ORIGINAL ARTICLE

Dynamic Effects of Axial Loading on the Lumbar Spine During Magnetic Resonance Imaging in Patients with Suspected Spinal Stenosis

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Background: Previous studies have shown that axial compression in extension (ACE) of the spine during magnetic resonance imaging (MRI) has revealed unexpected pathological features compared with the conventional psoas-relaxed position (PRP) used in imaging. The purpose of this study was to evaluate the dynamic effect of axial loading on lumbar spinal stenosis using MRI in patients with spinal stenosis.
Methods: A total of 14 women and 11 men with lumbar spinal stenosis were examined in both PRP and ACE positions. We calculated the dural-sac cross-sectional area (DCSA) to evaluate severity of spinal canal stenosis. DCSA, as well as the dural-sac anteroposterior diameter (DAPD) and dural-sac transverse diameter (DTD) in both positions were measured using a digital image view station. A paired *t* test determined the differences in DCSA, DAPD and DTD between the two positions at each intervertebral disc level.
Results: Axial loading increased severity of lumbar spinal stenosis during MRI, as demonstrated by a decrease in DCSA from 20.5% to 6.3% (mean, 11.40 ± 3.66%) between the PRP and ACE positions ($p < 0.01$). Significant differences were also noted in DAPD and DTD between the PRP and ACE positions ($p < 0.01$). A significant correlation was found between the decrease in mean DCSA and that in DAPD and DTD. The decrease in mean DCSA, DAPD and DTD following axial compression was greatest at the L4/5 and L5/S1 levels.
Conclusion: Axial loading increases severity of lumbar canal stenosis and the effect of axial loading on MRI examination is greatest at the L4/5 and L5/S1 levels. [*J Formos Med Assoc* 2008;107(4):334–339]

Key Words: axial loading, lumbar spine, magnetic resonance imaging, spinal stenosis

Magnetic resonance imaging (MRI) has replaced myelography in the evaluation of lumbar spinal stenosis due to the advantages it provides in both multiplanar imaging and noninvasiveness. Its one disadvantage is that it is typically performed with the lumbar spine in a supine relaxed position, which results in an absence of axial loading on the spine. Encroachments on the spinal canal during axial loading may not be evaluated. According to the results of a number of recent studies, axial loading of the lumbar spine in spinal extension (axial compression in extension, ACE) during MRI spinal examinations for patients with suspected spinal stenosis, have revealed pathologic features that were undetected in the conventional, unloaded-spine examination position (psoas-relaxed position, PRP).[1] In reference to the results of a number of previous studies, ACE examination is recommended

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when the dural-sac cross-sectional area (DCSA) is $< 130\ mm^2$ during a conventional PRP examination, and a significant difference occurs when reduction in DCSA is $\geq 15\ mm^2$ from PRP to ACE.[2–4]

The purpose of this study was to evaluate the impact of axial loading at every test disc level (L2/3 to L5/S1) of the lumbar spinal canal using MRI in patients with dural-sac stenosis. In addition, we investigated the conditions that may lead to dural-sac stenosis and correlated the decline in DCSA, dural-sac anteroposterior diameter (DAPD) and dural-sac transverse diameter (DTD) between the PRP and ACE positions at every disc level.

Methods

For this study, a total of 25 patients (not including 2 excluded patients) were examined (14 women, 11 men), aged 25–68 years (mean age, 53 years). All subjects had clinical symptoms of neurogenic claudication provoked by either walking or prolonged standing, and symptoms that persisted after medical treatment for at least 2 months. Patients with sciatica were not included in our study. Patients with comorbidity, including osteoporosis or fractured spine, or a spine containing a bone tumor, were also excluded from this study.

