ORIGINAL ARTICLE

Imaging-based planning for spine surgery

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Abstract

The planning of decompressive and reconstructive spine surgery is based on clinical findings and diagnostic imaging. The evaluation of segmental instability, but also of the risk of destabilization following a needed decompression of the spinal canal and/or neural foramina make complex spine surgery a challenge, bearing in mind the risk of failures in case of an inadequate operation. The insufficient correlation between imaging and clinical symptoms originating from the spine and its nerve roots has been frustrating for some decades. This review focuses on the new upright, dynamic-kinetic, i.e., “functional” MRI and its ability to detect load- and motion-dependent disc herniations, stenosis, instabilities, and combinations of these pathologies not seen during recumbent imaging.

Key words: Spine MR, functional imaging, spine instability, upright MRI (fmri), intervertebral disks, stenosis

Introduction

The insufficient correlation between diagnostic imaging and clinical symptoms originating from the spine is an increasingly discussed problem among spine surgeons. It is currently experienced in daily practice not only during preoperative planning discussions, but also during surgery, where pathologic findings underreported by the radiologists have to be dealt with.

In a comment for the Journal Spine (1), Gollogly recently pointed out the lack of concordance between the position in which patients experience pain and the positions that are amendable to plain film, computed tomography, or magnetic resonance imaging.

Dynamic changes in all the planes (including sagittal alignment) that occur under loading and during motion are not yet completely understood and must play a significant role when researching why and when symptoms occur in the degenerative, but also in the posttraumatic spine.

The evaluation of dynamic compressions of neural structures related to a decrease of spinal stability have up to now been investigated by functional myelogram and postmyelographic CT Scan or by MRI and dynamic conventional radiographs (2). There is a need for future developments in functional clinical imaging in order to help all of us to better understand the pathophysiology of the spine by showing pictures correlating to the complaints and the clinical findings, including neurological abnormalities of the patients.

Imaging of the spine during axial loading and during kinetic maneuvers is now feasible with a top-front open MRI unit (Upright Multi-Position(TM) MRI, FONAR Corporation, Melville, NY, USA). The first imaging studies obtained at the fmri center in Zurich (3–5) confirm the positive statements made by the pioneers, as published by Jinkins et al. (5–9), Smith et al. (10), and Weishaupt et al. (11).

Patients with a history of recurrent positional or motion-dependent pain and/or neurological dysfunction of the cervical and lumbar spine were investigated in the upright-seated or standing position, including neutral and flexion-extension imaging.

Recent clinical results and illustrative cases

A position-dependent appearance or increase of posterior disc protrusions, a varying degree of central canal and foraminal stenosis, and of mobile spinal instability including spondylolisthesis has been
demonstrated in cases where preceding recumbent MRI examinations have yielded less remarkable or even negative results (3–5). Other case examples include cervical and lumbar unilateral and bilateral spinal instability, lateral, rotational instability, dynamic spinal cervical and lumbar stenosis and position-dependent disc herniations.

A Type I Chiari Malformation, with positional increase of cerebellar tonsils downward herniation and brainstem compression was identified in a patient studied for a C5/6 degenerative disc disease. At this level an increased disc protrusion and segmental kyphosis were seen during upright imaging (12).

Functional magnetic resonance imaging (fmri) revealed a dynamic stenosis with a L4/5 synovial cyst compressing the thecal sac during retroflexion only, where the anteroposterior diameter of the canal additionally decreased. In the flexion study, only synovial fluid accumulation was visible inside the distended intervertebral joints, and no critical narrowing of the central canal (4).

Unilateral (left) sciatic pain in a football player could be correlated to a load and position-dependent left foraminal stenosis developing in upright position, and increasing even more in extension, while the diameter looked normal in flexion and recumbency (3).

In patients with prior spinal fusion procedures, motion and axial loading-dependent mobile stenosis/instability at an adjacent segment were detected.

A garage mechanic, who had undergone percutaneous discectomy and interbody grafting at L3/4 in 1990, with revision by posterior lumbar interbody fusion (PLIF) for nonunion in 1991, remained pain-free and able to work until early 2006. At that point, i.e. 15 years later, he developed a dynamic L4/5 stenosis...
with vertical instability and loss of lordosis. A L4/5 decompression with PLIF was now performed with good initial result (4).

Illustrative cases

A 69-year-old patient suffering from increasing leg pain during sportive activities five years after a L5/S1 decompression underwent an upright flexion-extension MRI which showed a stable L4/L5 anterolisthesis and a dynamic L3/L4 stenosis during retroflexion, without recurrent pathology at the operated L5/S1 level. He improved following a selective L3/4 decompression (Figures 1–3).

