Imaging of degenerative lumbar intervertebral discs; linking anatomy, pathology and imaging

Ashok Adams,[1] Oran Roche,[2] Asif Mazumder,[3] Indran Davagnanam,[4] Kshitij Mankad[5]

[1]The Royal London Hospital, Barts Health NHS Trust, London, UK
[2]Department of Radiology, Barts Health NHS Trust, London, UK
[3]St George's Healthcare NHS Trust, Tooting, London, UK
[4]Department of Neuroradiology, National Hospital for Neurology and Neurosurgery, London, UK
[5]Department of Neuroradiology, Great Ormond Street Hospital for Children, London, UK

Correspondence to
Dr Ashok Adams, The Royal London Hospital, BartsHealth NHS Trust, Whitechapel Road, London E1 1BB, UK; ashokadams@hotmail.com

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ABSTRACT

Low back pain is a common medical condition that has significant implications for healthcare providers and the UK economy. Low back pain can be classified as 'specific' in which an underlying pathophysiological mechanism is identified (eg, herniated intervertebral disc). Advanced imaging should be performed in this situation and in those patients in whom systemic disease is strongly suspected. In the majority (approximately 90%), low back pain in 'non specific' and there is a weak correlation with imaging abnormalities. This is an area of ongoing research and remains controversial in terms of imaging approach and treatment (eg, theory of discogenic pain, interpretation and treatment of endplate changes). With regards Modic endplate changes, current research suggests that an infective component may be involved that may identify novel potential treatments in patients with chronic low back pain refractory to other treatment modalities. MRI is the imaging modality of choice for the assessment of degenerative changes in intervertebral discs. MRI has superior soft tissue contrast resolution when compared to other imaging modalities (eg, plain radiography, CT). An understanding of normal anatomy and MR appearances of intervertebral discs, particularly with regards to how these appearances change with advancing age, is required to aid image interpretation. Knowledge of the spectrum of degenerative processes that may occur in the intervertebral discs is required in order to identify and explain abnormal MRI appearances. As the communication of MRI findings may guide therapeutic decision making and surgical intervention, the terminology used by radiologists must be accurate and consistent. Therefore, description of degenerative disc changes in the current paper is based on the most up-to-date recommendations, the aim being to aid reporting by radiologists and interpretation of reports by referring clinicians.

INTRODUCTION

Low back pain is extremely common, and patients often undergo advanced imaging to guide treatment and exclude sinister pathology. The focus of this article is on imaging degenerative lumbar intervertebral discs and to combine anatomy and pathology with imaging findings on MRI. This includes various conditions including annular tears, disc herniations and vertebral endplate changes. The aim is to aid image interpretation by radiologists and increase awareness of the information MRI can provide to referring clinicians. The limitations of certain MRI findings is addressed, and current area of resaerch into Modic endplate changes is highlighted, as this has potential treatment implications for patients with chronic lower back pain.

An understanding of reports provided by radiologists is further aided through the use of standardised terminology for describing normal and pathological conditions of lumbar discs. The communication of these findings may guide therapeutic decision making and surgical intervention, therefore, the terminology used must be accurate and consistent. This is based on recommendations from the combined task forces of the North American Spine Society, American Society of Spine Radiology and the American Society of Neuroradiology.[1 2]

ANATOMY

Lumbar vertebrae are connected by intervertebral discs and ligaments designed to support axial compression and enable movement. Vertebral body endplates consist of a flat bony disc with an elevated rim (ring apophysis) producing a central depression covered by hyaline cartilage.[3] Between adjacent endplates is the intervertebral disc composed of the annulus fibrosus and nucleus pulposus. The annulus fibrosus is composed of concentric lamellae of fibrocartilage forming the circumference of the disc with the annuli inserting into the rounded apophyseal rings on the surface of the vertebral body (Sharpey's fibres). The nucleus pulposus forms the central core of the intervertebral disc and is located slightly posteriorly as the lamellae of the annulus fibrosus are thinner and less numerous posteriorly. The nucleus pulposus is more gelatinous with a higher water content enabling it to be distinguished from the annulus in the intervertebral discs of children and young infants.[4 5] In the young adult, the disc contour coincides with the margin of adjacent endplates.

On MRI, the intervertebral disc returns intermediate to low T1 signal intensity and high T2 signal intensity. With increasing age, there is a decrease in water and proteoglycan content of the intervertebral disc with a concomitant increase in collagen. As a result, the high signal intensity from the intervertebral discs on T2-weighted images gradually decreases with eventual formation of a 'black disc' (figure 1).[6] As early as the third decade, a horizontal band of low signal, called the intranuclear cleft, develops in the central part of the disc representing fibrous transformation of the gelatinous matrix of the nucleus pulposus.[7]

Vertebral notches are indentations formed by the projections of the body and articular processes above and below the pedicles. Between the superior and inferior notches of adjacent vertebrae is the intervertebral foramen, with the superior and inferior articular facets located posteriorly. Nerve roots in the lumbar spine leave the theca under the pedicle and exit thought the superior half of the

