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Changes in posterior disc bulging and intervertebral foraminal size associated with flexion-extension movement: a comparison between L4–5 and L5–S1 levels in normal subjects

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Abstract

Background context: No previous study has used magnetic resonance imaging (MRI) to evaluate changes of posterior disc bulging and intervertebral foraminal size in the normal spine with flexion-extension movement, comparing L4–5 versus L5–S1 intervertebral levels.

Purpose: To determine changes in posterior disc bulging and intervertebral foraminal size with flexion-extension movement, comparing L4–5 versus L5–S1 intervertebral levels.

Study design: An in vivo study of magnetic resonance kinematics with spine flexion extension.

Methods: Spines of three volunteers with no history of low back pain were scanned in neutral, flexion, and extension positions in a vertically open MRI system. MRI was repeated after 6 hours of normal activity and an additional 4 hours of heavy activity with a weighted vest. Posterior bulging of the intervertebral disc and the size of intervertebral foramen were measured at the L4–5 and L5–S1 levels.

Results: With spine flexion, posterior bulging of the discs increased at L4–5 in eight of nine measurements (three different spine-loading states for each of three subjects) and L5–S1 discs in six of nine measurements. In most cases, posterior bulging decreased with extension. No significant difference was noted in the degree of disc bulge between levels. Foraminal size at L4–5 increased with flexion and decreased with extension, and the extent of these changes was greater at the L4–5 level than at L5–S1.

Conclusions: This pilot study demonstrates two distinct behavior characteristics of the normal spine with flexion-extension movement.

Keywords: Flexion-extension; Intervertebral foramen; Posterior disc bulging; Vertically open MRI

Introduction

The articulation at the lumbosacral junction is unique. Because the sacrum is markedly curved and tilted backward, the first sacral vertebra articulates with the fifth lumbar vertebra at a pronounced angle, that is, the lumbosacral angle. Biomechanics of the intervertebral disc and the intervertebral foramen at the L5–S1 intervertebral level are thought to be different from those of the L4–5 intervertebral level with flexion-extension of the spine [1].

Flexion and extension of the spine induces movement of the intervertebral disc and mechanical stimulus on pain-sensitive structures. However, it is not clear to what degree flexion and extension movements have the ability to change posterior bulging of the intervertebral discs [2–5]. Also, the

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difference in the change of posterior bulging of intervertebral discs between intervertebral levels has not been determined.

The size and shape of the intervertebral foramen and their spatial relationship with the nerve root is important, especially in lumbar spinal stenosis. Variations in the size and shape of these foramen are often associated with symptoms of nerve root compression in the lumbar region [6]. Because the dimensions and anatomic relationships of the neural foramina are constantly changing during normal daily activities, intermittent and dynamic compression or mechanical irritation of the nerve can develop [7]. To determine the effect of activities on the neural foramen, there have been several cadaveric studies [8].

However, two important shortcomings arise when attempting to extrapolate these results to living people. First, the disc of a living individual exerts an internal pressure that is believed to be important for the disc's response to axial compression [9,10]. Keller et al. [11] demonstrated that disc deformation is more rapid in live specimens.

The second shortcoming is that all of the in vitro studies have force applied in a direction perpendicular to the vertebral end plate, whereas, in a human spine under physiologic conditions, each disc level has force applied to it in a different and characteristic vector [12]. This may be especially obvious at the lumbosacral junction.

Recent advances in the design of magnets and gradient coils have made possible the development of "open" magnetic resonance imaging (MRI) systems, which provide gradient capabilities and field homogeneity sufficient for evaluation of the musculoskeletal system in various positions. With the advent of this system, it is possible to perform MRI with flexion–extension motion of the spine. Using this system, Zamani et al. [13] reported changes of the foraminal size and disc bulge with flexion-extension movement of the spine. However, the changes were not quantitatively measured, and the difference between levels was not studied.