All MRI was performed on a 1.5-T system (Sigma MRI Echo-Speed Plus; GE Medical Systems, Milwaukee, WI, USA) using a phased-array surface coil. All subjects were first examined with MRI when they were in a supine PRP featuring slight flexion of the hips and knees. In this position, sagittal T2-weighted and axial T1-weighted fluid attenuated inversion recovery (FLAIR) and T2-weighted fast recovery fast spin-echo (FRFSE) sequences were performed. The repetition time (TR)/echo time (TE) was 3275/110 for T2-weighted sagittal and 3750/120 for axial images. The TR/TE was 2000–2200/24 for T1-weighted FLAIR axial images. The slice thickness was 5 mm, and the field of view was 280–448/224 mm for sagittal images and 160–256/224 mm for axial images. The imaging matrix was 280–256/224 for sagittal images and 160–256/224 for axial images. The number of excitations was two or three for both sagittal and axial images. The disc levels from L2/3 to L5/S1 were examined and a total of 100 intervertebral disk spaces were studied.

Axial loading of the spine was performed using a non-magnetic compression device and harness (DynaWell, Int AB, Stockholm, Sweden).[3,4] The patient was placed in the supine position with a cushion behind the lumbar spine with hips and knees extended and feet against a footplate on the compression device. The patient wore a harness that was attached to the compression device using tight side straps, for purposes of axial loading of the lumbar spine. It took 10 minutes to complete the above procedure. The spinal loading elicited by this harness was regulated by tightening or loosening adjustment knobs on the compression device, and the total loading was registered on indicators with the details recorded at the time of MRI.

Approximately 50% of the subject's body weight was chosen as loading pressure as in previous studies[5,6] with equal load distribution upon each leg. After 5 minutes of loading, axial and sagittal T1- and T2-weighted sequences were performed. It took another 15 minutes to complete the scan. If a patient was unable to tolerate the compression, we stopped immediately. In the process of loading, another two patients, who were excluded finally, complained of increased leg pain and numbness before the loading reached 50% of the subject's body weight and we stopped immediately.

The DCSA, DAPD and DTD at four lumbar spine disc levels (L2/3, L3/4, L4/5, L5/S1) were measured for each of the 25 patients, for a total of 100 disc levels. DCSA, DAPD and DTD were measured on three occasions during the acquisition of each image by using a measurement program on a digital image view station (Advantage Workstation; GE Medical Systems), and the mean value was calculated (Figure 1). The image in which the tested area appeared to be the smallest was selected from the three images acquired at each disc level. By careful inspection of the soft and skeletal tissues surrounding each disc, as well as the spinal canal