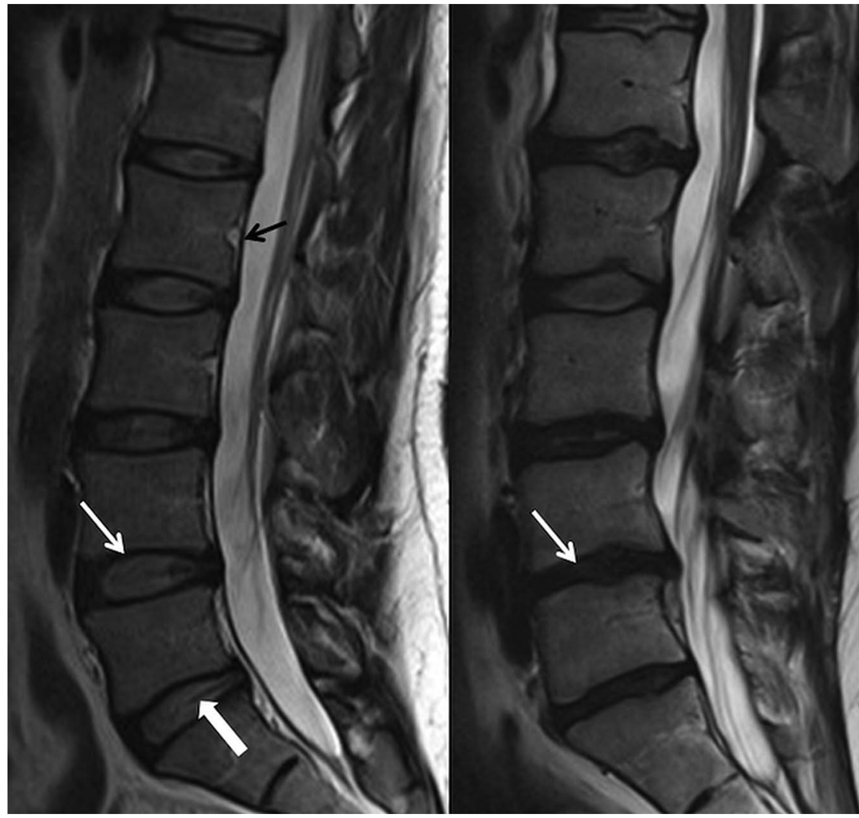

Figure 1 Sagittal T2 weighted images from a 31-year-old male patient (left hand image) and a 57-year-old male (right hand image) demonstrating the differences in the T2 signal within the intervertebral disc (thin white arrows) that occurs as part of the normal ageing process. The thick white arrow indicates the intranuclear cleft as a hypointense band within the T2 hyperintense disc. Note the emerging basivertebral vein identified as the T2 hyperintense area interposed between the posterior aspect of the vertebral body and posterior longitudinal ligament (thin black arrow).

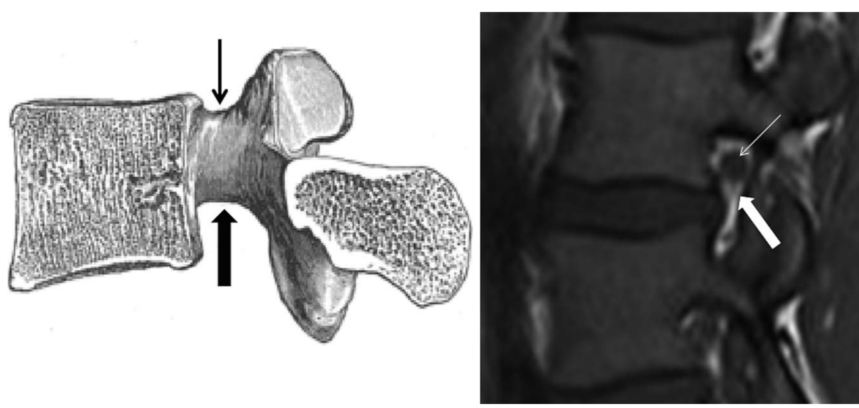

Figure 2 Superior (thin black arrow) and inferior (thick black arrow) vertebral notches of the lumbar vertebra. On the sagittal T1 sequence, the exiting lumbar nerve root (thin white arrow) exits via the intervertebral foramen between the superior and inferior vertebral notches. Epidural fat (thick white arrow) surrounds the nerve root as it exits below the pedicle.

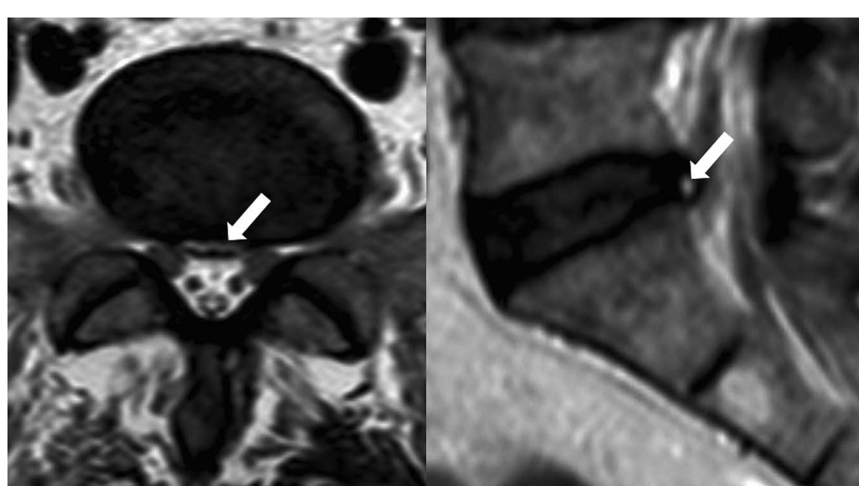

Figure 3 Axial and mid-sagittal T2 weighted images demonstrating a concentric annular fissure with the linear area of T2 hyperintensity representing the ‘high intensity zone’ (white arrow).