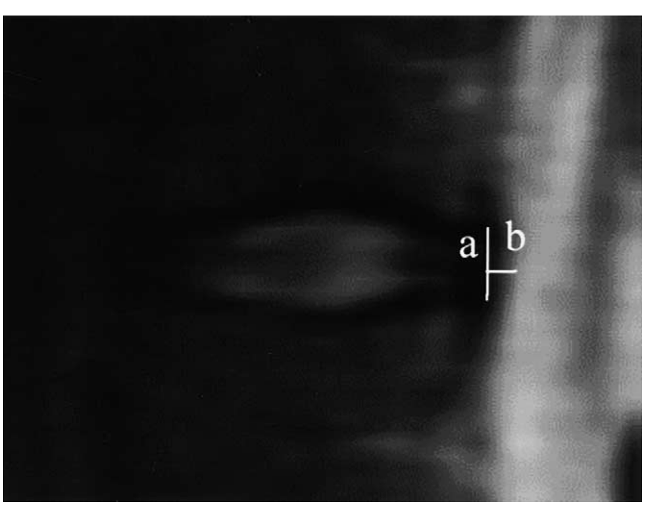

Fig. 1. Example measurement of posterior disc bulge on MRI. First, line a was drawn connecting the two posterior edges of the endplates. A second perpendicular line b was drawn from the most posterior edge of the disc to the line.

The purpose of this study is to determine the changes in dimensions of the spinal canal and intervertebral foramen during flexion and extension. Specifically, we sought to determine whether posterior bulging of the disc increases or decreases with flexion-extension of the spine and at which level, L4–L5 or L5–S1, the extent of bulging is greater, and whether the size of the neural foramen increases or decreases with flexion-extension of the spine and whether this change varies between L4–5 and L5–S1. To answer these questions, we examined the spine with MRI under three states of spinal loading: early in the morning, after 6 hours of normal activities, and after 4 hours of additional axial loading. We compared posterior disc bulging and area of the intervertebral foramen of L4–L5 with those of L5–S1.

Methods

Subjects

Three healthy subjects (two men and one woman), 27 to 31 years old, average age 29.7 years, volunteered to participate in the study. The institutional review board for studies in human subjects granted approval for the study, and informed, written consent was obtained from each subject. Selection criteria for the subjects included no previous history of back pain, no prior back surgery and no contraindications for MRI.

Magnetic resonance imaging

MRI was performed with a vertically open superconduction 0.5-T MRI system (Signa-SP; GE Medical Systems, Milwaukee, WI). This system is characterized by two verti-

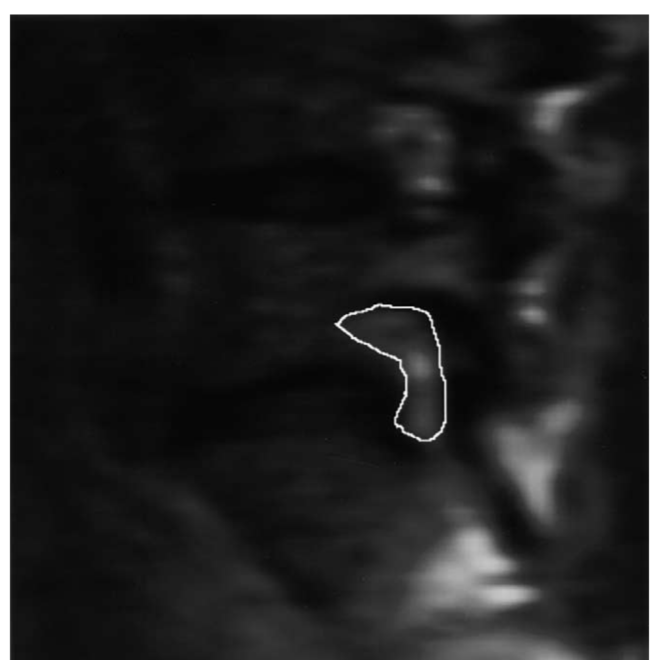

Fig. 2. Example size measurement of the intervertebral foramen.

