Low back pain is an exceedingly common problem, with a lifetime prevalence of 70% to 85%. This condition is the most common cause of disability in people ages 45 years or younger, with an estimated economic impact of over $100 billion dollars per year, predominantly due to loss of productivity. The etiology of low back pain is multifactorial and is influenced by genetics, age, sex and mechanical stresses.

Imaging plays a critical role in the diagnosis of low back pain. MRI has become a mainstay in the workup of low back pain due to its excellent soft tissue contrast, cross-sectional capability, and lack of ionizing radiation. This paper will present common MRI findings associated with low back pain, as well as grading systems and common nomenclature to assist in consistent and reproducible reporting of these findings.

**MRI Imaging Techniques**

An MRI of the lumbar spine generally includes a sagittal T1-weighted spin echo sequence, a sagittal T2-weighted spin echo sequence, and axial T2-weighted images. Additional sequences including axial T1-weighted sequences, sagittal fat-nulling T2-weighted sequences such as short tau inversion recovery (STIR) or modified Dixon (mDixon), and gadolinium-based contrast enhanced T1-weighted sequences may be obtained depending on the institution and the indication for the MRI examination.

Sagittal T1-weighted images are useful in the assessment of bone marrow, which is normally fatty in adults and demonstrates high T1 and T2 signal. Alignment of the vertebral bodies can also be assessed on the sagittal T1-weighted sequence. Due to the high contrast between fat and nerve roots, the T1 sagittal sequences are excellent for assessing the degree of neural foraminal stenosis.

Sagittal T2-weighted images provide excellent contrast between cerebrospinal fluid (CSF) in the thecal sac and the surrounding structures, allowing for assessment of the degree of spinal stenosis at multiple levels on a single image. These sequences are also useful for assessment of the intervertebral discs, and the presence of disc herniation. Fluid sensitive sequences such as STIR and mDixon are used for detecting areas of bone marrow edema.

Axial T2-weighted images provide a level-by-level assessment of the relationship between the thecal sac and the surrounding bony and ligamentous structures and are particularly useful for assessing spinal stenosis and narrowing of the lateral or subarticular recesses. These sequences are also used in assessing the facet joints and ligamentum flava.

In addition to the previously mentioned techniques, several other MRI sequences can be used for assessment of the lumbar spine. There is evidence to suggest that upright MRI of the lumbar spine provides a more accurate assessment of the physiology of low back pain as many patients are more symptomatic when standing. However, limited availability, high false-positive rates, and increased motion artifact have limited widespread adoption of this technique. Other techniques such as T1 and T2 relaxation mapping and new sequences like sodium MRI, magic echo and T1ρ are being developed to assess early molecular changes in the intervertebral disc.

**Normal Anatomy**

**Vertebral Bodies**

Lumbar vertebrae are composed of a vertebral body anteriorly, which gives rise to bilateral pedicles from its superior aspect. These extend posteriorly and connect to the transverse processes, which project laterally, and the lamina, which project posteromedially. The
lamina come together in the midline and connect to the posteriorly projected spinous process. Interposed between each pedicle and lamina are the superior and inferior articular processes, joined by the pars interarticularis.

The vertebral bodies consist of an outer layer of cortical bone, which is low signal intensity on T1- and T2-weighted imaging and surrounds the inner trabecular bone. Trabecular bone is normally high signal on T1- and T2-weighted sequences in adults due to its fatty marrow.

The posterior wall of the vertebral body and inner margins of the pedicles and lamina form a bony ring around the thecal sac. The neural foramina are bordered superiorly and inferiorly by the pedicles of adjacent vertebral bodies, anteriorly by the posterolateral margin of the suprajacent vertebral body and intervertebral disc, and posteriorly by the superior articular process of the subjacent vertebral body. Neural foramina allow the passage of lumbar nerve roots from the thecal sac to the peripheral tissues. Nerve roots within the neural foramina are low signal on T1- and T2-weighted imaging and are normally surrounded by a rim of perineural fat.