Figure 4 Intravertebral disc herniations or Schmorl's nodes (thin white arrows) that may be surrounded by reactive bone marrow changes (not present in this case).

intervertebral foramen along with recurrent meningeal nerves and radicular blood vessels (figure 2). The intervertebral joint forms the inferior half of the anterior aspect of the intervertebral foramen while the superior half is formed by the vertebral body of the superior vertebra. On MRI, assessment of the intervertebral foramen on parasagittal images demonstrates low signal from the exiting nerve surrounded by high signal from fat in the intervetebral foramen on T1 and T2 weighted images (figure 2).

The anterior longitudinal ligament is a strong fibrous band that overlies the anterior aspects of the vertebral bodies and intervertebral discs, extending from the pelvic surface of the sacrum to the anterior tubercle of C1 and basilar portion of the occipital bone. The posterior longitudinal ligament is narrower and weaker, overlying the posterior aspect of the vertebral bodies extending from the sacrum to C2 with extension superiorly as the membrana tectoria.[3 4] It is firmly attached to the intervertebral discs but it is separated from the posterior aspect of the vertebral bodies by the emerging basivertebral veins (figure 1). Ligamentous structures and cortical bone of the vertebrae return low signal on T1 and T2 weighted imaging.

Disc herniations typically occur posterolaterally where the annulus fibrosus is thin and poorly supported by longitudinal ligaments. The subarticular space, also known as the lateral recess, is used to describe the anterolateral portion of the spinal canal that is formed anteriorly by the posterior surface of the intervertebral disc and vertebral body, laterally by the pedicle and posteriorly by the superior articular facet.[1 2]

DEGENERATIVE/TRAUMATIC DISC DISEASE

Clinical features and epidemiology

Low back pain is a common medical condition, and according to a survey published in 2000, almost half the adult population of the UK report low back pain lasting for at least 24 h at some time in the year.[8] This has significant implications for healthcare providers and the UK economy, the total cost of back pain corresponding to 1–2% of gross national product.[9]

Low back pain is defined as pain, muscle tension or stiffness below the costal margin and above the inferior gluteal folds with or without leg pain.[3] It can be classified as 'specific', in which an underlying pathophysiological mechanism is identified (eg, herniated intervertebral disc, spondylodiscitis). In this situation, advanced imaging can identify the cause of serious spinal pathology or nerve root/radicular pain.

In the majority (approximately 90%), the back pain is 'non specific', and is classified according to duration.[3] Most patients make a good recovery and there is a weak correlation with imaging abnormalities, and a number of systematic reviews have shown that advanced imaging should be reserved for patients who are considering surgery, or in those in whom systemic disease is strongly suspected.[10] This is an area of ongoing research and remains controversial in terms of imaging approach

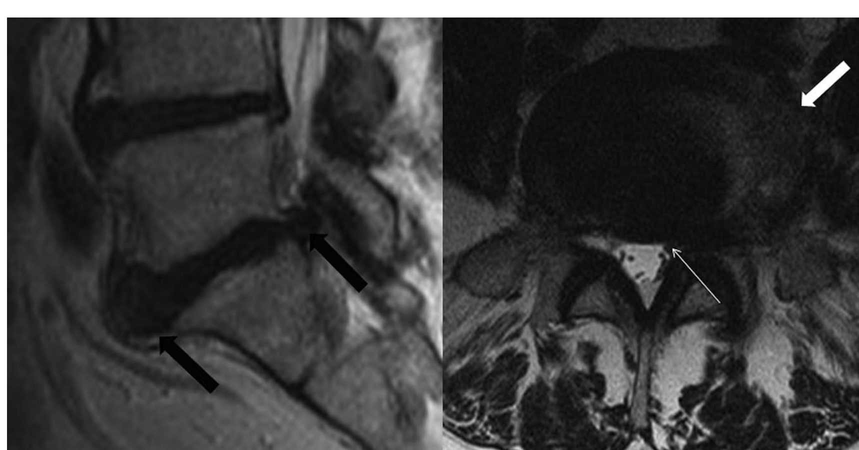

Figure 5 Sagittal and axial T2 weighted images demonstrating a circumferential disc bulge (thick black arrows) at the L5/S1 level with a prominent left lateral component (thick white arrow). There is bilateral subarticular space, and left-sided foraminal narrowing with contact with the forming left S1 nerve root (thin white arrow).