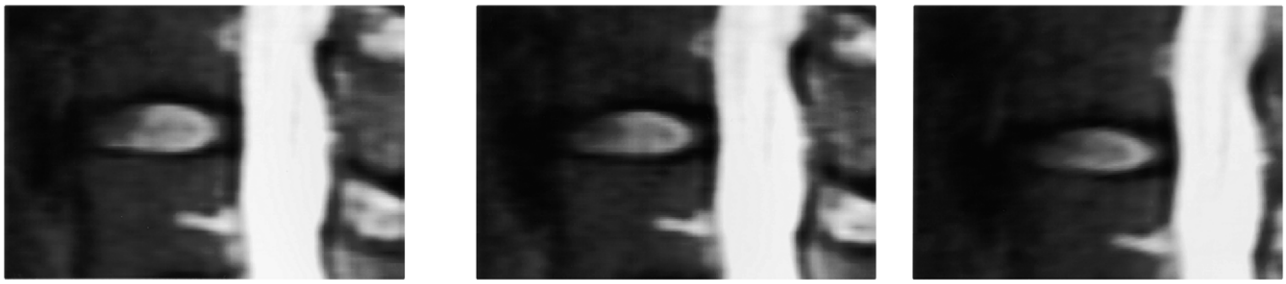

Fig. 3. Example images of spine in neutral position at three different loading states: (A) spine without load, (B) spine loaded with 6 hours of normal activity, and (C) spine loaded with 4 hours of additional heavy activity.

cally oriented doughnut-shaped superconducting magnetic coils, with a gap of 60 cm between the coils.

Imaging parameters were fast spin echo technique, 4300/100 (repetition time ms/echo time ms), 6.0-mm section thickness, 2.0-mm intersection gap, 30 cm-field of view, 256×128 image matrix, 7.81-kHz bandwidth, and two signals acquired.

Examination protocol

Subjects were instructed not to perform any activities involving extra load on their spine, except for getting up after a full night of sleep, and coming to the vertically open MRI unit. A baseline scan of the spine was performed. The subject sat on a specially designed plastic chair placed within the opening of the magnet. The position of the pelvis was fixed with a belt. With the backrest in a 90-degree angle, the spine was scanned in a neutral position. After the scan, the subject was told to flex the spine actively as far as possible within the chair and the scan was repeated. After the scan of the spine in flexion, we had the patient extend the spine as far as possible and again scanned the spine. After the scanning of the baseline images, we immediately repeated the examination of the spine for the purpose of determining the reproducibility of the measurements. To assess changes with progressive spinal loading, two additional scans were performed. One was done after 6 hours of "normal daily activity," and the other was performed after the subject completed an additional 4-hour continuous hike in the adjacent foothills with a 30-pound upper body vest. Subjects were instructed to hike at a pace during which they could still carry on a normal conversation and were allowed standing or sitting rest breaks as needed for 10 minutes every hour.

Measurements

Posterior bulging of the intervertebral disc

Posterior bulging of the disc was measured on the midsagittal images. Using the en-face appearance of the spinous processes as a confirmatory landmark, the image at the midsagittal plane was selected. The images were magnified to five times to see the contours of intervertebral discs more clearly. The magnification was performed with linear interpolation of the pixels. As shown in Fig. 1, a line was drawn connecting the most posterior-inferior point of the lower endplate of the upper vertebrae and the most posterior-superior point of the upper endplate of the lower vertebrae. From the most posterior edge of the bulging disc, a second line was drawn perpendicular to the previous line connecting the two posterior edges of endplates. The posterior bulging of the disc was defined as the distance of the second line.

Intervertebral foramen

For the measurement of the size of intervertebral foramen, T2-weighted images extending through the lateral vertebral plane were selected. The images of the lateral vertebral plane were defined as the images that contain the nerve root and the neural foramen. After the identification of the slice through the lateral vertebral plane, the boundary of the foramen was drawn with the trace function of the scanner's operator console. An example measurement is shown in Fig. 2. Using the region of interest function, the area of the

Fig. 4. Example images of spine in flexion (A), neutral (B), and extension (C) positions.