**Intervertebral Discs**

Interposed between the vertebral bodies are the intervertebral discs (Figure 1). These discs form the anterior articulation of the vertebral column and have two components: the outer annulus fibrosus (AF) and the inner nucleus pulposus (NP). The AF is a dense fibrocartilaginous structure comprised of 15 to 20 layers of obliquely oriented fibers that run from the inferior endplate of the suprajacent vertebral body to the superior endplate of the subjacent vertebral body. These fibers are primarily comprised of type 1 collagen. This portion of the intervertebral disc normally demonstrates low T1 and low T2 signal. The NP is composed of a loose type 2 collagen matrix and is 70% to 90% water and proteoglycans. The NP demonstrates high T2 and low T1 signal, due to its high water content. A low T2 signal band can be seen centrally within the NP in patients over age 30 and represents a fibrous band or cleft. These discs contact the vertebral body endplates, which are made up of hyaline

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**Table 1. Pfirrmann Classification for Disc Degeneration**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Disc Structure</th>
<th>NP/AP Distinction</th>
<th>NP Signal</th>
<th>Disc Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Homogeneous</td>
<td>Sharp</td>
<td>Bright hyperintense</td>
<td>Preserved</td>
</tr>
<tr>
<td>2</td>
<td>Inhomogeneous</td>
<td>Sharp, cleft may be present</td>
<td>Hyperintense</td>
<td>Preserved</td>
</tr>
<tr>
<td>3</td>
<td>Inhomogeneous</td>
<td>Unclear</td>
<td>Isointense</td>
<td>Preserved or slightly decreased</td>
</tr>
<tr>
<td>4</td>
<td>Inhomogeneous</td>
<td>No distinction</td>
<td>Hypointense</td>
<td>Mild to moderate decrease</td>
</tr>
<tr>
<td>5</td>
<td>Inhomogeneous</td>
<td>No distinction</td>
<td>Black signal</td>
<td>Collapsed</td>
</tr>
</tbody>
</table>

*Modified from reference 19
cartilage on the vertebral body side and fibrocartilage along the disc.\textsuperscript{11}

**Facet Joints**

The posterior articulation of the vertebral bodies is formed by the facet (zygoapophyseal) joints. These are obliquely oriented synovial joints comprised anterolaterally of the superior articular process of the subjacent vertebral body and posteromedially by the inferior articular process of the suprajacent vertebral body. Facet joints have articular surfaces composed of hyaline cartilage within a fibrous joint capsule lined with synovium.\textsuperscript{11} The joint spaces of the facet joints normally measure 2 to 4 mm and demonstrate isointense to high T2 signal.\textsuperscript{14}

**Ligamentum Flava**

Multiple ligamentous structures contribute to the stability of the spinal column. These include the anterior longitudinal ligament, the posterior longitudinal ligament, the interspinous ligament, and the supraspinous ligament. Of particular interest when considering degenerative disease of the lumbar spine are the ligamentum flava, paired ligaments that extend between the lamina of adjacent vertebral bodies. These ligaments are normally thin and low signal on T1- and T2- weighted sequences.

**Degenerative Disease**

**Intervertebral discs**

Normal intervertebral discs transition through three phases: growth, maturation, and degeneration.\textsuperscript{15} The growth phase is characterized by synthesis of aggrecan and procollagens and increased type 2 collagen and takes place between ages 0 and 15. The maturation phase occurs with a reduction in the synthesis and volume of type 2 collagen in the NP from approximately 15 to 40 years of age. The final stage is degeneration, characterized by increased fibrosis with decreasing type 2 collagen and increasing type 1 collagen, which takes place after age 40.

This disc degeneration, as well as annular fissures and apophyseal osteophyte formation, in the absence of disc height loss, have been termed spondylosis deformans and are considered normal processes associated with aging.\textsuperscript{16-18} On MRI, apophyseal osteophytes are characterized by low T1 and T2 outgrowths along the anterior and lateral margins of the endplates. Disc degeneration manifests as loss of T2 signal in the NP. Annular fissures are small areas of T2 hyperintensity in the posterior AF. More extreme changes, including severe disc fissuring, disc height loss and endplate erosion, have been termed intervertebral osteochondrosis, which is a pathologic process.\textsuperscript{16-18}

Pfirrmann et al proposed a grading system for intervertebral disc degeneration based on disc structure, distinction between the NP and AF, NP signal intensity and disc height (Table I).\textsuperscript{19} This grading system demonstrated good interobserver reliability. A review of the literature in 2005 by Kettler et al found that the Pfirrmann grading system was the only MRI-based system for disc degeneration with a kappa value of greater than 0.6.\textsuperscript{20} This system has since been modified by Griffith et al to increase the discriminatory power in the elderly population, with three additional severity levels and a quantitative measurement of disc height reduction.\textsuperscript{21}

