Dominik Weishaupt, MD
Marius R. Schmid, MD
Marco Zanetti, MD
Norbert Boos, MD
Ben Romanowski, RT
Ruedi O. Kissling, MD
Jiri Dvorak, MD
Juerg Hodler, MD

Index terms:
Nerves, abnormalities, 33.42
Nerves, MR, 33.121411
Nerves, roots, 33.42
Nerves, spinal, 33.42
Spine, abnormalities, 33.771, 33.783
Spine, intervertebral disks, 33.783
Spine, MR, 33.121411

Radiology 2000; 215:247–253

[1] From the Institute of Diagnostic Radiology, University Hospital, Zurich, Switzerland (D.W., M.R.S., B.R.); the Departments of Radiology (M.Z., J.H.), Orthopedic Surgery (N.B.), and Rheumatology (R.O.K.), Orthopedic University Hospital Balgrist, Forchstrasse 340, CH-8008 Zurich, Switzerland; and the Spine Unit, Schulthess Hospital, Zurich, Switzerland (J.D.). Received January 4, 1999; revision requested February 18; final revision received July 1; accepted August 25. **Address reprint requests to** J.H. (e-mail: *jhodler@balgrist.unizh.ch*).

Author contributions:
Guarantors of integrity of entire study, D.W., J.H.; study concepts, D.W., M.R.S., M.Z., J.H.; study design, D.W., M.Z., J.H.; definition of intellectual content, M.Z., N.B., J.H.; literature research, D.W.; clinical studies, D.W., B.R.; data acquisition, D.W., M.R.S.; data analysis, M.Z., J.H.; statistical analysis, D.W., J.H.; manuscript preparation, D.W., M.Z.; manuscript editing, D.W., J.H.; manuscript review, R.O.K., J.D., N.B., J.H.

Positional MR Imaging of the Lumbar Spine: Does It Demonstrate Nerve Root Compromise Not Visible at Conventional MR Imaging?[1]

PURPOSE: To evaluate whether positional magnetic resonance (MR) images of the lumbar spine demonstrate nerve root compromise not visible on MR images obtained with the patient in a supine position (conventional MR images).

MATERIALS AND METHODS: Thirty patients with chronic low back pain unresponsive to nonsurgical treatment and with disk abnormalities but without compression of neural structures were included. Positional MR images were obtained by using an open-configuration, 0.5-T MR imager with the patients seated and with flexion and extension of their backs. The disk and nerve root were related to the body position. Nerve root compression and foraminal size were correlated with the patient's symptoms, as assessed with a visual analogue scale.

RESULTS: Nerve root contact without deviation was present in 34 of 152 instances in the supine position, in 62 instances in the seated flexion position, and in 45 instances in the seated extension position. As compared with the supine position, in the seated flexion position nerve root deviation decreased from 10 to eight instances; in the seated extension position, it increased from 10 to 13 instances. Nerve root compression was seen in one patient in the seated extension position. Positional pain score differences were significantly related to changes in foraminal size ($P = .046$) but not to differences in nerve root compromise.

CONCLUSION: Positional MR imaging more frequently demonstrates minor neural compromise than does conventional MR imaging. Positional pain differences are related to position-dependent changes in foraminal size.

Magnetic resonance (MR) imaging findings and clinical symptoms do not necessarily correlate in the lumbar spine. This has been investigated extensively in asymptomatic individuals (1–6), who may have disk bulging, disk protrusion, or, more rarely, disk extrusion at presentation. Nerve root compression, however, appears to be infrequent in asymptomatic volunteers (4,6).

Nerve root compression may not be visible at routine MR examinations performed with the patient in a supine position. With the patient in a seated position, disk abnormalities or foraminal stenosis may become more pronounced and cause nerve root compromise not visible on conventional images. Several investigations (7–11) have demonstrated position-dependent changes in the dimensions of the dural sac and the neural foramen (intervertebral foramen) with computed tomography (CT) or MR imaging. With the increasing availability of open-configuration MR systems, in vivo imaging of the lumbar spine with the patient in the seated position has become feasible (11–13).

The purpose of this investigation was to evaluate whether positional MR imaging can demonstrate nerve root compromise not visible at conventional (supine) MR imaging.

MATERIALS AND METHODS

Patients

Thirty-six patients were recruited after MR imaging of the lumbar spine. Inclusion criteria were low back pain or leg pain for more than 6 weeks, unresponsiveness to a trial of nonsurgical treatment, surgery not indicated or not urgent on the basis of clinical findings, and age between 20 and 50 years. Moreover, disk protrusion and/or extrusion without compression of neural structures was required to be present at at least one level for inclusion. In six of the 36 enrolled patients, the positional MR examination could not be finished owing to severe pain.