Table 1
Changes of posterior bulging of the disc with flexion of the spine at three different axial loading status in L4–5 and L5–S1 intervertebral discs of three subjects

	No axial loading		After 6 hours of normal activity		After additional 4 hours of activity	
	Neutral	Flexion	Neutral	Flexion	Neutral	Flexion
L4–L5						
Subject 1	0.9	1.8	1.1	1.1	1.2	2.8
Subject 2	1.3	2.2	1.2	3.3	1.6	2.1
Subject 3	1.3	1.4	1.8	2.2	2.3	2.4
L5–S1						
Subject 1	1.7	1.8	1.1	1.9	1.3	1.6
Subject 2	1.8	1.9	2.1	2.1	2.6	2.5
Subject 3	1.3	2.4	2.3	2.3	1.5	1.7

At L4–5 level, all except one event showed increase in disc bulging. At L5–S1 level, seven of nine events showed increase. Values are posterior disc bulging in millimeters.

Table 2
Changes of posterior bulging of the disc with extension of the spine at three different axial loading status in L4–5 and L5–S1 intervertebral discs of three subjects

	No axial loading		After 6 hours of normal activity		After additional 4 hours of activity	
	Neutral	Extension	Neutral	Extension	Neutral	Extension
L4–L5						
Subject 1	0.9	0.8	1.1	0.8	1.2	1.1
Subject 2	1.3	0.9	1.2	1.1	1.6	1.2
Subject 3	1.3	1.0	1.8	2.1	2.3	2.1
L5–S1						
Subject 1	1.7	0.8	1.1	1.2	1.3	1.1
Subject 2	1.8	1.1	2.1	0.9	2.6	1.8
Subject 3	1.3	0.8	2.3	0.5	1.5	0.4

At L4–5 level, all except one event showed decrease in disc bulging. At L5–S1 level, all events showed decrease in posterior disc bulging. Values are posterior disc bulging in millimeters.

foramen was measured. These measurements were performed for the images with the spine at neutral, flexion, and extension.

Data analysis

Changes of the foramen size with flexion or extension movement of the spine were calculated as percentage difference from the foramen size with the spine in neutral position. To assess inter-reader variability in the measurements, two observers independently performed the measurements in one subject. Statistical analysis performed using 95% limits of agreement as proposed by Bland and Altman [14] was calculated as (mean difference of the two measurements − 2 S.D.) to (mean difference of the two measurements + 2 S.D.). It represents the range of agreement between two measurements that was obtained in 95% of instances. The agreement was also tested using the Spearman's correlation coefficient rho.

Results

Interobserver and intertest reliability

Interobserver reliability between the two observers in measurement of posterior bulging of the discs was extremely high, at rho=0.98 ($P \leq .001$; Spearman's correlation coefficient), with mean 0.01 and standard deviation 0.09. Interobserver reliability between the two observers in measurement of neural foraminal size was rho=0.98, with mean 0.45 and standard deviation 4.09. The correlation coefficient was also high for intertest reliability at 0.96. This was determined for the same examiner performing identical