Annular fissures are regions of high T2 signal intensity seen in the posterior AF of degenerated discs (Figure 2). Nearly all degenerated discs have annular fissures, although these may not be visible on MRI.\textsuperscript{22} The role of annular
fissures in pain generation is uncertain, with multiple studies noting that annular fissures are often seen in asymptomatic individuals.\textsuperscript{23-26} Additionally, evidence suggests that the presence of annular fissures does not increase progression of degenerative disc disease when compared to discs without fissures.\textsuperscript{27} For these reasons, the Combined Task Force (CTF) of the North American Spine Society, American Society of Spine Radiology and American Society of Neuroradiology recommend the term “annular fissure” instead of “annular tear” to avoid implying that these regions of signal intensity are a type of acute disc injury.\textsuperscript{28}

Another common disc-related finding in degenerative disease of the lumbar spine is disc herniation. There are multiple systems for classification of disc herniations; however, the two most studied systems are those proposed by Jensen et al\textsuperscript{29} and Fardon et al.\textsuperscript{28} The Jensen classification system splits disc herniations into three categories: disc bulges, protrusions and extrusions. Bulges are defined as symmetric extensions of disc material beyond the interspace. Protrusions are focal or asymmetric extensions of disc material beyond the interspace with the base of the herniation being wider than the apex. Finally, extrusions are defined as more extreme extensions of disc material beyond the interspace with the dimension of the extruded component either wider than the base or not connected to the base. The findings of the CTF published by Fardon et al do not consider disc bulges a form of herniation as bulging can be a normal variant or the result of adjacent bony remodeling or ligamentous laxity.\textsuperscript{28} The CTF defines protrusions and extrusions as involving less than 25% of the circumference of the disc, in addition to the features described by Jensen et al (Figure 3). Additional terminology proposed by the CTF includes “sequestration” as a subset of extrusion where the extruded material is not continuous with the parent disc (Figure 4). A recent systematic review of the literature found that the recommendations by the CTF demonstrated superior interrater reliability compared to Jensen et al.\textsuperscript{30} The CTF recommends that this classification be coupled with the localization system proposed by Wiltse et al,\textsuperscript{31} which divides the spinal canal into central, subarticular, foraminal and extraforaminal zones (Figure 5).

An alternate method for classification of disc herniations differentiates subligamentous herniations from extra-ligamentous herniations. This classification scheme, proposed by Oh et al,\textsuperscript{32} describes five criteria that can be used to determine extra-ligamentous herniations: spinal canal compromise of more than half its dimension, internal signal difference in the herniated disc, ill-defined margin of the herniation, disruption of low-signal intensity line covering the herniation, and the presence of an internal dark line in the herniated disc. The authors note that this type of classification is potentially more clinically useful as minimally invasive methods are more successful with subligamentous disc herniations than extra-ligamentous herniations.

Another clinically oriented classification scheme was developed at Michigan State University by Mysliwiec et al.\textsuperscript{33} This grading system proposes to separate disc herniations into those that are “substantial” and require surgical intervention, and those that are not and are more likely to have poor surgical outcomes. The authors propose using a line drawn between the anterior margins of the facet joints in the axial plane.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Disc protrusion and extrusion. Axial T2-weighted image of an intervertebral disc (A) demonstrates a focal disc herniation (less than 25% disc circumference) on the left. This posteriorly displaces the nerve root in the left lateral recess (arrowhead). Axial T2-weighted image of the subjacent disc in the same patient (B) demonstrates a similar appearing focal disc herniation located centrally. Sagittal T2-weighted image in the same patient (C) differentiates between the upper level extrusion and lower level protrusion. Note that the extrusion has an apex (arrowheads) that is wider than its base (dashed lines), while the protrusion does not.}
\end{figure}
as a reference for the extent of disc herniation. Those herniations that do not extend more than 50% of the distance between the interspace and intrafacet line are classified grade 1 and should be managed conservatively. Those extending beyond grade 1 but not beyond the intrafacet line (grade 2), and those extending beyond the intrafacet line (grade 3) were treated surgically, with good outcome rates that compared favorably to existing literature. While this technique is less subjective than other schemes, it is somewhat limited in that it cannot be used in patients with abnormal facet joints and ligamentum flavum hypertrophy.

