal with MRI (Fig. 4-9).

With disc degeneration and endplate degenerative changes, abnormal movement begins in the lumbar spine. Facet joints begin to have abnormal motion, which leads to a progressive loss of the articular cartilage. The facets begin to become hypertrophic and arthropathic. Simultaneously, the ligamentum flavum begins to hypertrophy and encroach on the central lumbar spinal canal and the lateral recess. MRI gives a multiplane view of these acquired degenerative changes[6] (Fig. 4-10).

Sagittal MRIs provide a clear look at degenerative spondylolisthesis (see Fig. 4-5). Comparing axial images with sagittal images allows assessment of central canal stenosis and exclusion of pars interarticularis defects. With degenerative spondylolisthesis, the central canal becomes narrowed and compromised. Weight-bearing MRI scanners have been introduced into modern imaging technology. Although not yet widely available, these scanners have been reported to be superior in assessing spinal cord and nerve root impingement.

Degenerative scoliosis is the final stage of lumbar degeneration. Coronal and axial MRI allow assessment of abnormal lateral curvature. Degenerative scoliosis leads to further osseous encroachment of the lateral recess and neuroforamen—findings that are also seen clearly with MRI.

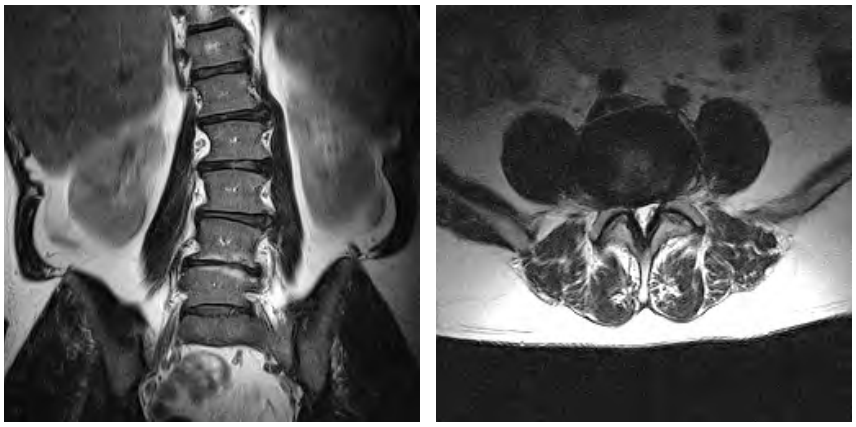

FIG. 4-10 This multiplane T2-weighted MRI demonstrates multilevel disc degeneration with secondary central canal and lateral recess stenoses. The advanced disc and osseous degeneration has led to secondary degenerative scoliosis.

Lumbar degeneration proceeds in a stepwise fashion. Disc degeneration allows disc collapse, abnormal motion, and misalignment of the lumbar spine. Abnormal motion leads to posterior and lateral osteophytes. Facet arthropathy and cartilage loss allow an additional increase in abnormal motions of the lumbar spine. Further progression of lumbar degeneration leads to spondylolisthesis and degenerative scoliosis. The combination of disc degeneration and osseous degeneration leads to central canal, lateral recess, and neuroforaminal stenoses (see Fig. 4-10).

Conclusion

Although conventional radiographs remain beneficial for assessing lumbar degenerative disease, advancements in cross-sectional imaging, including multiplane MRI and three-dimensional CT, have provided improved assessment of disc spaces and the osseous lumbar spinal canal. This enhanced assessment improves the ability to localize a patient's symptoms. As assessment and diagnosis accuracy improves, treatments and clinical outcomes for lumbar degeneration will also continue to improve.

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