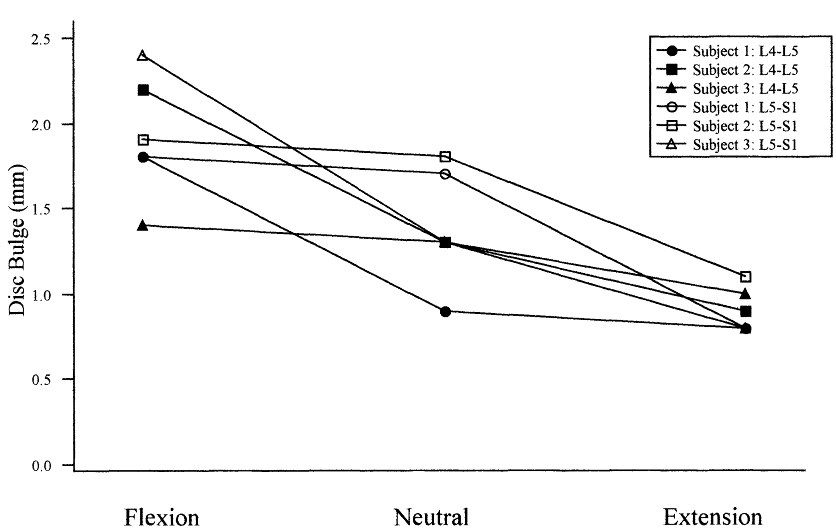

Fig. 5. Disc bulge measurements for all three subjects at both L4–L5 and L5–S1. These data are graphed for the early morning time point only. There is a clear trend toward increased bulge at flexion and decreased bulge at extension.

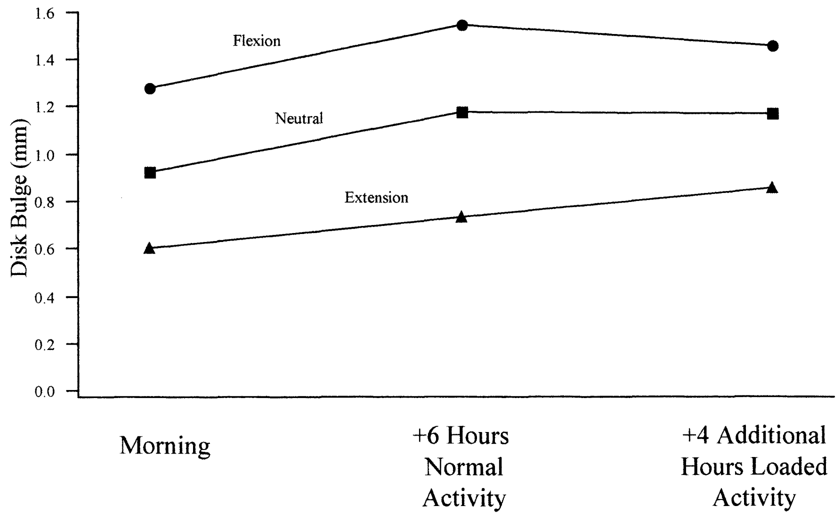

Fig. 6. Summary of all data in Tables 1 and 2, averaged across subjects and disc levels. For each loaded condition, bulge increases in flexion and decreases in extension. For each position, activity increases disc bulge.

measurements on two consecutive MRIs performed in the early morning on the same patient.

Posterior bulging of the disc in neutral position

Fig. 3 shows the changes of posterior bulging of the disc in one subject with increased loading of the spine. After 6 hours of normal activity, posterior bulging of the L4–5 disc in neutral position increased in two subjects and decreased in one subject in comparison with the baseline study. After an additional 4 hours of heavy activity, all the subjects showed increased posterior disc bulging compared with measurements made initially before activity and after 6 hours of normal activity. At the L5–S1 discs, 6 hours of normal activity increased the posterior bulging in two subjects, but in one subject the posterior bulging decreased. After an additional 4 hours of heavy activity, two of three subjects showed increase in posterior bulging, and one showed decrease when compared with posterior bulging of the disc in neutral position after 6 hours of normal activity.

Posterior bulging of the disc with flexion-extension

The images in Fig. 4 show examples of the changes of posterior bulging of the disc in three different spine positions. The measurements are provided in Table 1 for flexion and Table 2 for extension for each of the three loading states of the spine (baseline, after 6 hours of normal activity and after 4 hours of heavy activity). Thus, the total number of the spine flexion or extension events at each level was nine, because each of the three subjects was scanned in neutral, flexion, and extension for the three different loading conditions. As shown in Table 1, with flexion of the spine, posterior bulging of the discs increased in eight of nine events and in one event showed no change at L4–5. At L5–S1, six of nine events showed increase, two events showed no change, and one event showed decrease in posterior bulging. As shown in Table 2, with extension of the spine, posterior bulging of the L4–5 discs decreased, except in one event. At L5–S1 discs, posterior bulging decreased in eight of nine events, with increase in one (Table 2). There was no significant difference in the degree or direction of disc bulge between levels.