Of the remaining 30 patients, 17 were men and 13 were women (age range, 20–50 years; mean age, 38 years). According to the clinical charts, 10 of the 30 patients (33%) had only low back pain, 19 patients (63%) had predominantly radicular pain, five patients (17%) had reflex deficits, 14 patients had sensory deficits (47%), two patients had motor deficits (7%), and one patient had pseudoradicular pain (3%).

The study was approved by the University Hospital (Zurich, Switzerland) Institutional Review Board, and informed consent was obtained from all patients.

MR Imaging Protocols

Conventional MR imaging was performed with a 1.0-T magnet (Impact Expert; Siemens, Erlangen, Germany) with a dedicated receive-only spinal coil. The patients were placed in a supine position with a cushion under both knees. The protocol consisted of sagittal, T1- (700/12 [repetition time msec/echo time msec]) and T2-weighted (5,000/130), turbo spin-echo imaging of the entire lumbar spine. The image matrix was 512 × 210, the field of view was 225 × 300 mm, the section thickness was 4 mm, the intersection gap was 0.5 mm, and the echo train lengths were three and 15 for T1- and T2-weighted imaging, respectively.

In addition, transverse oblique, T2-weighted, turbo spin-echo images (4,000/96) of at least three intervertebral spaces were obtained, with inclusion of all degenerated disks. The image matrix was 256 × 210, the field of view was 150 × 150 mm, the section thickness was 4 mm, the intersection gap was 0.5 mm, and the echo train length was seven.

Positional MR imaging was performed with a 0.5-T MR imager (Signa Advanced SP imager; GE Medical Systems, Milwaukee, Wis) by using a flexible transmit-receive wraparound surface coil. The patients were seated upright on a wooden chair placed in the gap between the two vertically oriented, doughnut-shaped magnetic coils, with the pelvis fixed in position by a belt (11). All patients were imaged in seated flexion and in seated extension positions. For seated flexion, the patients were asked to bend forward over a wedge-shaped sponge placed on top of the thighs. For seated extension, a cushion was placed posterior to the lumbar spine and the patients were asked to bend backward. Patients were asked to flex and extend as much as possible without the administration of pain medication.

In both the seated flexion and seated extension positions, sagittal, T2-weighted, fast spin-echo images (4,100/95) of the lumbar spine were obtained. Additional imaging parameters were an image matrix of 256 × 192, a field of view of 220 × 220 mm, a section thickness of 4 mm, an intersection gap of 0.5 mm, and an echo train length of 12. The number of signals acquired was four.

In addition, transverse oblique, T2-weighted, fast spin-echo images (4,200/100) of at least two of the intervertebral spaces included in the conventional (supine) MR images were obtained at all abnormal levels and at at least one normal level (two levels in 18 patients, three levels in eight patients, and four levels in four patients). The transverse images were obtained parallel to the superior endplates for each included segment. Therefore, transverse images had identical angulation with regard to the dural sac during positional and conventional MR imaging. The image matrix of the angled transverse, T2-weighted images was 256 × 192, the field of view was 200 × 200 mm, the section thickness was 4 mm, the intersection gap was 0.5 mm, and the echo train length was 12. The number of signals acquired was four. The imaging time for each sequence was 4:56 minutes.

Quantitative Image Evaluation

The cross-sectional area of the dural sac was measured on the transverse angled sections through the central part of the disk on conventional and corresponding positional MR images. The measurements were obtained on the MR console by using the MR manufacturer's software (0.5-T GE Medical Systems Signa Advanced SP imager, software version 5.5; Siemens Impact Expert, software version VB31B). One of the authors (D.W.) performed three measurements on each image. The mean cross-sectional area of the dural sac was calculated in all three positions (seated flexion, seated extension, and supine). This mean was used for further evaluations.

Qualitative Image Evaluation

The images were interpreted by two experienced musculoskeletal radiologists (M.Z., J.H.) in conference. In case of disagreement, a third radiologist (D.W.) decided which of the two diagnoses would be used for further evaluation. Only those levels for which angled transverse (transverse oblique) images were available were used for this evaluation.

The analyzed MR imaging findings included disk abnormalities, degree of nerve root compromise, and foraminal size. With regard to the appearance of the disks, the following terms were employed: normal, which was grade 0; bulging, which was grade 1; protrusion, which was grade 2; extrusion, which was grade 3; and sequestration, which was grade 4 (4,14,15). A normal disk was defined as a disk that did not reach beyond the borders of the adjacent vertebral bodies. Bulging was defined as circumferential, symmetric disk extension beyond the vertebral border. A protrusion was defined as a focal or asymmetric extension of the disk beyond the vertebral border, with the origin broader than any other dimension of the protrusion. An extrusion was defined as a more pronounced extension of the disk beyond the vertebral border, with the base against the disk of origin narrower than the diameter of the extruding material itself. Sequestration was considered to be present when there was a free disk fragment that had intermediate signal intensity on T1-weighted images and increased signal intensity on T2-weighted images.