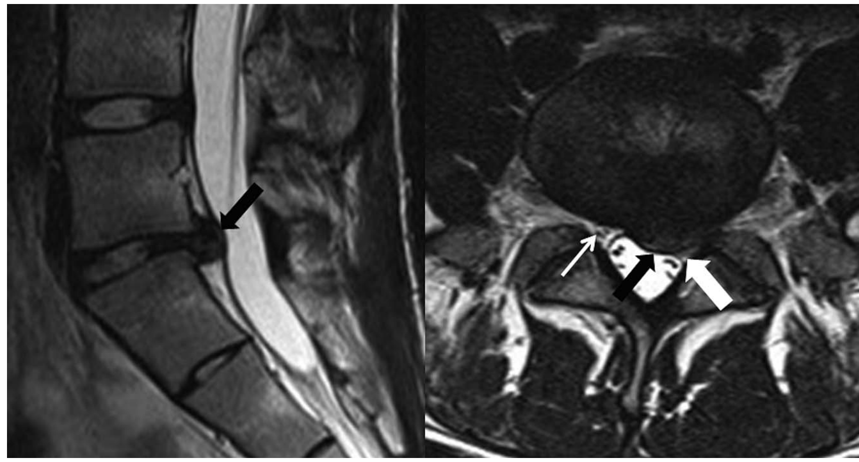

Figure 6 Mid-sagittal and axial T2 weighted images demonstrating a left-sided L5-S1 focal disc protrusion (black arrows) in a central and subarticular location as evident on the axial imaging. It is focal in that it involves less than 25% of the disc circumference, and it is a protrusion, as the base is wider than the distance between the protruded disc materials. This disc protrusion was contacting and displacing the transiting left S1 nerve root posteriorly (thick white arrow). The normal S1 nerve rootlets are also highlighted (thin white arrow).

and treatment (eg, theory of discogenic pain, interpretation and treatment of endplate changes).

PATHOLOGY AND IMAGING

Annular fissure/tear

An annular fissure or annular tear refers to separations between the annular fibres, avulsion of fibres from vertebral body insertions and breaks through the fibres in a radial, transverse or concentric pattern.[2] As a result, fluid and mucoid material fills the resulting gap. Concentric fissures are circumferential lesions found in the outer layers of the annulus, and represent splitting between adjacent lamellae of the annulus. (figure 3).[11] Transverse fissures result from disruption of the attachment of the annulus (Sharpey's fibres) to the bony ring apophyses. A radial annular fissure begins within the centre of the disc (nucleus pulposus) and progresses in an outward or radial direction either in the transverse plane or in a cranio-caudal direction.

It has been proposed that fissures are the result of spinal instability and degenerative disc changes.[12] Degenerative discs are more fibrous and less elastic, due to loss of water and glycosaminoglycans with increase in collagen, and they are damaged by overload and repetitive microtrauma. Fissures may be asymptomatic and identified as an incidental finding, and are considered by some authors to represent an insignificant part of the ageing process.[13 14] However, given that there are nociceptive pain receptors in the outer annulus, they can be symptomatic and hence clinically relevant.[15–17] The theory of 'discogenic' pain relates to chronic back pain thought to be due to leakage of nucleus pulposus into the outer annulus or epidural canal without frank herniation thus can occur without modification of disc contour.[18] Therefore, disc rupture may result in pain in the absence of direct contact between extruding disc material and nerve root, the theory being that the herniated disc material inititates an inflammatory reaction.[15–17]

Discography is more sensitive for detecting radial annular tears than MRI, however, this is an invasive test that involves injection of the nucleus pulposus with contrast material.[19 20] Annular fissures produce a detectable change in signal intensity on T2 weighted MR images sometimes with a peripheral focus of high signal intensity often referred to as the 'high intensity zone' (HIZ, figure 3).[21–25] This HIZ is in contrast with the low signal annulus, and brighter than the nucelus pulposus.[25] The hyperintensity can be linear or globular in appearance and may enhance following intravenous injection of a paramagnetic contrast agent.[26] This enhancement on gadolinium-enhanced T1-weighted images results from a combination of blood vessels that grow into the disc and granulation tissue.[27] On precontrast T1-weighted images, the extradural inflammatory process is identified by intermediate signal material replacing fat.[28]

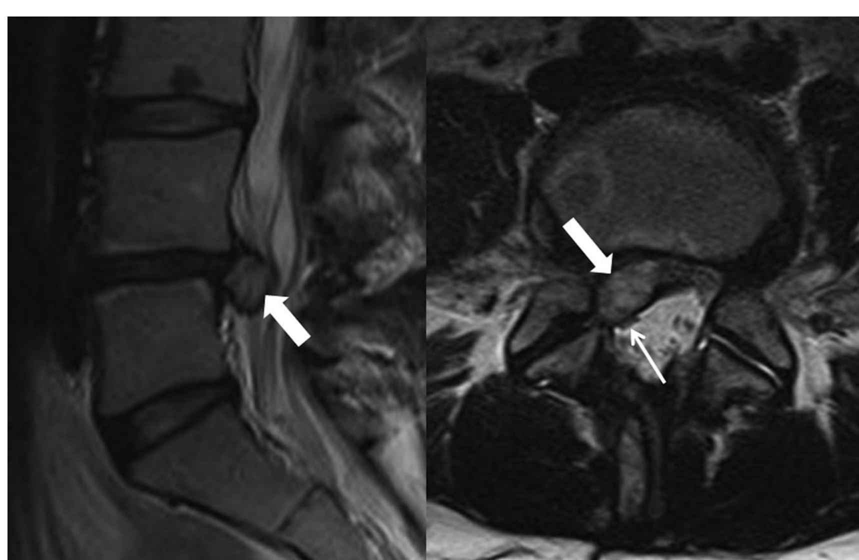

Figure 7 Para-sagittal and axial T2 weighted images demonstrating a focal L4-L5 disc extrusion (thick white arrows). It is focal in that it involves less than 25% of the disc circumference, and it is an extrusion, as the width of the extruded disc material is wider than the base from which the material herniated. The focal disc extrusion is contacting the descending right L5 nerve root (thin white arrow).