Disc bulge measurements for the morning time point for all three subjects at each level are shown in Fig. 5. There is a clear trend toward increased bulge during flexion and decreased bulge during extension.

All the data provided in Tables 1 and 2 are summarized in Fig. 6. The measurements from all three subjects at both levels are averaged. This graph demonstrates that the average disc bulge increases with activity at all three positions: flexion, neutral, and extension. It also demonstrates that for each activity level, disc bulge is greatest at flexion and least at extension.

Foraminal size

Percent changes in intervertebral foraminal size are provided in Table 3 for flexion and Table 4 for extension. A

Table 3
Changes of the disc hydration at different axial loading states of the spine compared with minimally loaded spine

	Daily activity for 6 hours		Heavy activity for 4 hours	
	L4–L5	L5–S1	L4–L5	L5–S1
Subject 1	−8.2%	−8.2%	−19.6%	−13.6%
Subject 2	−4.0%	−8.0%	−4.4%	−10.4%
Subject 3	−12.2%	−13.4%	−14.2%	−19.6%
Mean ± S.D.	−8.1 ± 4.1	−8.7 ± 4.5	−14.7 ± 4.7	−13.7 ± 5.8

Values are percent changes from the baseline value of disc hydration.

Table 4
Percent changes of intervertebral foramen from neutral with flexion of the spine in three different loading states

	Baseline		Daily activity for 6 hours		Heavy activity for 4 hours	
	L4–L5	L5–S1	L4–L5	L5–S1	L4–L5	L5–S1
Subject 1	21.8%	13.3%	33.0%	11.7%	46.6%	16.1%
Subject 2	15.9%	3.0%	5.9%	2.5%	28.4%	5.5%
Subject 3	8.2%	9.3%	10.9%	9.9%	5.0%	3.4%
Mean ± S.D.	15.3±6.8	8.5±5.1	16.6±14.4	8.0±4.9	26.7±20.8	8.3±6.8

Values are the percentage of changes in the foraminal area from neutral position. With flexion of the spine, size of the intervertebral foramen increased at L4–5 and L5–S1 levels. The extent of size change was greater at L4–5 intervertebral levels.

summary is shown in Fig. 7. Flexion movement increased the foraminal size more at the L4–5 level (mean, 15.3%) than at the L5–S1 level (mean, 8.5%) for all activity levels. With extension of the spine, the size of the intervertebral foramen decreases more at the L4–5 level (mean, 18.6%) than at the L5–S1 level (mean, 15.7%) at all activity levels. With increasing activity, intervertebral foraminal size increased more and decreased more at the L4–5 level than at the early morning time point. With increasing level of activities, there was little change in foraminal size with flexion and extension at the L5–S1 level.

Discussion

Posterior bulging of the disc has been observed to increase after axial loading in studies that evaluated a functional spinal unit, that is, two adjacent vertebrae and interconnecting soft tissues [15–17]. Results of experiments on cadaveric spines have indicated that the nucleus migrates posteriorly during flexion and anteriorly during extension in nondegenerate discs [2,3]. In living people, MRI with patients lying on their side [4] demonstrated that the nucleus pulposus moved posteriorly with flexion of the spine and anteriorly with extension. More recent studies with a vertically open MRI system [5,18] demonstrated that the cross-sectional area of the spinal canal decreased with flexion and increased with extension. However, they did not specifically examine posterior disc bulging. Our study examined dynamic changes in normal subjects with no history of back pain and normal MRIs under three different loading states of the spine (baseline, after 6 hours of normal activity, and after 4 hours of additional heavy activity). The results showed that, in general, flexion of the spine increases posterior bulging of the disc and extension of the spine decreases posterior bulging of the disc. Overall, there was no significant difference in the direction or degree of disc bulging between the L4–5 and L5–S1 levels with flexion-extension movement.