Nerve root compromise was described as follows: no contact of the disk with the nerve roots, which was grade 0; contact without deviation, which was grade 1; nerve root deviation, which was grade 2; and nerve root compression, which was grade 3 (4). Nerve root compression was considered to be present when the nerve root was deformed. Our definition did not necessarily require that spinal fluid be obliterated.

Foraminal size was assessed qualitatively, as published by Wildermuth et al (11). Grade 0 indicated normal foramina (normal dorsolateral border of the intervertebral disk and normal form at the foraminal epidural fat [oval or inverted pear shape]); grade 1, slight foraminal stenosis and deformity of the epidural fat,

TABLE 1
Cross-sectional Area of the Thecal Sac: Positional Dependence

Form of the Disk in Supine Position	Mean Cross-sectional Area (mm^2) of the Thecal Sac ± SD			*P* Value for Two-tailed Student *t* Test		
	Supine Neutral	Seated Flexion	Seated Extension	Neutral versus Flexion	Neutral versus Extension	Extension versus Flexion
Normal (*n* = 23)	178.6 ± 50.2	181.2 ± 52.4	165.5 ± 40.5	.74	.07	.007
Bulging (*n* = 14)	172.3 ± 50.0	175.9 ± 52.2	158.2 ± 53.3	.31	.02	.007
Protrusion (*n* = 22)	181.0 ± 70.4	177.4 ± 70.5	161.2 ± 67.9	.38	<.001	<.001
Extrusion (*n* = 17)	165.9 ± 57.5	161.9 ± 58.1	144.6 ± 60.1	.27	.001	.01
All (*n* = 76)	175.3 ± 57.4	174.8 ± 58.7	158.4 ± 55.7	.82	<.001	<.001

TABLE 2
Overall Prevalence of Disk Degeneration, Nerve Root Compromise, and Foraminal Stenosis: Positional Dependence

Imaging Finding	Supine Neutral Position	Seated Flexion Position	Seated Extension Position
Disk form (*n* = 76)*			
Normal (grade 0)	23	23	24
Bulging (grade 1)	14	16	13
Protrusion (grade 2)	22	21	22
Extrusion (grade 3)	17	16	17
Relationship of disk with nerve root (*n* = 152)†			
No contact (grade 0)	108	82	93
Contact without deviation (grade 1)	34	62	45
Contact with deviation (grade 2)	10	8	13
Compression of nerve root (grade 3)	0	0	1
Foraminal stenosis (*n* = 152)‡			
None (grade 0)	65	70	56
Slight (grade 1)	72	70	80
Marked (grade 2)	15	12	14
Advanced (grade 3)	0	0	2

* Data are the number of intervertebral disks.
† Data are the number of nerve roots evaluated.
‡ Data are the number of foramina evaluated.

with the remaining fat still completely surrounding the exiting nerve root; grade 2, marked foraminal stenosis, with epidural fat only partially surrounding the nerve root; and grade 3, advanced stenosis with obliteration of the epidural fat.

Pain Assessment

A visual analogue scale was used for assessing pain intensity. The visual analogue scale is considered to be a valid, reliable, and easily understood tool for pain assessment (16). The visual analogue scale was presented to the patients as a 100-mm-long horizontal line with anchors at either end. After completion of the positional MR examination, the patients were instructed to mark the degree of pain (back pain and/or pain radiating into the leg) on this line separately for extension and flexion. The left anchor was defined as no pain at all, and the right anchor was defined as the maximum pain experienced during recent lower back problems. The distance between the left anchor and the patient's mark was then measured to the nearest millimeter and expressed as a percentage of the distance between the two anchors.

The flexion-extension difference in this pain score was compared with morphologic differences (cross-sectional areas of the dural sac, disk abnormalities, nerve root compromise, and foraminal size). Because many patients had multisegmental morphologic abnormalities, the level with the greatest difference in dural sac area was selected for this correlation. When two levels had the same difference, the one with the smaller dural sac diameter was selected.

Statistical Analysis

For comparison of mean dural sac areas and pain scores, a paired Student *t* test was used. Qualitative grades were analyzed with χ^2 statistics. A *P* value less than .05 was considered to indicate statistical significance.

RESULTS

In 30 patients, a total of 76 intervertebral spaces at the L2-3 through L5-S1 levels were analyzed. No anomalies of the lumbar spine, such as additional lumbar vertebrae, incomplete fusion of the dorsal arch, or spondylolysis, were found on MR images. The results are summarized in Tables 1–3.

