Magnetic resonance imaging (MRI) provides excellent visualisation of the soft tissue anatomy of the spine but it is recognised that imaging findings may often inadequately explain the clinical findings, particularly with regard to degenerative conditions of the lumbar region. Gravity may play a role in this limited clinical correlation. After all, humans uniquely have evolved to adopt an erect posture and, as a result, the lower spine, pelvis and lower limbs are exposed to load stresses that the upper body evades. This postural nuance is not reflected on routine supine magnetic resonance imaging (MRI). It is logical then to surmise that MRI acquired in the upright posture may benefit the diagnostic pathway.

The advent of upright MRI has allowed imaging to be performed in the erect posture but also with flexion, extension or rotation and in bending positions or, indeed, in any position that precipitates the patient's symptoms. In utilising this strategy, upright MRI may uncover findings that were not visible with routine supine imaging. Assessment of the degree of spinal stability in the degenerate and post-operative lumbar spine is also possible. This article will discuss the limitations of imaging the lumbar spine in the supine posture and will demonstrate examples of pathology revealed by upright MRI.

From the myelography images of figure 1, acquired in standing flexion, neutral and extension positions respectively, it is clear that lumbar spine flexion maximises the dimensions of the spinal canal and this phenomenon is evident also within the neural exit foramina. Further, in the supine position, where the hips and knees are held in a flexed position and the lumbar spine is closely applied to the imaging couch, the relative lumbar lordosis seen in the erect position is lost, as the patient effectively adopts a flexed spinal posture. Therefore, the true magnitude of spinal canal or foraminal stenosis will be reduced when supine imaging is employed, resulting in false negative diagnoses.

In the erect position, gravity increases the loads upon the spine in a caudal direction such that maximal loading is present on the lumbar spine and least upon the cervical spine. Consequent pressure effects upon the disco-ligamentous structures, employment of core and paravertebral muscles and relative motion between adjacent vertebrae are significant features in erect and dynamic postures which, in turn, affect the calibre of the spinal canal and neural foramina, particularly in the lumbar region. The clinical symptoms evident in sitting, standing, flexed, extended or other dynamic positions cannot be fully appreciated by the relatively passive supine position, where gravity has no role, that is traditionally employed for MRI acquisition.

The importance of gravity is demonstrated by the myelography images of figure 2. Image (i) reveals the normal dimensions of the spinal canal in the prone position but image (ii) reveals the complete spinal canal stenosis that is present in the standing position. This example elegantly demonstrates the positional dependence of spinal stenosis, which reflects dynamic changes in soft-tissue structures (ligaments, disc, dural sac, epidural fat and nerve roots) and highlights the issues of false negative results that may be obtained when the spine is imaged without considering the effects of gravity.

It is well established that weight-bearing radiographs of the knees, hips and spine are considered superior diagnosis as they reflect the effects of gravity when compared with supine imaging. Although simple to acquire, plain weight-bearing radiographs of the spine do not provide the soft tissue information that MRI delivers so exquisitely. Standing myelography, however, can provide some implied imaging of the neural structures but, as the intrathecal contrast falls to the lumbosacral region when the erect posture is adopted, only the lower lumbar spinal canal and foramina can be imaged. Additionally, the risks of ionising radiation, infection, contrast reaction and headache must be considered. Axially loaded supine MRI has been used to simulate the effects of adopting an erect posture, but pressure effects upon the vertebrae are delivered uniformly throughout the spine and do not increase in the usual caudal direction and, also, core muscles are not activated. This device is not truly representative of the effects of the erect spinal posture.

Upright MRI
An MRI system has been developed to allow imaging under the influence of gravity (Upright MRI, Fonar Corporation, Melville, NY, USA) where a gap exists between two vertical electromagnets. A mid-strength 0.6 T horizontal field is generated between the magnets. A tilting table is sited between the magnets and can be positioned at any angle from a horizontal to a vertical position, allowing supine and standing imaging. An MRI compatible seat can be added to allow imaging in the seated position.