To determine the effect of normal activities on the intervertebral foramen, Panjabi et al. [9] demonstrated through cadaveric study that flexion of the spine increased the cross-sectional area of the neural foramen by 30% and extension of the spine decreased by 20% in nondegenerated intervertebral discs. In the degenerated discs, flexion motion increased by about 20% and extension decreased by 20%. Mayoux-Benhamou et al. [8] reported that there is a reduc-

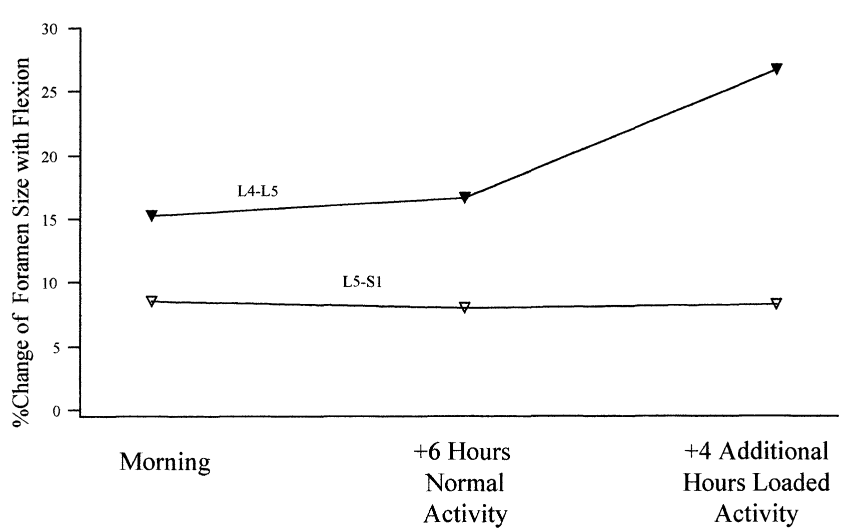

Fig. 7. Summary of foraminal size measurements averaged across subjects for flexion. Foraminal size increased more with flexion and decreased more with extension at the L4–L5 level than it did at the L5–S1 level.

Table 5
Percent changes of intervertebral foramen from neutral with extension of the spine in three different loading states

	Baseline		Daily activity for 6 hours		Heavy activity for 4 hours	
	L4–L5	L5–S1	L4–L5	L5–S1	L4–L5	L5–S1
Subject 1	−19.4%	−16.7%	−28.5%	−6.3%	−32.4%	−4.0%
Subject 2	−8.8%	−7.6%	−21.2%	−22.0%	−40.3%	−25.0%
Subject 3	−27.6%	−22.9%	−48.6%	−26.0%	−45.1%	−24.7%
Mean ± S.D.	−18.6±9.4	−15.7±7.7	−32.8±14.2	−18.1±10.4	−39.3±6.4	−17.9±12.0

Values are the percentage of changes in the foraminal area from neutral position. With extension of the spine, size of the intervertebral foramen decreased at L4–5 and L5–S1 levels in all subjects. The extent of size change was greater at L4–5 intervertebral levels.

tion of 17.9% in foraminal height, and of 14.1% in upper foraminal width in extension, compared with the respective dimensional changes in flexion.

In our study, during flexion and extension of the spine in vivo, the extent of change in the foraminal size was different between L4–5 and L5–S1 intervertebral levels. Flexion movement increased the foraminal size, and extension movement decreased the foraminal size, greater at the L4–5 than the L5–S1 intervertebral level, for all three loading conditions. The differences between the two intervertebral levels may have been caused by the differences in the alignment of the vertebral bodies. As mentioned in the introduction, the first sacral vertebra articulates with the fifth lumbar vertebra at a pronounced angle of extension. This may have caused lesser changes in the L5–S1 intervertebral foramen. To our knowledge, there was no previous study that reported the difference in foramen size changes with flexion and extension movement of the spine between lumbar levels.