Quantitative Image Evaluation

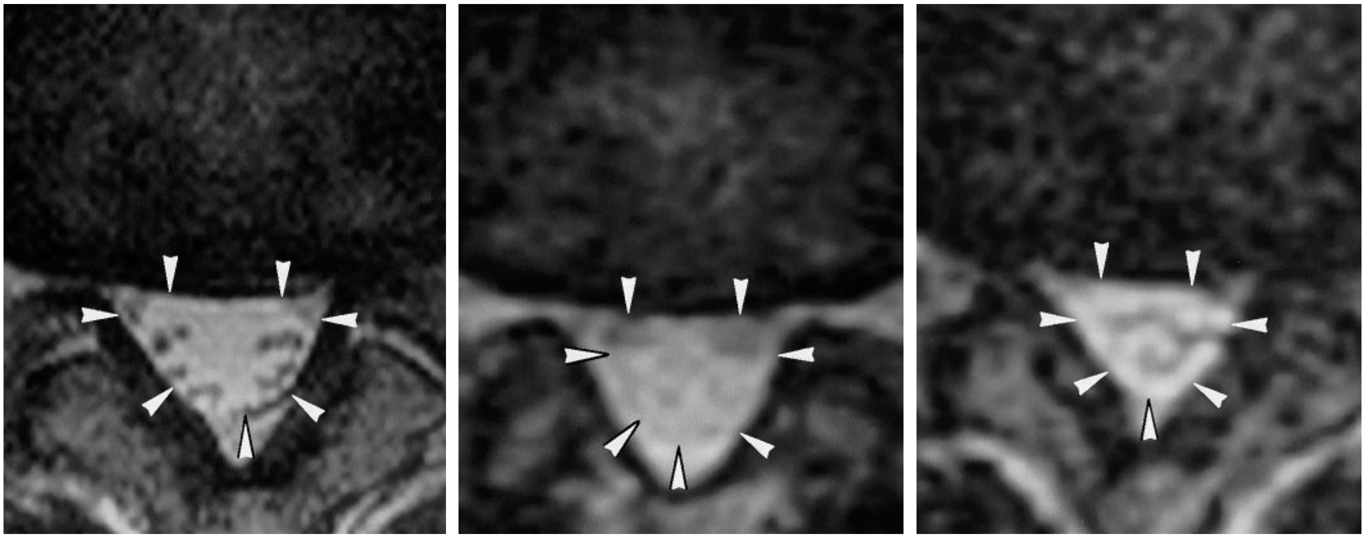
The cross-sectional area of the dural sac varied between 70 and 300 mm^2 in the supine position. Between the supine neutral and seated extension positions, the mean cross-sectional area of the dural sac significantly decreased by 16.9 mm^2 (9.6%, $P < .001$) (Fig 1); between the seated flexion and extension positions, it significantly decreased by 16.4 mm^2 (9.4%, $P < .001$). These differences were significant (*P* of <.001 to .02) for all subgroups of disk abnormalities, with the exception of the combination of neutral and extension positions in normal disks. No significant difference was found between the supine neutral and seated flexion positions (0.5-mm^2 difference [0.3%], $P = .82$).

Qualitative Image Evaluation

In the supine neutral position, 23 disks were diagnosed as normal, 14 disks demonstrated bulging, 22 disks demonstrated protrusion, and 17 disks demonstrated extrusion (Table 2). These diagnoses changed in four disks (5%) between the supine neutral and seated flexion positions (decreased grading in all four disks), in seven disks (9%) between the supine neutral and the seated extension positions (increased grading in six disks, decreased grading in one disk), and in four disks (5%) between the two seated positions (increased grading between flexion and extension in all four disks) (Table 3) (Fig 2).

Of the 152 evaluated nerve roots, 108 did not have any contact with the adjacent disks in the supine neutral position. Contact without deviation was found in 34 instances, contact with deviation was found in 10 instances, and nerve root compression was found in no instances (Table 2).

Nerve root contact without deviation increased in frequency from 34 instances



a. b. c.

Figure 1. Positional dependence of the cross-sectional area of the dural sac in a 36-year-old man. **(a)** Transverse, T2-weighted, turbo spin-echo, conventional MR image (4,000/96) at the L4-5 intervertebral space and **(b, c)** corresponding fast T2-weighted, positional MR images (4,200/100) obtained with the patient in **(b)** seated flexion and **(c)** seated extension. The cross-sectional area of the dural sac increased slightly from 159 mm^2 in **a** to 175 mm^2 in **b** and decreased to 99 mm^2 in **c**. In **a–c**, the arrowheads indicate the dural sac margin.

in the supine position to 62 instances in the seated flexion position (+18.4%) and to 45 instances in the seated extension position (+7.2%). Nerve root contact with deviation decreased in frequency from 10 instances in the supine position to eight instances in the seated flexion position (−1.3%) and increased in frequency to 13 instances (+2%) in the seated extension position. In a single patient, nerve root deviation in the supine position changed to nerve root compression in the seated extension position (Fig 3). Overall, the diagnoses changed in 40 instances (26.3%) between the supine neutral and seated flexion positions, in 34 instances (22.4%) between the supine neutral and seated extension positions, and in 43 instances (28.3%) between the two seated positions (Table 3).

