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Missed Lumbar Disc Herniations Diagnosed With Kinetic Magnetic Resonance Imaging

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Study Design. A novel dynamic magnetic resonance imaging (MRI) system, kinetic MRI (kMRI), was used to study lumbar disc herniations.

Objective. The objective of this study was to determine if adding flexion and extension MRI studies to the traditional neutral views would be beneficial in the diagnosis of lumbar disc herniations.

Summary of Background Data. Prior studies demonstrate that only 70% of patients with lumbar disc herniations based on physical examinations are confirmed by MRI studies. Recently, kMRI delivers the ability to scan patients in neutral, flexion, and extension positions, which may allow for improved diagnosis of this problem.

Methods. Five hundred fifty-three patients underwent kMRI with assessment of the degree of disc bulge in neutral and flexion and extension. The images were analyzed using computer measurement technology to objectively quantify the amount of disc herniation.

Results. For patients with normal or <3 mm of disc bulge in neutral, 19.46% demonstrated an increase in herniation to >3 mm bulge in extension, and 15.29% demonstrated an increase to >3 mm bulge in flexion. For patients in the neutral view that had a baseline disc bulge of 3 to 5 mm, 13.28% had increased herniations to >5 mm in extension and 8.47% had increased herniations to >5 mm in flexion. For patients with a baseline disc bulge of 5 to 7 mm in neutral, 10.58% increased in extension and 5.78% increased in flexion. In addition, for patients with a baseline disc bulge of 7 to 9 mm in neutral, 9.09% increased in extension and 4.55% increased in flexion.

Conclusion. A significant increase in the degree of lumbar disc herniation was found by examining flexion and extension views when compared with neutral views alone. kMRI views provide valuable added information, especially in situations where symptomatic radiculopathy is present without any abnormalities demonstrated on conventional MRI.

Key words: kinetic MRI, lumbar disc herniation, missed diagnosis. **Spine 2008;33:E140–E144**

Lower back pain is the second most common reason for physician visits in the United States, second only to colds and flu.[1] Americans spend at least $50 billion each year on low back pain. One common reason for lower back pain is herniation of the intervertebral disc into the spinal canal. In the United States in 2003, the National Hospital Discharge Survey reported that 3,57,000 procedures were performed for disorders of the intervertebral disc,[2] 8.5% higher than in 2000.[3]

Magnetic resonance imaging (MRI) is a good tool most frequently used for lumbar disc herniation because it can show abnormal areas of soft tissue around the spine. However, traditional MRI has significant limitations, although it reveals musculoskeletal disease. The patients are placed in a horizontal, nonweight-bearing position where conventional scans may not reveal the causative pathology. However, only 70% of patients who were diagnosed with a lumbar disc herniation based on clinical examination had a lumbar disc herniation confirmed by MRI.[4]

Recently, kinetic MRI (kMRI) permits us to image the patient in a weight-bearing position (either standing up or sitting), and in the flexed and extended positions, which can, of course, reveal abnormalities that were missed by a conventional MRI study. It may supply a more thorough investigation of each patient and allow us to better understand the true nature of the pathology. Imaging the spine in the weight-bearing position with extension and flexion or placing the spine in the position of pain may increase the diagnostic accuracy for the surgeons. The purpose of this study was to study the use of kMRI for evaluation of missed herniated discs when compared with conventional MRI studies and to determine the changes in the disc herniations according to the flexed and extended positions.

Materials and Methods

Study Population

From July 2005 through July 2006, 553 patients with symptomatic back pain with/without radiculopathy were referred to kMRI for lumbar MRI examination. There were 234 males and 319 females. The mean age was 46.2 years (range, 18–76 years). This represented 2765 lumbar discs in total.

Imaging Instrumentation

MRI of the lumbar spine was performed by using a 0.6 Tesla MRI scanner (Fonar Corp. UPRIGHTTM, Multi-Position, NY, NY). The MR unit uses a vertical orientation of the 2 opposing magnet doughnuts, allowing scanning of the patient in an upright axially loaded position. An 18-inch gap between the magnets is present. Images were obtained using a quad channel planar coil. T1 weighted sagittal spin echo images (repetition time 671 milliseconds, echo time 17 mil-

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liseconds, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, NEX 2) and T2 weighted fast spin echo images (repetition time 3000 milliseconds, echo time 140 milliseconds, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, NEX 2, flip angle).