Although the lower field strength of the system results in a reduced signal to noise ratio and, therefore, reduced overall image quality when compared with high-field magnets, it is certainly adequate for diagnostic purposes. Movement artefact may be an issue if the patient is being imaged in the position of extreme pain. Positively, this mid-strength system has fewer issues with chemical shift and metal blooming artefact when compared with higher strength systems, therefore, has some advantages in imaging the post-operative spine laden with hardware.

The brain, cervical and cerebral vessels and large joints of the body can also be imaged adequately by this 0.6T system and are often performed in the seated position for comfort. The standing position is employed for imaging the hips and pelvis. Images acquired in the standing position are prone to degradation from movement artefact. The patient must remain motionless in the standing posture and this is rarely achievable for more than 10 minutes before the threat of a vasovagal episode occurs. But the seated position, while more comfortable and stable, may underestimate the true extent of disease due to relative flexion of the lumbosacral junction that is adopted when sitting, as the sacrum is employed to support the weight of the spine. Therefore, in order to simulate the lumbar lordosis that exists when standing, the spine is imaged in the seated position and in extension. This recreates the true upright posture, provides greater stability and, therefore, less degradation from movement artefact and ensures the appropriate weight bearing effects are present upon the spinal column.

Extension is achieved by placing a small cylindrical cushion just above the lumbosacral junction, with the thoracic spine supported by the backrest of the seat. Flexion is
achieved by leaning forward and stability is ensured by resting the arms onto a horizontal bar to support the weight of the upper body. The extent of flexion and extension that can be performed is limited by the physical parameters of the chair and the position that the patient can most comfortably hold without movement. A dedicated lumbar spine quadrature coil is used for signal acquisition.

With the couch placed between two vertical magnets, there is no surrounding hardware in front of the patient. A 42-inch television and supply of DVDs is provided for the patient’s entertainment. This design provides comfort for claustrophobic patients and children alike and may reduce the need for sedation. It is also practical for patients with extreme spinal deformity, such as severe kyphosis or scoliosis, and the grossly obese. Patients who cannot lie in the recumbent position due to cardiac or respiratory conditions may find MRI in the upright position entirely possible.

**Imaging protocol**

The imaging protocol for upright MRI of the lumbar spine includes standard sagittal T1-weighted (T1w) fast spin-echo (FSE) and sagittal and axial T2-weighted (T2w) FSE sequences through the lumbar spine in the upright neutral seated position. Seated flexion and extension sagittal, and extension axial T2w FSE images are performed when positional MRI is requested. This may be supplemented with sagittal and axial T2w FSE sequences acquired in the standing position. Standing images are acquired with a 7° tilt off the vertical plane in order to provide some support in order to reduce image degradation from movement artefact. All images are obtained with 4.5mm section thickness and 0.5mm gap. Acquisition time is between 2 and 4 minutes per sequence.

**Clinical features**

The lordotic posture adopted by the lumbar spine in the standing position effectively distributes the weight of the upper body through the posterior aspects of the lumbar disco-vertebral units. This creates a concertina effect upon the soft tissue elements of the spine. In this situation, the disco-vertebral units. This creates a concertina effect upon the soft tissue elements of the spine. In this situation, the normal disc may demonstrate no change or a minor reduction of the height of its posterior border. The degenerate disc, however, exaggerates this phenomenon. These features are demonstrated on figure 3, whereby the position and alignment of the endplates is highlighted by the annotations. It is clear that the normal L3/4 disc maintains its height and appearance in the upright posture (ii), but the degenerate L4/5 and L5/S1 discs reduce their posterior height on adopting the upright position (ii).

Indeed, if a small disc bulge is evident on supine imaging, it may become a prominent disc herniation when imaged in the upright posture as the hydrostatic cushioning properties of the normal disc are lost and the degenerate disc becomes less able to withstand the associated compressive forces. This phenomenon is demonstrated by the L4/5 discs of figures 3 and 4.