In the supine neutral position, foramina were completely normal in 65 instances. Grade 1 foramina were found in 72 instances, grade 2 foramina were found in 15 instances, and grades 3 foramina were found in no instances. Other than several changes from grade 1 to grade 0 between the supine and the seated flexion positions and from grade 0 to grade 1 between the supine and the seated extension positions, changes in foraminal grading were rare (Table 2). The grading changed in 24 instances (15.8%) between the supine neutral and the seated flexion positions, in 22 instances (14.5%) between the supine neutral and the seated extension positions, and in 40 instances (26.3%) between the two seated positions (Table 3) (Fig 4). For these differences between the two seated positions, statistical significance was nearly reached (P = .08).

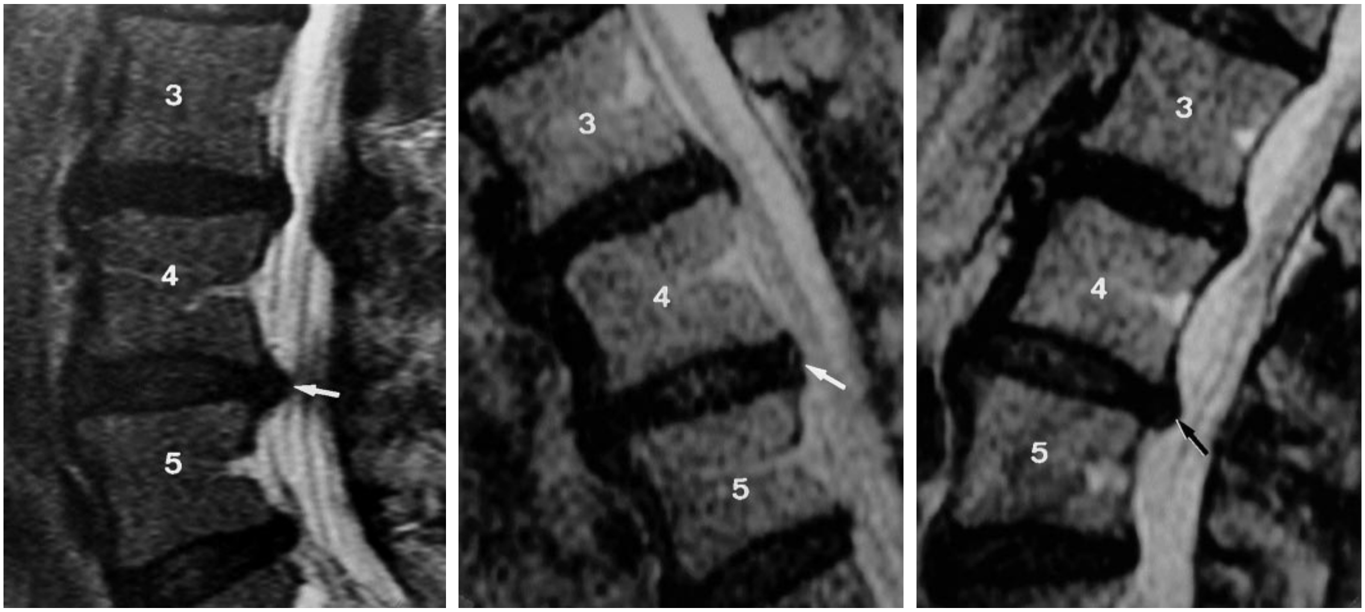
TABLE 3
Individual Patients: Changes in Disk Form, Relationship of Disk with Nerve Root, and Foraminal Stenosis among Various Positions

Change in Grading	Positional Change: Neutral to Flexion	Neutral to Extension	Flexion to Extension
Disk form			
P value	.97	<1.00	.97
No. of disks with higher grade	0	6	4
No. of disks with same grade	72	69	72
No. of disks with lower grade	4	1	0
Nerve root compromise			
P value	.06	.06	.20
No. of nerve roots with higher grade	32	26	27
No. of nerve roots with same grade	112	118	109
No. of nerve roots with lower grade	8	8	16
Foraminal stenosis			
P value	.46	.48	.08
No. of foramina with higher grade	6	16	24
No. of foramina with same grade	128	130	112
No. of foramina with lower grade	18	6	16

Note.—*P* values from χ^2 test. "Higher," "same," and "lower" refer to grading change from neutral position to flexion position (column 1), from neutral position to extension position (column 2), and from flexion position to extension position (column 3). Also note that numbers in Tables 2 and 3 cannot be directly compared: Table 2 reports overall prevalences, but Table 3 reports changes in individual patients that may cancel each other out with regard to overall prevalences.