A 55-year-old woman developed increasing neck and left shoulder pain about 12 years after anterior cervical fusions, limiting her in her working and daily activities. Fmri revealed a bulging black C3/4 disc with a left-sided anterolisthesis, causing cord compression during anteflexion, whereas the alignment was almost normal during retroflexion. She improved after an anterior cervical fusion with an Ostapek cage filled with autologous bone (Figures 4 and 5).

A 28-year-old professional ice-hockey player experienced a transient quadripareisis following a body check. He subsequently recovered, but had some paresthesia and impaired coordination in the hands and feet for a few weeks. There were two high intensity lesions in the central cord behind the vertebral bodies of C3 and C4. Fmri disclosed a dynamic C3/4 stenosis during retroflexion, with disc herniation and unilateral retrolisthesis (Figures 6–8).

Discussion, future questions and direction

Intradiscal pressure changes occur according to the position of the individuum: The pressure is lowest in recumbent position and increases in standing,
Figure 3. The axial T2W extension image shows a marked L3/4 stenosis.

Figure 4. The upright extension fmri (left parasagital) shows a black C3/4 disc above a fusion performed 12 years before without evident malalignment.

Figure 5. In the upright flexion study from left to right, fmri reveals a unilateral left C3 anterolisthesis with cord compression.
sitting and even more in bended forward position – this was first studied and reported by Nachemson in 1976 (13). The logical drawback was that changes in a spinal motion segment could be seen more reliably during upright, functional imaging. Dynamic myelography may reveal unstable spondylolisthesis leading to a critical narrowing of the central canal, but foraminal pathologies are missed by this invasive technique, and unilateral instabilities remain mostly unrecognized.

Cartolari (14) promoted the axial-loaded CT and MR technology, where the effect of the body weight is imitated by pressing with 70% body weight on the patient’s shoulders, however in the recumbent patient.

Smith et al. (10) from the University of Aberdeen, Scotland, performed a study of 25 patients with low back pain and sciatica referred for lumbar spine Upright MRIs following at least one prior “normal” recumbent MRI within six months of referral. In 13

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Figure 6. Upright flexion T2W showing two high intensity lesions in the central cord behind the vertebral bodies of C3 and C4.

Figure 7. Upright extension T2W slices showing a dynamic a C3/4 disc herniation with a posterior buckling of the ligamentum flavum (left) and a unilateral left sided retrolisthesis of C3 compressing the cord (right).
patients (52%) fmri demonstrated abnormalities “in one or more of the seated postures that were not evident in the supine (or recumbent) examination”. There were three cases with lateral disc herniation, six cases with hypermobile disc at one or more levels, two cases with previously unsuspected Grade I spondylolisthesis and two cases with significant spinal canal stenosis. Each of the 13 patients had an appropriate surgery with successful outcome six months post-operatively.

By visualizing position-related alterations in the bony structures and the underlying soft tissues in the upright weight-bearing position, fmri enables the physician to make more accurate decisions regarding treatment options and alternatives, as compared to recumbent MRI. The targeted surgical treatment of previously undiagnosed dynamic neural compressions should allow to decrease the rate of the so-called “failed back surgery syndrome”. Likewise unnecessary long-term conservative management of now detectable mechanical spinal disorders – which we could call “failed back conservative treatment” – may be avoided.

There will be future indications for fmri to study the posttraumatic spine (15). We investigated e.g. two patients with head and neck pain who were found to suffer from a C1-2 instability following unrecognized odontoid fracture, several years after a car accident.

Fmri might also help us to better understand possible organic damages following “whiplash injuries”.

In cases of recurrent problems following a spinal fusion, postoperative functional MRI allows the detection of dynamic stenosis/disc protrusion and mobile spondylolisthesis at supra- and/or infradiscal levels, which is called ”adjacent segment disease“ (16). It may be promoted by insufficient correction of disc height and spinal balance (restoration of physiological lordosis, sagittal alignment) during surgery, but is often the manifestation of an ongoing multilevel degenerative disc disease.

Finally the proper function (17) or dysfunction of dynamic stabilizing implants can also be studied by fmri.

**Conclusion**

The actual results show that the correlation between patient complaints and imaging findings is improved by fmri. In the near future it could become the imaging modality required before performing complex spinal surgery. The need for dynamic myelograms will decrease, this invasive technique being useful for patients with ferromagnetic hardware, but not adequate to demonstrate intra-to extraradicular pathology.

Apart from degenerative disc disease and spondylolisthesis, juvenile scoliosis could potentially be followed benignly by serial fmri. As an added practical point, children can also sit in the Upright (TM) MRI scanner while in their mothers lap, and undergo basic cranial or spinal imaging mostly without sedation.

Fmri can also be used as an investigational tool, e.g. for whiplash injuries, but also to assess the pathophysiology of functional joint disease. There is a presently not used fmri-research potential in sports medicine, in minimally invasive technologies and robotics.

**References**

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