Several limitations were inherent in this pilot study design. First, the number of the subjects was too small to be analyzed statistically. The results, however, do support a future study with a larger number of patients. Second, the images after flexion or extension of the spine were not completely identical to the images in neutral position, although we tried to obtain the same plane. This is because of the incidental rotation that occurs as the subject moves from neutral into flexion or extension. However, obtaining three-dimensional images may be able to remedy this problem [13]. Third, the same external load does not translate into the same force applied to each individual spine. This is the inherent shortcoming of in vivo study. The load applied to the spine may differ with differences in height, weight, and muscular strength between subjects. Although cadaveric studies are more accurate in this aspect, extrapolating cadaveric studies to human ones has obvious limitations.

Conclusion

In this pilot study of normal subjects with no history of back pain and normal MRIs, it was observed under three conditions of spinal loading that posterior bulging of the disc increased with flexion of the spine and decreased with extension of the spine in most cases; there was no significant difference between L4–5 and L5–S1 levels in the direction or degree of movement of the disc with flexion and extension of the spine; the size of the intervertebral foramen

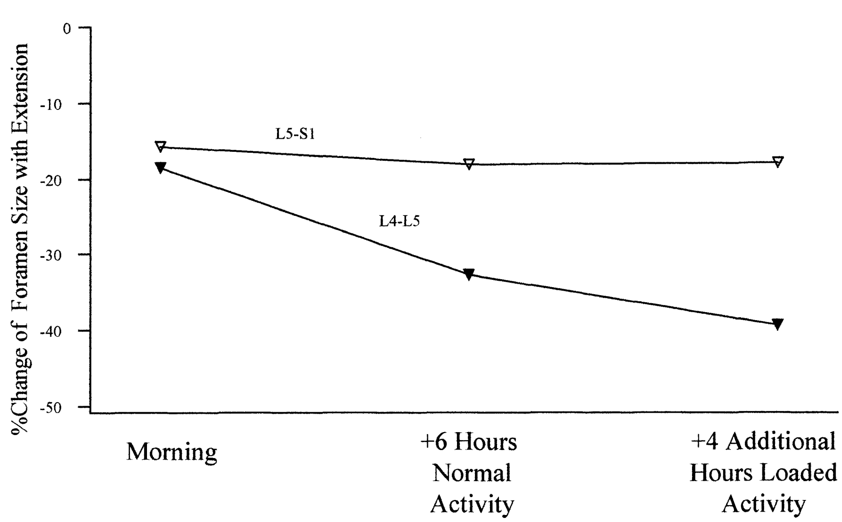

Fig. 8. Summary of foraminal size measurements averaged across subjects for extension. Foraminal size increased more with flexion and decreased more with extension at the L4–L5 level than it did at the L5–S1 level.

increased with flexion of the spine and decreased with extension of the spine and the extent of these changes was greater at the L4–5 level than at the L5–S1 level.

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Spineposts

Ninety Years Ago in Spine

At the March, 3, 1911, meeting of the Medico-Chirugical Society of Glasgow, George S. Middleton, the treating physician, and John H. Teacher, the examining pathologist, described a patient who sustained a lifting injury followed by a cauda equina syndrome, and death on the sixteenth postinjury day [1]. Dr. Teacher's postmortem revealed cord injury from a thoracolumbar disc extrusion. They cited a similar case without neurologic injury, reported by Kocher in 1896 [2]. Later in 1911, Joel Ernest Goldthwait, a US orthopedic surgeon, published a monograph in which he described herniation of the lumbosacral disc with compromise of the vertebral canal, and he speculated on the mechanism of neurologic injury and sciatic pain [3].

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