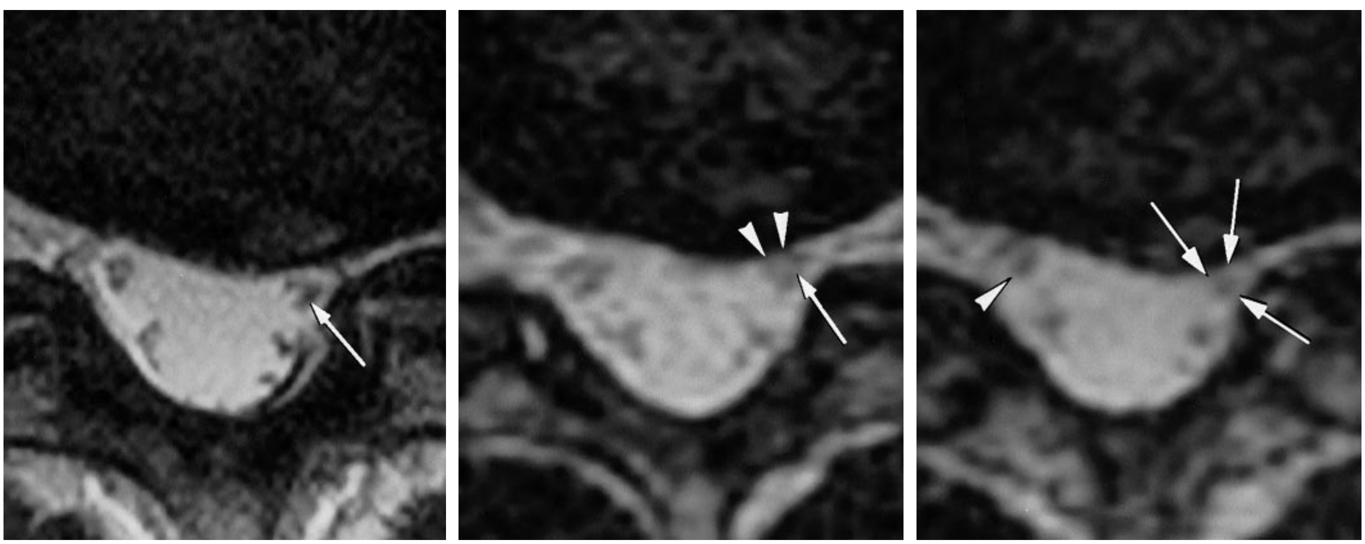
Pain Assessment

Pain was scored higher in extension (mean on the visual analogue scale, 63%) than in flexion (mean on the visual analogue scale, 33%; P = .065). In 19 patients, pain increased from flexion to extension; in the remaining 11 patients, pain decreased. In the four patients with a disk abnormality increasing between flexion and extension (Table 3), the pain score increased by 22 percentage points. For those patients with worsening nerve



a. b. c.

Figure 2. Positional dependence of the L4-5 disk form in a 48-year-old woman. **(a)** Protrusion (grade 2) of the L4-5 disk (arrow) on a sagittal, T2-weighted, turbo spin-echo, conventional MR image (5,000/130). **(b)** Sagittal, T2-weighted, fast spin-echo, positional MR image (4,100/95) obtained with the patient in seated flexion. The L4-5 disk (arrow) did not reach beyond the vertebral border and was therefore graded as a normal disk (grade 0). **(c)** Sagittal, T2-weighted, fast spin-echo, positional MR image (4,100/95) obtained with the patient in seated extension shows protrusion (grade 2) of the L4-5 disk (arrow). In **a–c**, the numbers indicate the lumbar vertebrae.



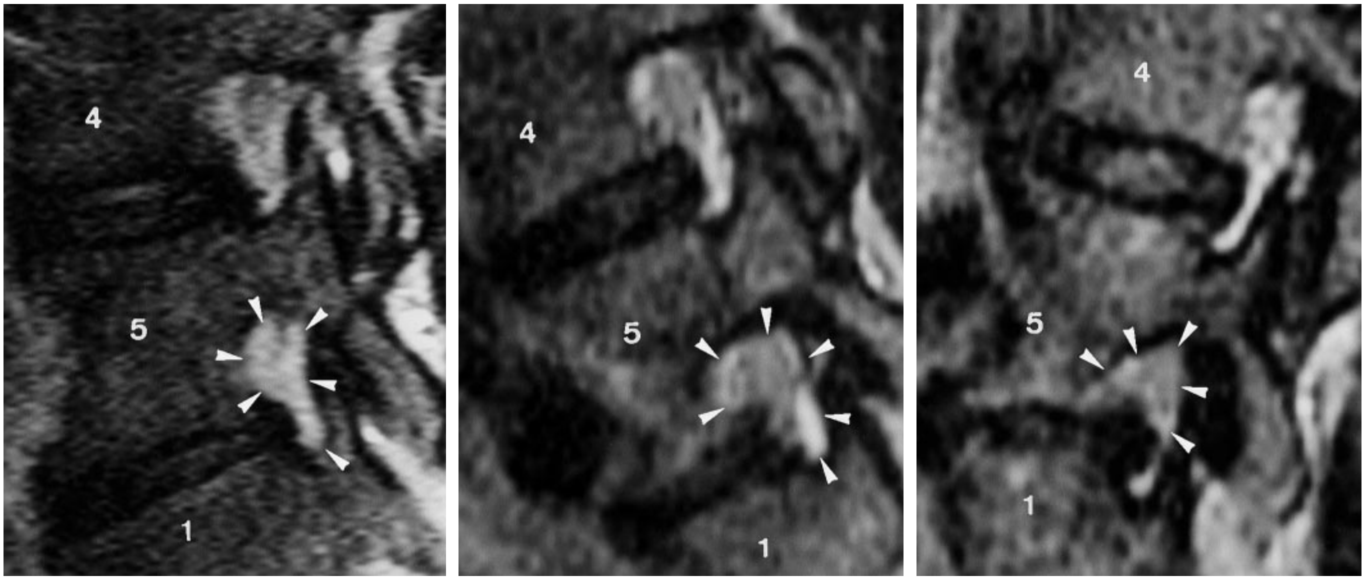
a. b. c.