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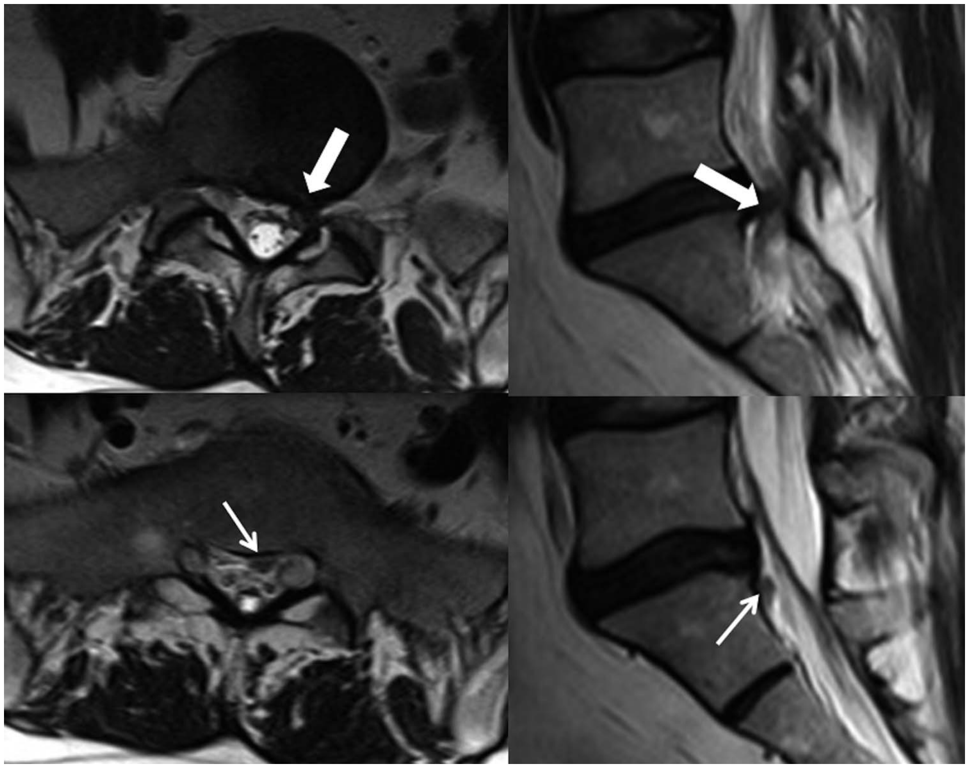

Figure 8 Axial and sagittal T2 weighted images that demonstrate a left-sided focal disc protrusion contacting and displacing the forming left S1 nerve root (thick white arrow). More inferiorly, there is a small sequestered fragment posterior to the S1 vertebral body in a central location (thin white arrow). This had lost continuity with the parent L5/S1 disc, and was confirmed following surgical intervention.

However, the significance of annular fissures and identification of the HIZ remains an area of controversy. Subsequent studies have questioned whether the HIZ represents a specific finding of symptomatic internal disc degeneration.[29–31]

Disc herniation

The localised displacement of disc material beyond the limits of the intervertebral disc space results in a herniated disc but the exact causative pathological processes have not been fully elucidated. The disc space itself is defined craniad to caudad by the vertebral body endplates and peripherally by the outer edges of the ring apophyses (this is exclusive of osteophytes that may have formed). Herniated disc material consists of one or more of the following; nucleus pulposus, cartilage, fragmented apophyseal bone and annular tissue.[1 2]

In order to be considered herniated, disc material must be displaced from its normal location. This includes herniations via the vertebral endplates which are referred to as intravertebral herniations or Schmorl's nodes (figure 4). It has been proposed that intravertebral herniations occur via weak points in the endplates at the site of vascular channel regression, and often there are reactive bone marrow changes.[32]

The presence of disc material circumferentially (ie, involving between 50% and 100% of the periphery of the disc) is referred to as a generalised disc bulge and is not considered a form of disc herniation. Bulging can be symmetrical with equal displacement of disc material in all directions, or asymmetrical, and it can occur as part of the normal ageing process. However, it may be seen in advanced disc degenerative disease and

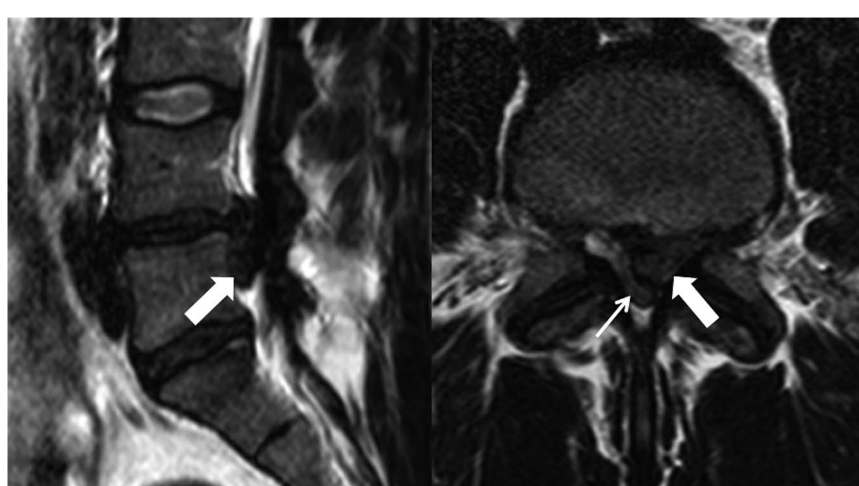

Figure 9 Parasagittal and axial T2 weighted images demonstrate a focal central and subarticular L4-L5 disc protrusion with caudal migration of the protruded disc material (thick white arrows). The disc protrusion can be seen to compress and efface the thecal sac with obliteration of cerebrospinal fluid signal (thin white arrow).