**Vertebral Body Endplates**

Degenerative endplate changes have been classified by Modic et al.\(^{34,35}\) into three categories: Type 1 changes are edematous changes related to subchondral end plate fractures, formation of vascularized fibrous tissue and an acute reparative response. On MRI, these changes are characterized by increased T2 and decreased T1 signal in the bone marrow adjacent to the endplate. Type 2 changes are related to fatty replacement of normal marrow and are more chronic and stable. These changes will demonstrate increased T1 and T2 signal, with loss of signal on fat suppression sequences. Type 3 changes relate to chronic endplate sclerosis and development of dense woven bone. This dense bone is low signal intensity on both T1- and T2-weighted sequences. Transitions through these stages are not uniformly progressive, and multiple studies have shown resolution of Type 1 changes or progression from Type 2 change to Type 1 change.\(^{35-37}\)

**FIGURE 4.** Disc sequestration. Axial T2-weighted image (A) demonstrates herniated disc material in the left lateral recess (asterisk), posteriorly displacing and compressing the traversing nerve root (arrow). Para-midline sagittal T2-weighted image (B) of the same disc sequestration (asterisk), which demonstrates higher T2 signal than the parent disc. Note the lack of continuity with the parent disc (arrowhead). Pre-contrast T1-weighted (C) and postcontrast T1-weighted (D) axial images demonstrate the T1 hypointense sequestration (asterisk) with thin peripheral enhancement, again displacing and compressing the traversing nerve root (arrow).

**FIGURE 5.** Anatomic scheme proposed by Wiltse et al.\(^{31}\) Solid line = midline, dashed line = medial margin of the articular facet, dotted line = medial margin of the pedicle, dot-dash line = lateral margin of the pedicle. These landmarks are used to separate the left-central (LC), subarticular (SA), foraminal (F), and extra-foraminal (EF) zones.
and Type 3 changes are more associated with low back pain and instability, while Type 2 change is more frequently seen in degenerative disc disease and is less associated with back pain.\textsuperscript{38} The Modic classification system has been shown to have good interrater reliability.\textsuperscript{39}

More recently, a classification system for endplate changes based on morphology was proposed by Rajasekaran et al.\textsuperscript{40} This system grades defects in the endplate, with severity based on the area of the endplate involved. The authors demonstrated good correlation between increasing stage of endplate destruction and increasing degeneration of the associated disc.

### Facet Joints

Degenerative changes can occur in the facet joints independent of the presence of degenerative disc disease.\textsuperscript{41} Findings of degenerative disease in the facet joints include joint space narrowing, subchondral erosions and cystic change, osteophyte formation, and synovial cyst formation (Figure 6). Weishaupt et al utilized these features to develop a grading system for facet disease on MRI.\textsuperscript{13} (Table 2). This system was found to have moderate to good agreement with CT grading of facet disease, and excellent agreement when allowing for differences of only one grade. This was the only system for MR facet joint degeneration grading recommended by Kettler et al following their literature review.\textsuperscript{20}

Superimposed on independent degeneration of the facet joints, loss of disc height can produce a cascade of events causing increased degeneration of the facet joints and surrounding structures. Loss of height causes abnormal contact of the superior tip of the superior articular process of the subjacent vertebra with the undersurface of the pedicle of the suprajacent vertebra. Additional abnormal contact forms between the inferior tip of the inferior articular process of the suprajacent vertebra with the posterior surface of the pars interarticularis of the subjacent vertebra. These contact points cause additional degenerative remodelling, osteophyte formation, and neocyst/synovial cyst formation secondary to altered mechanical forces. These changes can lead to thinning and fractures of the pars interarticularis, neoarthroses of the superior articular facet/pedicle, and narrowing of the neural foramina. These changes are summarized and ac-

<table>
<thead>
<tr>
<th>Grade</th>
<th>Joint Space</th>
<th>Hypertrophy/Osteophytes</th>
<th>Subarticular Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal (2-4 mm)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Narrow</td>
<td>Mild/Small</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Narrow</td>
<td>Moderate</td>
<td>Mild erosions</td>
</tr>
<tr>
<td>3</td>
<td>Narrow</td>
<td>Severe/Large</td>
<td>Severe erosion and/or subchondral cysts</td>
</tr>
</tbody>
</table>

*Modified from reference 13
Ligamentum Flava

Ligamentum flavum thickening is a common finding in degenerative disease of the lumbar spine, manifested by increased thickness of low T1 and T2 signal along the posterolateral spinal canal (Figure 7). Debate remains about the etiology of the thickening of the ligamentum flavum seen in degenerative spine disease. Some authors suggest that this is due to true hypertrophy of the ligament secondary to increased fibrotic change in response to adjacent inflammatory markers. Others suggest that the thickening observed is not true hypertrophy, but rather buckling of a redundant ligament secondary to loss of disc height.