Procedure

Patients were placed in the upright axially loaded neutral position (T1 and T2 weighted images) and upright axially loaded flexion and extension positions (T2 weighted Fast Spin Echo images only). Five-level units (L1/2, L2/3, L3/4, L4/5, L5/S1) were chosen from these patients and assessed on the T2-weighted midsagittal images.

For each film, points were marked for digitization by a fellowship-trained spine surgeon. From L1–S1, the vertebral body was marked as 4 points (corner of anterior-inferior, anterior-superior, posterior-superior, posterior-inferior) and disc height was marked as 2 points (middle of endplate), pedicle diameter and spinal cord diameter was marked as 2 points.

The disc bulge on MRI was recorded on computer-based measurement and all calculations were done using MRI Analyzer Version 3 (Truemetric Corp., Bellflower, CA) anatomic software to objectively quantify the amount of disc bulge in millimeters.

Evaluation

To ascertain the missed diagnosis of lumbar disc herniations, the extent of lumbar disc bulges in neutral, flexed, and extended views were graded as follows: grade 1, (no disc bulge or disc bulge, <3 mm); grade 2 (disc bulge, 3–5 mm); grade 3 (disc bulge, 5–7 mm); grade 4 (disc bulge, 7–9 mm); and grade 5 (disc bulge, >9 mm). All lumbar segments were evaluated and recorded. A functional disc bulge was considered present if the disc was bulged or was more bulged after lumbar flexion or extension. "More bulged" was defined by means of measurement of an increase in the bulged disc size after lumbar flexion or extension, which was considered a positive finding. This evaluation was performed by 2 spine surgeons independently without knowing the patient's history and clinical findings.

Statistical Analysis

The statistical significance was calculated using the χ^2 test and the paired *t* test. Data were analyzed with a software program (SPSS, version 13, Chicago, IL). All significance levels were set at $P < 0.05$.

■ Results

Dynamic Change in Lumbar Disc Herniations During Lumbar Extension and Flexion

On extension images, the pair *T*-test showed significant increases in disc herniation from the neutral position to the extension position at each level ($P < 0.005$). The results were as followed: L1/L2 (2.12 ± 1.06 *vs*. 2.39 ± 1.83 mm), L2/L3 (2.44 ± 1.24 *vs*. 2.69 ± 1.77 mm), L3/L4 (2.78 ± 1.28 *vs*. 3.08 ± 2.25 mm), L4/L5 (3.48 ± 1.59 *vs*. 3.82 ± 2.47 mm), and L5/S1 (3.45 ± 1.78 *vs*. 3.77 ± 2.58 mm). On extension images, the pair *T*-test showed significant differences only at L3/L4 and L4/L5 from the neutral position to the flexion position, L3/L4 (2.78 ± 1.28 *vs*. 2.68 ± 1.33 mm), L4/L5 (3.48 ± 1.59 *vs*. 3.34 ± 1.57 mm) ($P < 0.05$). There were no significant changes at L1/L2 (2.12 ± 1.06 *vs*. 2.15 ± 1.24 mm), L2/L3 (2.44 ± 1.24 *vs*. 2.36 ± 1.30 mm), and L5/S1 (3.45 ± 1.78 *vs*. 3.34 ± 1.70 mm) ($P > 0.05$) (Figure 1). Distribution of lumbar disc herniation among neutral, extension, and flexion images is showed in the Table 1. On neutral views, the disc bulge was classified as grade 1 in 1557 (56.31%) of the 2765 discs, grade 2 in 956 (35.58%), grade 3 in 208 (7.52%), and grade 4 in 44 (1.59%). 1254 in the grade 1, 1132 in the grade 2, 313 in the grade 3, 62 in the grade 4, 4 in the grade 5 were noted at extension images. 1319 in the grade 1, 1113 in the grade 2, 277 in the grade 3, 54 in the grade 4, 2 in the grade 5 were noted on flexion images (Table 1). Increased disc bulge at extension and flexion MRI was seen in 456 (16.49%) and 333 (12.04%) discs, respectively.