Figure 3. Positional changes of the left S1 nerve root in a 36-year-old man. **(a)** Extrusion of the L5-S1 disk. The left S1 nerve root (arrow) shows deviation on this transverse, T2-weighted, turbo spin-echo, conventional MR image (4,000/96). **(b)** With the patient in seated flexion, the S1 nerve root (arrow) is in contact with the adjacent extruded disk (arrowheads) on this transverse, T2-weighted, fast spin-echo, positional MR image (4,200/100). **(c)** With the patient in seated extension, the S1 nerve root (arrows) shows compression on this transverse, T2-weighted, fast spin-echo, positional MR image (4,200/100). Nerve root compression was diagnosed because the nerve root is deformed as compared with the contralateral root (arrowhead), although spinal fluid appears to surround at least part of the nerve root.

root compromise, the pain score increased by 19 percentage points (n = 27, P = .35), and for those with worsening foraminal score the pain score increased by 21 percentage points (n = 24, P = .046).

DISCUSSION

Although CT and MR imaging are accurate for the detection of disk abnormalities (17), the clinical importance of such findings has been debated. A high prevalence of disk abnormalities, such as disk bulging, focal protrusion, and high-signal-intensity zones within the anulus fibrosus of the intervertebral disk, have been



a. b. c.

Figure 4. Positional dependence of foraminal size in a 36-year-old man. **(a)** Sagittal, T2-weighted, turbo spin-echo, conventional MR image (5,000/130). **(b)** Sagittal, T2-weighted, fast spin-echo, positional MR image (4,100/95) obtained with the patient in seated flexion. **(c)** Sagittal, T2-weighted, fast spin-echo, positional MR image (4,100/95) obtained with the patient in seated extension. On the basis of our grading system, the L5-S1 foramen (arrowheads in **a–c**) was graded as a slight foraminal stenosis (grade 1) in **a** and **b**. **c** shows a marked foraminal stenosis (grade 2). On the visual analogue scale, the patient graded the pain in extension (**c**) as 80% of the maximum pain experienced during his recent lower back problems. During flexion (**b**), the patient had no pain at all. In **a–c**, the numbers indicate the lumbar and sacral vertebrae.

demonstrated in asymptomatic volunteers (1–6).

One reason for the low predictive value of such imaging findings may be their positional dependence. Findings of several studies in which CT and MR imaging have been employed mainly in cadaveric lumbar specimens have demonstrated the influence of spinal motion and transverse load on the cross-sectional area of the dural sac and the size of the neural foramina (7–13).

Until recently, such examinations could not easily be performed in vivo. Willen et al (9) performed MR imaging and CT in patients with sciatica or neurogenic claudication. The patients were first examined in a relaxed supine position followed by an examination in a supine position with slightly extended hips and transverse loading of the spine. In 79% (n = 66) of the 84 patients, a statistically significant reduction in the cross-sectional area of the dural sac was demonstrated in this position.

With open-configuration MR systems, imaging can be performed in the seated position (11–13). Our results are in accordance with those of the investigations detailed in references 11–13 and support published findings (7–9,11–13) that indicate that the dimension of the dural sac is position dependent. The reduction of the area of the dural sac between a flexed and an extended spine has been experimentally shown by Schönström et al (7) in a cadaveric specimen by using CT.

In our study, significant changes between the cross-sectional areas of the dural sac were found only between the supine and the seated extension positions and between the seated flexion and the seated extension positions. No significant changes were found between the supine neutral and the seated flexion positions.

These results are in accordance with the findings of Schmid et al (12) obtained in asymptomatic volunteers and indicate that seated flexion images are not crucial to assess the cross-sectional area of the dural sac.