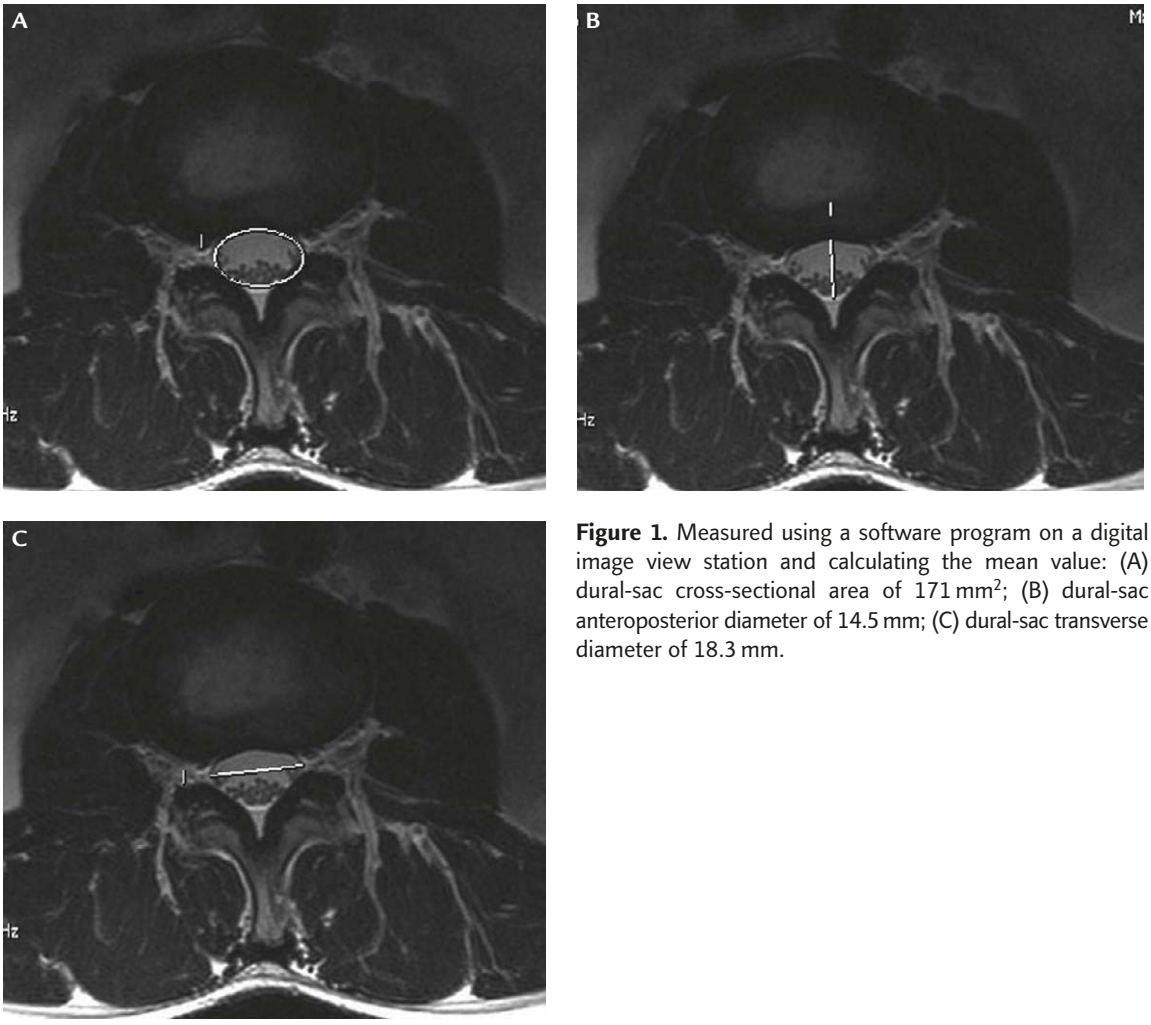

Figure 1. Measured using a software program on a digital image view station and calculating the mean value: (A) dural-sac cross-sectional area of 171 mm^2; (B) dural-sac anteroposterior diameter of 14.5 mm; (C) dural-sac transverse diameter of 18.3 mm.

at each selected level, we were able to ensure that the selected images used for comparison of PRP and ACE were at the same level (Figure 2).

The measured DCSA, DAPD and DTD values for each specific disc level of all 25 patients were summated, and thus an average value with standard deviation of DCSA, DAPD and DTD were obtained for each disc level. We used the paired *t* test to determine if a statistically significant difference existed in the average value at each disc level of DCSA, DAPD and DTD between the PRP and ACE positions. Spearman's correlation was used to evaluate the correlation between change in the average value of DCSA after axial compression and the change in the corresponding value for DAPD and DTD for all cases at every disc level.

The percentage decrease in DCSA, DAPD and DTD at each level between the PRP and ACE positions was calculated. The effect of axial loading on DCSA value varied from case to case. In a previous study,[3,7] a significant decrease in DCSA was defined as a decrease of ≥ 15 mm^2.

Results

There were 45% of disc levels with DCSA < 100 mm^2 in the PRP position, and 61% < 100 mm^2 in the ACE position. There was a significant reduction in DCSA at 30% of the disc levels and no reduction in DCSA at four disc levels after axial loading. The total DCSA value of every test level in each case decreased after axial loading by 20.5% to 6.3% (Table 1).

The average value of DCSA, DAPD and DTD for all cases at each level tested are listed in Table 2