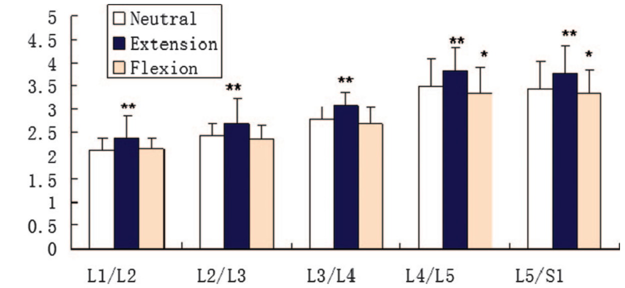

Figure 1. Bar graph shows dynamic changes in lumbar disc herniation during lumbar extension and flexion. The values of lumbar disc herniation (mean ± SD) in the extension and flexion views were compared with the neutral view (*$P < 0.05$, **$P < 0.01$).

Incidence of Missed Diagnosis of Lumbar Disc Herniation Showed by Extension and Flexion Images

On extension MRI in the grade 1 group, grade 1 of lumbar disc herniation was maintained in 1254 (80.54%) of the 1557 discs and progressed to a more advanced grade in 303 discs. The incidence of a missed diagnosis of a disc herniation in this group is 19.46%. In the grade 2 group, disc bulges in 829 (86.72%) of the 956 discs maintained grade 2, but 127 (13.28%) discs progressed to grade 3. In the grade 3 group on extension MRI, the disc bulge was more severe than in neutral position in 22 (10.58%) of the 208 discs and was maintained at grade 3 in 186 (89.42%). In the grade 4 group, disc bulge in 40 discs (90.91%) of the 44 discs maintained grade 4 and progressed to grade 5 in 4 (9.09%). The χ^2 test showed significant difference between these 4 groups for increasing disc herniation during extension ($P < 0.05$). On flexion MRI, lumbar disc herniations maintained grade 1 in

Table 1. Distribution of Lumbar Disc Herniation Among Neutral, Extension, and Flexion Images

	Grade 1 (0–3 mm)	Grade 2 (3–5 mm)	Grade 3 (5–7 mm)	Grade 4 (7–9 mm)	Grade 5 (>9 mm)
Neutral	1557	956	208	44	0
Extension	1254	1132	313	62	4
Flexion	1319	1113	277	54	2

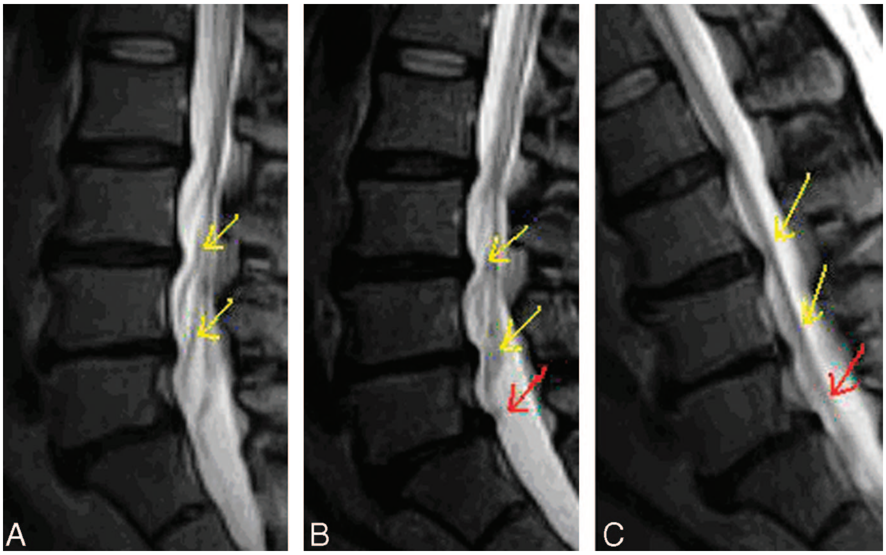

Figure 2. Lumbar disc herniation in a 58-year-old man. In the neutral position (**A**), T2-weighted sagittal MR image shows L2–L3, L3–L4, and L4–L5 levels disc herniation. In extension (**B**) and flexion (**C**), a new disc herniation (L5–S1 level) is noted. And more severe disc bulges are also seen in the both L3–L4 and L4–L5 levels.