In our investigation, position-dependent changes in the relationship of the nerve root with the adjacent disk were frequent. Although marked nerve root compression was uncommon, it appeared to be more closely related to clinical symptoms than to other morphologic signs (4).

With regard to foraminal size, our results are consistent with those of studies in which the dimensions of the neural foramina were shown to be position dependent (7,8,11,13). Although our grading system is a relatively insensitive assessment of foraminal size, nearly statistically significant differences were found between the seated flexion and extension positions. Together with data obtained in cadaveric specimens, the concept of dynamic foraminal stenosis may be valid (10), and positional MR images may add additional information when this diagnosis is suspected. This is supported by the fact that a change in pain score was most closely associated with foraminal changes.

In conclusion, positional MR imaging more frequently demonstrates minor forms of neural compromise than conventional MR imaging. Positional pain differences are related to position-dependent changes in foraminal size.

References

1. Weinreb JC, Wolbarsht LB, Cohen JM, Brown CE, Maravilla KR. Prevalence of lumbosacral intervertebral disk abnormalities on MR images in pregnant and asymptomatic nonpregnant women. Radiology 1989; 170:125–128.
2. Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic resonance scans of the lumbar spine in asymptomatic subjects. J Bone Joint Surg Am 1990; 72:403–408.
3. Jensen MC, Brant-Zawadzki MN, Obuchowski N, Modic MT, Malkasian D, Ross JS. Magnetic resonance imaging of the lumbar spine in people without low back pain. N Engl J Med 1994; 331:69–73.
4. Boos N, Rieder R, Schade V, Spratt KF, Semmer N, Aebi M. The diagnostic accuracy of magnetic resonance imaging, work perception, and psychosocial factors in

identifying symptomatic disc herniations. Spine 1995; 20:2613–2625.
5. Stadnik TW, Lee RR, Coen HL, Neirynck EC, Buisseret TS, Osteaux MJ. Annular tears and disk herniation: prevalence and contrast enhancement on MR images in the absence of low back pain and sciatica. Radiology 1998; 206:49–55.
6. Weishaupt D, Zanetti M, Hodler J, Boos N. MR imaging of the lumbar spine: disk extrusion and sequestration, nerve root compression, endplate abnormalities and osteoarthritis of the facet joints are rare in asymptomatic volunteers. Radiology 1998; 209:661–666.
7. Schönström N, Lindahl S, Willen J, Hansson T. Dynamic changes in the dimensions of the lumbar spinal canal: an experimental study in vitro. J Orthop Res 1989; 7:115–121.
8. Nowicki BH, Yu S, Reinartz J, Pintar F, Yoganandan N, Haughton VM. Effect of axial loading on neural foramina and nerve roots in the lumbar spine. Radiology 1990; 176:433–437.
9. Willen J, Danielson B, Gaulitz A, Niklason T, Schánstrám N, Hansson T. Dynamic effects on the lumbar spine: axially loaded CT-myelography and MRI in patients with sciatica and/or neurogenic claudication. Spine 1997; 22:2968–2976.
10. Nowicki BH, Haughton VM, Schmidt TA, et al. Occult lumbar lateral spinal stenosis in neural foramina subjected to physiologic loading. AJNR Am J Neuroradiol 1996; 17:1605–1614.
11. Wildermuth S, Zanetti M, Duewell S, et al. Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. Radiology 1998; 207:391–398.
12. Schmid MR, Stucki G, Debatin JF, Romanowski B, Duewell S. Influence of inclined and reclined position to cross sectional area of the spinal canal: experiences with functional imaging of the lumbar spine in the upright position on an open MR system (abstr). In: Proceedings of the Fifth Meeting of the International Society for Magnetic Resonance in Medicine. Berkeley, Calif: International Society for Magnetic Resonance in Medicine, 1997; 428.
13. Zamani AA, Moriarty T, Hsu L, et al. Functional MRI of the lumbar spine in erect position in a superconducting open-configuration MR system: preliminary results. J Magn Reson Imaging 1998; 8:1329–1333.
14. Brant-Zawadzki MN, Jensen MC, Obuchowski N, Ross JS, Modic MT. Interobserver and intraobserver variability in interpretation of lumbar disc abnormalities: a comparison of two nomenclatures. Spine 1995; 20:1257–1263.
15. Masaryk TJ, Ross JS, Modic MT, Boumphrey F, Bohlman H, Wilber G. High-resolution MR imaging of sequestered lumbar intervertebral disks. AJR Am J Roentgenol 1988; 150:1155–1162.
16. Langley GB, Sheppeard H. The visual analogue scale: its use in pain measurement. Rheumatol Int 1985; 5:145–148.
17. Modic MT, Masaryk TJ, Boumphrey F, Goormastic M, Bell G. Lumbar herniated disk disease and canal stenosis: prospective evaluation of surface coil MR, CT, and myelography. AJR Am J Roentgenol 1986; 147:757–765.