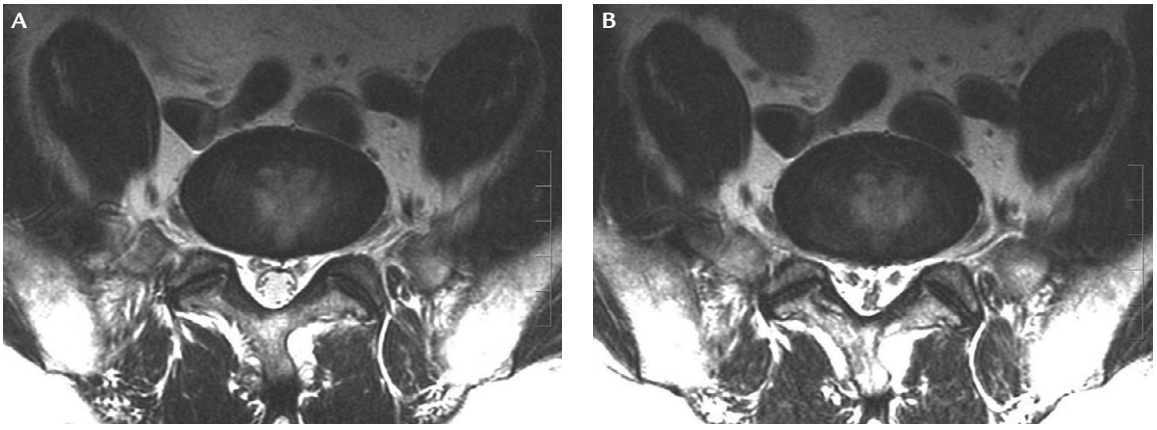

Figure 2. A 61-year-old man presented with neurogenic claudication. (A) Axial T2-weighted magnetic resonance imaging at the L5/S1 level revealed severe constriction of the dural sac not detected with the patient in psoas-relaxed position (PRP), but (B) found during axial compression in extension (ACE). The dural-sac cross-sectional area (DCSA) decreased from 79 mm^2 during PRP to 23 mm^2 during ACE. Increase in epidural fat rather than ligamentum flavum hypertrophy probably accounted for the decrease in DCSA found during ACE.

for both positions. The decrease in the average value of DCSA, DAPD and DTD following axial compression was greatest at the L4/5 and L5/S1 levels (Table 2). Application of the paired *t* test revealed differences for DCSA, DAPD and DTD between the PRP and ACE positions at every level tested, and all such differences were significant ($p < 0.01$). The correlation between change in the average value of DCSA due to axial compression and the change in the corresponding value for DAPD and DTD for all cases at every disc level by Spearman's correlation is shown in Table 3.

Discussion

In our study, 30% of disc levels showed a significant decrease in DCSA. To emphasize the effect of axial loading, we measured DCSA at every disc level for all subjects. A percentage reduction in the total DCSA varied from case to case, and was likely to be related to differences in trunk resistance to the loading. Further study is needed to define any correlation between spinal stenosis and trunk resistance.

Axial loading causes a reduction in the area and diameter of the dural sac at the L2/3 to L5/S1 levels of the lumbar spine. We observed significant differences between the corresponding

Table 1. Percentage decrease in total dural-sac cross-sectional area (DCSA)

Case	DCSA (mm^2)			
	PRP	ACE	Difference	% decrease
1	366	291	75	20.5
2	206	168	38	18.4
3	362	302	60	16.6
4	415	352	63	15.2
5	459	390	69	15.0
6	349	301	48	13.8
7	410	356	54	13.2
8	350	308	42	12
9	443	390	53	12
10	463	408	55	11.9
11	319	282	37	11.6
12	398	353	45	11.3
13	427	380	47	11
14	458	408	50	10.9
15	372	333	39	10.5
16	439	396	43	9.8
17	380	344	36	9.5
18	456	414	42	9.2
19	492	448	44	8.9
20	346	317	29	8.4
21	472	434	38	8.1
22	498	458	40	8
23	556	520	36	6.5
24	494	463	31	6.3
25	431	404	27	6.3

PRP = psoas-relaxed position; ACE = axial compression in extension.

Table 2. Dural-sac cross-sectional area (DCSA), dural-sac anteroposterior diameter (DAPD) and dural-sac transverse diameter (DTD) in psoas-relaxed position (PRP) and axial compression in extension (ACE) and decrease in area (mm^2) or distance (mm) following compression for each spinal level tested*