1319 (84.71%) of 1557 discs and progressed to grade 2 in 238 (15.29%). In the grade 2 group, disc bulge in 875 (91.53%) of the 956 discs maintained grade 2 and progressed to grade 3 in 81 (8.47%). In the grade 3 group on extension MRI, disc bulge was more severe than that in neutral position in 12(5.78%) of the 208 discs and was maintained at grade 3 in 196(94.22%). In the grade 4 group, disc bulge in 42 (95.45%) of the 44 discs maintained grade 4 and progressed to grade 5 in 2 (4.55%) (Figure 2). The Fisher's exact test showed significant difference these 4 groups for increasing disc herniation during flexion ($P < 0.05$). With regard to the grade of disc herniation, the χ^2 test was used to examine the difference between extension and flexion imagining. There are significant differences in all grades ($\chi^2 = 16.19, 14.11, 5.06$, respectively, $P < 0.05$) except grade 4 ($\chi^2 = 0.5$, $P > 0.05$) (Table 2).

■ Discussion

Since chronic low back pain is not a single factorial disease, it has various etiologies. However, low back pain has been believed in some cases to be related to the intervertebral disc, the surrounding soft tissue, or the facet joints. MRI has become the examination of choice for diagnosing lumbar disc herniation.[5] The pros of it is that it has no known side effects, no radiation exposure, and noninvasive. In fact, weight bearing, flexion, extension, or lateral bending may change anatomic relationships. Compressive load can increase the load in the lumbar spine by 80% compared with that in the supine position.[6] In addition, the intradiscal pressure also changes with the position of spine where it increases in standing, sitting, and in a forward flexed position.[7] Prolonged standing can diminish the size of the neural foramens and central spinal canal because the discs lose water content and height whenever the load on the spine is increased. Axial loading of the spine decreases the disc height measured on MR images, and axial compression of the spine also causes bulging of the intervertebral disc and narrowing of the diameters of the neural foramen and central canal. Scanning patients in a recumbent position may potentially miss an occult disc herniation, which may be revealed in a weight-bearing or more positional mode such as flexion or extension. Radiologists failed to report certain pathologic findings, which had to be handled during the surgery. Cases where there is such limited association between diagnostic imaging and clinical symptoms perplexed surgeons a long time.

Flexion and extension radiographs and computed tomography myelography were the standard methods of obtaining positional images of the spine. However, because MRI yields an image that is superior to radiographs and less invasive than myelography, physicians have been experimenting with ways of using MRI to obtain positional images of spine. To help in a better understanding of the pathophysiology of the spine, there seems to be a need for further developments in functional clinical imaging.

Cartolari[8] set up an axial-loaded computed tomography and MR technology by pressing on the recumbent patients' shoulders with 70% body weight. Smith[9] figured out a study of 25 patients with low back pain and sciatica for lumbar spine upright MRI. Upright MRI demonstrated abnormalities in 13 patients (52%) that were not evident in the recumbent posture. There were 3 cases with lateral disc herniations, 6 cases with hypermo-

Table 2. Incidence of Missed Diagnosis of Lumbar Disc Herniation Showed by Extension and Flexion Images

Grade of Disc Bulge (in the Neutral Position)	Extension	Flexion	χ^2
Grade 1 (<3 mm)	19.46% (303/1557)	15.29% (238/1557)	16.19*
Grade 2 (3–5 mm)	13.28% (127/956)	8.47% (81/956)	14.11*
Grade 3 (5–7 mm)	10.58% (22/208)	5.78% (12/208)	5.06†
Grade 4 (7–9 mm)	9.09% (4/44)	4.55% (2/44)	0.5

*$P < 0.01$.
†$P < 0.05$.