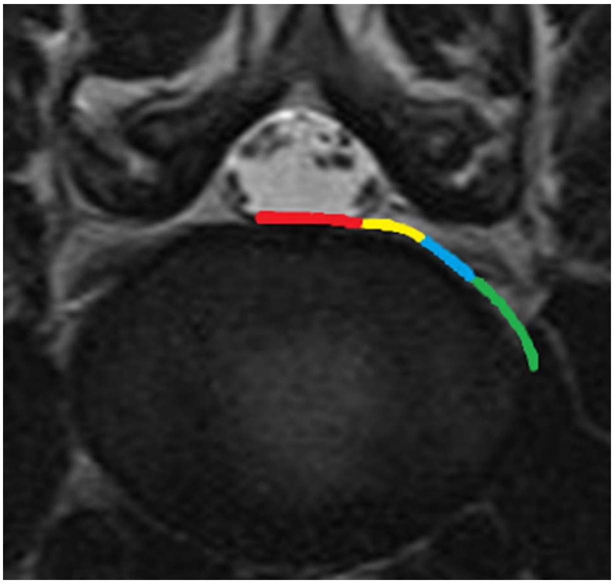

Figure 10 Axial T2 weighted image to demonstrate the geographical locations used to describe disc herniations. The divisions include the central (red line), subarticular/lateral recess (yellow line), foraminal (blue line), and extraforaminal/far lateral (green line).

circumferential disc bulges that have the potential to narrow the spinal canal and compromise the neural foramina (figure 5).

A localised disc herniation involves less than 50% of the periphery of the disc in an axial plane. This is subsequently divided into a broad-based disc herniation if it involves 25–50% of the disc circumference or a focal disc herniation if it involves <25% (figure 6).

Disc protrusion and extrusion are distinct entities with extrusion referring to protrusion of the nucleus pulposus in which there are no overlying intact annular fibres. This distinction cannot be reliably made on MRI, therefore, a herniated disc is considered protruded if the greatest distance (in any plane) measured between the edges of the disc material is less than the distance between the base of the disc (in the same plane) (figure 6). The base is defined as the area of disc material at the outer margin of the disc space from which the herniated disc material originated.

A herniated disc is referred to as extruded if, in at least one plane, the distance between the edges of the disc material is greater than the distance between the edges of the base (figure 7). Extrusion can result in sequestration, also known as a 'free fragment', if the displaced disc has lost all continuity with the parent disc (figure 8). The term 'migration' refers to the displacement of disc material away from the site of extrusion

Figure 11 Sagittal and axial T2 weighted images a left-sided L5-S1 foraminal/far lateral focal disc protrusion (thick white arrows). This has resulted in posterior displacement of the exited left L5 nerve root (thin white arrows).

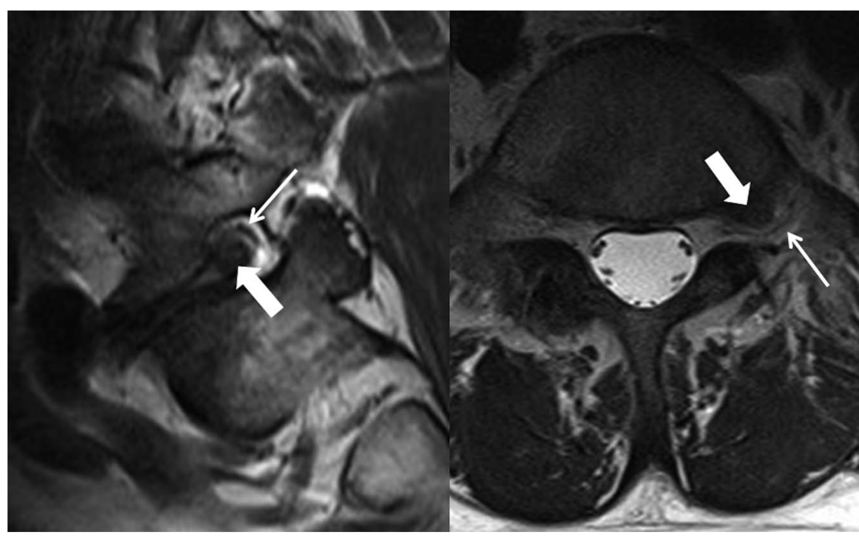

Figure 12 Parasagittal T1 weighted image and axial T2 weighted image demonstrate a left-sided L5-S1 broad-based disc herniation (thick white arrows) with a foraminal and far lateral components. On the parasagittal image, note the effacement of the epidural fat in the left L5-S1 intervertebral foramen (thin white arrow) when compared to the normal left L4-L5 intervertebral foramen (white arrowhead).