Disc level	DCSA (mm^2)	DAPD (mm)	DTD (mm)
L2–3			
PRP	143.92 ± 29.18	5.74 ± 0.68	7.76 ± 0.80
ACE	132.68 ± 28.22	5.51 ± 0.71	7.47 ± 0.74
Average of difference	11.24 ± 7.10	0.24 ± 0.25	0.30 ± 0.27
Decline (%)	7.78	4.18	3.71
L3–4			
PRP	113.84 ± 27.08	4.99 ± 0.71	7.09 ± 0.83
ACE	101.40 ± 27.87	4.67 ± 0.73	6.72 ± 0.90
Average of difference	12.44 ± 5.97	0.32 ± 0.21	0.38 ± 0.30
Decline (%)	11.73	6.47	5.42
L4–5			
PRP	79.64 ± 23.04	4.14 ± 0.71	5.93 ± 0.91
ACE	69.00 ± 25.03	3.91 ± 0.79	5.73 ± 0.92
Average of difference	10.64 ± 7.95	0.23 ± 0.34	0.19 ± 0.42
Decline (%)	14.54	5.52	2.81
L5–S1			
PRP	77.04 ± 17.05	4.20 ± 0.43	5.93 ± 0.66
ACE	65.72 ± 16.62	3.73 ± 0.42	5.56 ± 0.63
Average of difference	11.32 ± 6.68	0.47 ± 0.30	0.36 ± 0.27
Decline (%)	15.00	11.0	6.02

**Data presented as mean ± standard deviation.*

Table 3. Spearman's correlations between changes in dural-sac cross-sectional area (DCSA) and changes in dural-sac anteroposterior diameter (DAPD) and dural-sac transverse diameter (DTD) ($n = 25$)

	Changes in DCSA, r (p)
Changes in DAPD	
L2–3	0.8789 (0.0000)
L3–4	0.9328 (0.0000)
L4–5	0.7438 (0.0000)
L5–S1	0.8164 (0.0000)
Changes in DTD	
L2–3	0.5055 (0.0059)
L3–4	0.5521 (0.0042)
L4–5	0.7777 (0.0000)
L5–S1	0.4504 (0.0239)

DCSA, DAPD and DTD values in the PRP and ACE positions at every test level. MRI with ACE can probably show the real stenotic condition of the lumbar spine more than PRP does. There is a high correlation between the change in the average values of DCSA and DAPD and that of DCSA and DTD. The reduction in DCSA came from increased prominence of epidural fat (Figure 2), which is probably secondary to venous stasis after axial compression, and/or from a bulging disc or ligamentum flavum hypertrophy.[1]

The decline in the average DCSA, DAPD and DTD associated with the two different positions was greater at the L4/5 and L5/S1 levels than at the L3/4 and L2/3 levels (Table 2). Such an outcome suggests that pressure upon the intervertebral discs under ACE conditions is more obvious at the lower levels of the spine than at the upper levels, a condition that more closely mimics the natural effect of upright posture on the spine.

In our study, there were no disc levels with DCSA $> 130\ mm^2$ under PRP that decreased to $< 75\ mm^2$ under ACE, as was previously reported.[3,8] In this study, MRI with ACE was not suggested if DCSA was $> 130\ mm^2$ under PRP at every disc level.

As has often been reported, the best way to analyze the soft tissues in the spinal canal is by means of MRI.[9] For patients who complain of degenerative stenotic symptoms, and in whom MRI with PRP cannot explain the clinical symptoms, an axially loaded MRI scan is suggested if there is no contraindication. A disadvantage of the axially loaded MRI scan is the additional 30 minutes required to perform the ACE examination, which includes loading of the compression device. In addition, a few patients, who were excluded from this study, complained of transient increased severe lower back pain.

According to our results, axial loading of the spine in patients during MRI examination is an option that can be performed following a conventional examination to optimize the radiologic diagnosis of lumbar spinal stenosis for patients with signs of neurogenic claudication. If an increase in severity of the canal stenosis is found after axial loading, it may change the patient's treatment plan.

Because it is not currently feasible to perform computed tomography or MRI examination with the patient in a standing or walking position that simulates the activity that typically elicits their neurogenic claudication, MRI with ACE seems to be a good alternative for the patient suspected of lumbar spinal stenosis. Axial loading is suggested as long as there is no medical contraindication, such as osteoporosis, fractured spine or spinal tumor, especially in patients whose MRI in PRP does not match their clinical symptoms, and DCSA is $< 130\ mm^2$.

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