Further, upright MRI may reveal annular tears hitherto hidden on supine studies. Often small disc bulges are revealed in association with the tears.

The soft tissues of the posterior elements of the vertebral, such as the ligamenta flava and the dorsal epidural fat, also undergo buckling effects and, similarly, facet joint cysts may be exposed. These appearances are demonstrated by figures 4, 5 and 6 respectively.

Although upright MRI may adequately reveal changes in the appearance of the individual elements of the disco-vertebral unit, it is the combination of these features that provides clinical relevance. Once the upright posture is adopted, the more prominent disc herniation seen anteriorly and the buckling of tissues posteriorly will circumferentially encroach upon the calibre of the spinal canal and together may result in significant narrowing or stenosis of the spinal canal, lateral recesses and the neural exit foramina (figure 7). As a consequence, compression of nerve roots within the foramina and the nerve rootlets of the cauda equina may be revealed and diagnoses may be made with upright MRI that were previously not possible with supine MRI.

Instability is often considered as a possible diagnosis in the symptomatic instrumented post-operative spine. Plain x-rays may demonstrate postural changes of alignment but will not reveal the effects of instability upon the neural elements of the spine as upright MRI might. Further, the 0.6T field strength of the upright MRI produces limited artefact from the hardware when compared with the traditional MRI systems and so may demonstrate the neural elements more adequately in this regard too. Figure 8 demonstrates an interspinous distraction device sited between adjacent spinous processes. These devices are used in order to impose a fixed flexed posture upon the lumbar spine. They are used in spinal canal stenosis to widen the calibre of the canal and reduce the compressive effects upon the neural elements, as demonstrated by the principle of figure 1. However, on adopting the upright posture (ii) it is clear that the dynamic and gravitational forces upon the spine have overcome the device in this case and spinal canal stenosis is revealed in the physiological upright posture that would have hitherto remained undiagnosed by any other imaging means.

This article has illustrated how MRI acquired in the upright posture can demonstrate changes that develop within the individual components of the degenerate or post-operative spine, which in turn can reveal associated compressive effects upon neural structures that could not be imaged directly by any other imaging method. Upright MRI has clear advantages over supine imaging and may be used as first line MRI for the spine or as an adjunct if supine MRI is non-diagnostic.

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All images are supplied courtesy of The London Upright MRI Centre. Telephone: 020 7637 2888. Website: www.uprightmri.co.uk

**References**


**Further reading**


FIGURE 1
Standing myelogram images acquired in flexion (i), neutral (ii) and extension (iii) positions demonstrating a disc herniation at the level above the pedicles screws. The compressive effect upon the spinal canal is minimal in the flexion position and maximal in the extension position.

FIGURE 2
Prone (i) and standing (ii) left posterior oblique myelogram images, revealing spinal canal stenosis only when the erect posture is adopted.

FIGURE 3
Image (ii) demonstrates the compression and buckling of the posterior aspects of the degenerate discs that occurs in the upright posture. The normal L3/4 disc is not altered in appearance.

FIGURE 4
Upright MRI in sagittal plane (ii) reveals spinal canal stenosis at the L4/5 level due to greater prominence of the disc herniation and buckling of the dorsal epidural fat.

FIGURE 5
Upright MRI in axial plane (ii) reveals spinal canal narrowing and lateral recess stenosis due to greater prominence of the disc herniation with buckling of ligamenta flava and dorsal epidural fat.

FIGURE 6
Upright MRI in axial plane (ii) reveals spinal canal narrowing and lateral recess stenosis due to buckling of ligamenta flava and increase in size of facet joint cyst.
FIGURE 7
The L3 and L4 neural exit foramina demonstrate significant narrowing with crowding of emerging nerve roots when the upright posture is adopted (ii).

FIGURE 8
Despite the fixation of an interspinous spacer device, spinal canal and lateral recess stenosis is present on adopting the upright posture (ii).