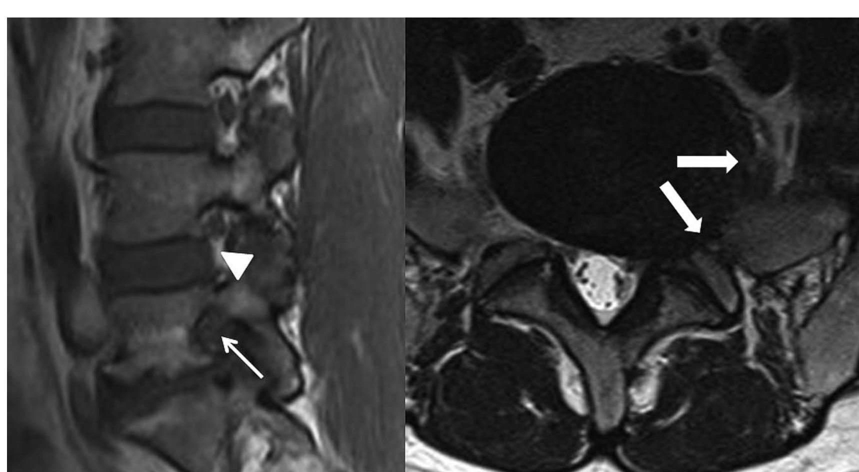

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Figure 13 Sagittal T1 weighted image to demonstrate the geographical locations used to describe disc herniations in a sagittal plane. The divisions include suprapedicular, pedicular, infrapedicular and disc levels.

regardless of whether it is sequestered or not. This migration may occur cephalad or caudad, but accurate description is required as it has implications for surgical intervention and approach (figure 9).

A system for classifying the geographical location disc herniations and migrated fragments has been developed based on anatomical landmarks familiar to surgeons.[33] In the axial plane, divisions include the central, subarticular, foraminal, extraforaminal/far lateral and anterior zone (figure 10). Extraforaminal/far lateral disc protrusions are easily overlooked (figures 11 and 12). In a sagittal plane, the divisions include suprapedicular, pedicular, infrapedicular and disc levels (figure 13). In addition to defining the location of the herniated disc or migrated fragments, an indication of the degree, canal compromise, and foraminal involvement, can also be provided. A commonly used method is to assess the degree of canal/foraminal narrowing in terms of thirds where <1/3 mild, 1/3–2/3 moderate, >2/3 severe.[1 2]

Grading systems have also been devised to help describe the severity of compression when using MRI to assess nerve compression through disc herniation. One grading system by Pfirrmann *et al*[34] relates to MRI evaluation and reporting of nerve root compromise. Grade 0 is described when no compromise of the nerve root is evident, with no contact with disc material, and preservation of the epidural fat between the nerve root and the disc material. Grade 1 relates to contact between the disc material and the nerve root, with no epidural fat layer evident between the two. In Grade 1 there is contact but no deviation. Grade 2 describes displacement of the nerve root by the disc dorsally, but with no compression of the root. In Grade 3, there is visible compression of the nerve root between the disc and the spinal canal, and the nerve root can be flattened or indistinguishable from the disc material.

The classification systems described are aimed at standardising and simplifying descriptive reporting, but this remains subject to interobserver variability.[35 36] There remains a need to standardise the nomenclature and classification system as demonstrated by the work of Kettler and Wilke[37] which identified up to 42 different grading systems for the assessment of cervical and lumbar disc/facet degeneration.

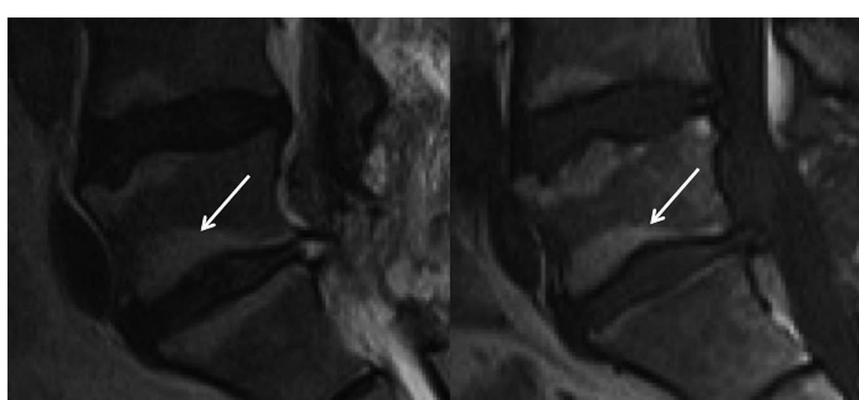
Vertebral endplate changes

Modic *et al*[38] described reactive degenerative changes that occur in vertebral endplates and subchondral bone. The changes are commonly observed on MRI and occur more frequently with ageing.[39] The changes more often involve both endplates, but one endplate or a segment of one endplate can also be involved. The modic classification is reliable with excellent interobserver and intraobserver reliability and includes[40]

- *Type 1 change*: Low T1 and high T2 signal intensity. This correlates with acute/subacute inflammation and disruption/fissuring of endplates with vascularised fibrous tissue and bone marrow oedema. Type 1 changes often transform into Type 2 changes.[41]
- *Type 2 change*: High T1 and intermediate/high T2 signal intensity due to replacement of normal bone marrow with fat (figure 14).
- *Type 3 change*: Low T1 and T2 signal intensity due to reactive osteosclerosis. Types 2 and 3 changes typically remain stable on imaging.