Structural sequelae

Spinal Stenosis

The previous section discussed the common degenerative findings affecting the ring of structures surrounding the thecal sac—at the endplates and discs anteriorly, the facet joints posterolaterally, and the ligamentum flavum posteriorly. There is conflicting evidence regarding the clinical significance of these findings in isolation and uncertainty regarding which degenerative findings are associated with low back pain. Indeed, a literature review by Brinjikji et al. found that the percentage of asymptomatic 80-year-old patients with disc degeneration, disc bulging and facet hypertrophy was 96%, 84%, and 83%, respectively. This uncertainty makes clinical correlation of back pain with imaging findings extremely difficult. However, these degenerative findings in combination often cause narrowing of the spinal canal and neural foramina with resultant compression of lumbar nerve roots. This compression results in radicular symptoms such as leg pain and weakness, which can be correlated with imaging findings of nerve compression.

As with disc herniation, there are multiple grading systems for nerve root compression in the spinal canal. Pfirrmann et al proposed a system to grade the effect of disc herniation on the lumbar nerve roots using three grades: contact of the nerve root, displacement of the nerve root (Figure 3A), and compression of the nerve root (Figure 4). This scale was found to have good interrater reliability and good correlation with surgical grading.

An alternate grading system was subsequently published by van Rijn et al, which used a 5-point scale that was subsequently dichotomized to either “no root compression” (for initial categories “definitely no root compression,” “possibly no root compression” and “indeterminate”) and “root compression” (for initial categories “possibly root compression” and “definitely root compression”).

A recent review of grading systems for lumbar disc herniations noted that while the van Rijn system was the most reliable grading system to date, the Pfirrmann system has been clinically correlated and demonstrates very good reliability at higher grades, allowing for accurate capture of symptomatic and clinically relevant lesions.

Neural Foraminal Stenosis

Classification systems for neural foraminal narrowing are based on the degree of effacement of perineural fat within the foramen on T1-weighted sagittal images (Figure 8). Two such systems were proposed by Wildermuth et al and Lee et al. Both systems use four grades that represent normal
foramina and mild, moderate, and severe foraminal narrowing (Table 3).

The clinical correlation of the Wildermuth and Lee systems was compared by Park et al. who concluded that while both systems had similarly excellent interrater reliability, the Wildermuth grading scheme more precisely reflected clinical symptoms, particularly in patients over 50 years of age.

Conclusion

Degenerative disease of the lumbar spine is a common condition that radiologists will encounter frequently. MRI is a mainstay in the assessment of low back pain and degenerative disease of the lumbar spine. This paper has reviewed the common findings affecting the vertebral bodies, intervertebral discs, facet joints, and ligamentum flavum, as well as the combined effects of these changes on the spinal canal and neural foramina. Multiple grading systems were presented, with supporting evidence, to help increase the accuracy and consistency when reporting these findings.

Table 3. Comparison of Wildermuth and Lee\textsuperscript{53,54} Foraminal Narrowing Classifications

<table>
<thead>
<tr>
<th>System</th>
<th>Normal</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildermuth</td>
<td>Perineural fat surrounds nerve root without indentation (grade 0)</td>
<td>Mild indentation of perineural fat still surrounds the nerve (grade 1)</td>
<td>Indentation of perineural fat only partially surrounding the nerve (grade 2)</td>
<td>Complete obliteration of perineural fat (grade 3)</td>
</tr>
<tr>
<td>Lee</td>
<td>Perineural fat surrounds nerve root (grade 0)</td>
<td>Perineural fat obliteration in two opposing directions without morphologic change (grade 1)</td>
<td>Perineural fat obliteration in four directions without morphologic change (grade 2)</td>
<td>Nerve root collapse or morphologic change (grade 3)</td>
</tr>
</tbody>
</table>

References