bile disc at 1 or more levels, 2 cases with previously unsuspected grade 1 spondylolisthesis, and 2 cases with significant stenosis. Powers *et al*[10] qualified segmental mobility of the lumbar spine during a posterior to anterior spinal mobilization procedure. Eleven asymptomatic subjects were positioned prone within a vertically open double donut design MRI system. An anteriorly directed force was applied manually at each lumbar spinous process. The result showed that the posterior to anterior force applied at the upper lumbar vertebrae (L1–L2) consequently decreased the lumbar lordosis. Force applied on the other vertebrae (L3–L5) resulted in an increased lumbar lordosis. That indicted how passive movement technique influenced segmental motion of healthy spines, which is important of understanding how altered mobility is related to symptoms. Karadimas *et al*[11] investigate how the degree of lumbar segmental degeneration affects sagittal changes in the lumbar spine as it shifts from the supine to the sitting (load-bearing) posture by conventional supine MRI and positional MRI. With positional MRI, they were able to demonstrate changes in healthy and degenerative discs in the weight-bearing position. As the lumbar spine was loaded from the supine to the sitting position, the endplate angles were decreased significantly as the degeneration was increased. There were also significant changes in the anterior and middle disc heights between the supine and the sitting postures irrespective of the degree of degeneration. The overall lumbar lordosis did not significantly change between the 2 postures.

Today, kMRI, a system using vertical magnets with 0.6 T midfield strength, delivers the ability to scan patients in a weight-bearing position. This allows us to image patients in the exact position that elicits symptoms and provide for a detailed evaluation of musculoskeletal pathology. The potential relative beneficial aspects of kMRI spinal imaging on this system, over that of convention MRI, is the potential unmasking of positionally related pathologies and the potential ability to scan the patient in the position of clinically relevant signs and symptoms. kMRI may prove to be efficacious to incorporate as a part of the clinical diagnosis—treatment paradigm in patients with spinal, radicular, and referred pain syndromes originating from spinal pathology. Furthermore, kMRI may better relate the patient's clinical symptoms objective images demonstrating pathology, which may be more specific and sensitive than conventional MRI studies.

In the present study, we found that kMRI could improve the detection of lumbar disc herniations. A significant increase in the degree of lumbar disc herniation was found by examining flexion and extension views when compared with neutral views alone. Using extension MRI alone compared with conventional MRI, the incidence of missed disc herniations is up to 19.46% (303/1557). Using only flexion MRI compared with conventional MRI, the incidence of missed disc herniations is up to 15.29% (238/1557). This also suggests that extension MRI views yield a higher detection rate of missed lumbar disc herniations than flexion views (456 discs, 16.49% *vs.* 333 discs, 12.04%). Flexion and extension MRI views provide valuable, added information when assessing patients for lumbar disc herniations, and may be especially useful in situations where symptomatic radiculopathy is present with unimpressive conventional MRI studies.

This imaging technology may prove to be useful to reveal hidden pathologies not only in occult disc herniations, but also in the other degenerative spinal disease. kMRI may be able to detect occult stenosis or occult instability in the spine by placing the spine in a weight-bearing position. In addition, it may reveal occult nerve root impingement by placing the patient's spine in the position that causes pain or in a position that should narrow the spinal canal and neural foramen (such as spinal extension). In addition, large or claustrophobic patients or patients who need to be scanned in an upright position because of congestive heart failure, severe chronic obstructive pulmonary disease, or severe spinal kyphosis, can be handled by this novel MRI.

■ Key Points

- Prior studies demonstrate that only 70% of patients who were clinically diagnosed with lumbar disc herniations based on physical examinations had lumbar disc herniations confirmed by MRI studies.
- A novel dynamic magnetic resonance imaging system, Kinetic MRI (kMRI), delivers the ability to scan patients in neutral, flexion, and extension positions, which may allow for improved diagnosis of this problem.
- Our study demonstrated that the disc herniations did change with the different positions of the spine.
- kMRI views could improve detection of missed lumbar disc herniations, and provide valuable added information, especially in situations where symptomatic radiculopathy is present without any abnormalities demonstrated on conventional MRI.

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