Type 1 Modic changes are commonly observed in, and associated with, low back pain.[42 43] Furthermore, infection is one of the proposed causes of bone oedema underlying Modic Type 1 changes.[44] *Propionibacterium acnes* has been postulated as a possible pathogen. The bacterium secretes propionic acid which has the potential to dissolve fatty bone marrow, and bone and may account for the Modic changes. In studies limited to patients with chronic lower back pain for >6 months, and with Modic type 1 changes following

Figure 14 Sagittal T2 and T1 weighted images in a patient with a focal disc protrusion and annular tear at L5/S1. There are Modic type 2 endplate changes noted at the L4/L5 and L5/S1 levels with high signal on T1 and T2 weighted sequences (white arrows).



Main messages

- Low back pain is extremely common, and advanced imaging with MRI is reserved for cases where a sinister cause needs to be excluded and cases of specific back pain that are likely the result of an underlying pathophysiological mechanism (eg, herniated intervertebral disc).
- In most patients with low back pain, the pain is non-specific and most patients make a good recovery. Additionally, there is weak correlation with imaging abnormalities in this patient group.
- Annular fissures are a potential source of discogenic back pain, and are readily identified on MRI, however, the significance of this finding remains an area of controversy.
- Disc herniations may account for radicular nerve root pain. MRI can identify the site of neural impingement, and with the use of a standardised classification system, the reporting radiologist can accurately describe the site of disc herniation in order to guide subsequent therapeutic intervention.
- Vertebral endplate changes, particularly type 1 Modic changes, are associated with low back pain. MRI can accurately distinguish between the different subtypes of endplate changes.

Current research questions

- Low back pain is very common, and MRI can accurately demonstrate degenerative intervertebral disc disease. However, how accurate is the correlation between imaging findings and clinical symptoms, and what is the optimal timing for the use of advanced imaging with MRI?
- With regards to annular fissures, does the high-intensity zone represent a specific finding of symptomatic internal disc degeneration?
- Is there an infective component in patients with Modic Type1 endplate change, and could antibiotic treatment in certain patient subgroups be of benefit?

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Self assessment questions

Please answer true (T) or false (F) to the below,

1. Material that may displaced beyond the limits of the intervertebral disc space as part of a herniation includes
   A. Nucleus pulposus
   B. Cartilage
   C. Fragmented apophyseal bone
   D. Annular tissue
   E. Ligamentum flavum
2. The geographical location of a disc herniation in an axial plane includes
   A. Far lateral
   B. Central
   C. Subarticular
   D. Infrapedicular
   E. Foramina
3. A focal disc herniation involves what following % of the disc circumference
   A. <25%
   B. <50%
   C. >75%
   D. >50%
4. Are the following statements true or false?
   A. Herniated disc is referred to as extruded if, in at least one plane, the distance between the edges of the disc material is greater than the distance between the edges of the base
   B. Disc extrusion refers to protrusion of the nucleus pulposus in which there are intact overlying annular fibres.
   C. Migration refers to the displacement of disc material away from the site of extrusion
   D. A localised disc herniation involves more than 50% of the periphery of the disc in an axial plane
   E. An annular fissure refers to separations between the annular fibres, and may be identified in asymptomatic individuals
5. The geographical location of a disc herniation in the sagittal plane includes
   A. Suprapedicular
   B. Pedicular
   C. Infrapedicular
   D. Disc
   E. Subarticular

a lumbar disc herniation, antibiotic treatment was associated with improvement in clinical and MRI parameters.[45] Further work is required to confirm this association and to determine if other patient groups would benefit from similar treatment.

CONCLUSION

The anatomy and pathology of degenerative intervertebral discs has been provided with an explanation for the corresponding appearances on MRI. An understanding of annular tears, disc herniations and vertebral endplate changes is important for radiologists and clinicians who assess patients with low back pain, and subsequently request further imaging. MRI can identify the cause of patients presenting with ‘specific’ back pain particularly in patients presenting with radicular pain secondary to degenerative change.

The role of MR in patients with ‘non-specific’ back pain remains controversial, but it can identify patients with annular tears and those with Modic endplate changes. With regards to the latter, current research suggests that an infective component may be involved, and this may identify novel potential treatment in patients with chronic low back pain refractory to other treatment modalities.

Throughout the article, an attempt has been made to use standardised terminology as recommended by guidelines from the American Task force. It is important that radiologists and clinicians use and recognise accepted descriptive terms in the assessment of lumbar spine disc disease, especially when this is used to guide further intervention.

Contributors All authors contributed to this article.

Competing interests None.

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Answers

1. A-T, B-T, C-T, D-T, E-F
2. A-T, B-T, C-T, D-F, E-T
3. A-T, B-F, C-F, D-F, E-F
4. A-T, B-F, C-T, D-F, E-T
5. A-T, B-T, C-T, D-T, E-F

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Imaging of degenerative lumbar intervertebral discs; linking anatomy, pathology and imaging

Ashok Adams, Oran Roche, Asif Mazumder, Indran Davagnanam and Kshitij Mankad

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