Original Article

Weight-Bearing MRI of the Lumbosacral Spine: Difference between Supine and Weight Bearing Positions and Additional Value in Patients with Low Back Pain

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Objective: To study the difference of magnetic resonance imaging (MRI) parameters of the lumbosacral spine between weight-bearing and supine positions, and evaluate whether there is additional value in patients with low back pain.

Materials and Methods: Eight-six patients with low back pain with or without leg pain who underwent MRI of the lumbosacral spine in weight-bearing and supine positions were included in the present retrospective study. The patients' characteristics and MRI parameters were measured. The data were analyzed to find significant differences between these two positions.

Results: MRI parameters which significantly increased in weight-bearing position compared to supine position ($p<0.05$) included lumbar lordotic angle, lumbosacral angle, presence of spondylolisthesis (at L4/L5 level), and presence of nerve root compression (at L3/L4, L4/L5, and L5/S1 levels). Parameters or findings that significantly decreased were spinal canal diameter (at L2/L3, L4/L5, and L5/S1 levels), and intervertebral disk height (at L2/L3, L4/L5, and L5/S1 levels). Older age group (mean age of 54.3 years versus 45.6 years as younger group) showed a significant change in number of nerve root compression. Forty-three percent of patients with radiating symptom showed a changed number of nerve root compression but this was not statistically significant.

Conclusion: Multiple MRI parameters of the lumbosacral spine show significant change in weight-bearing compared to supine position. Increased presence of spondylolisthesis and nerve root compression might be beneficial in patients with radiating symptom unexplained by conventional MR studies in supine position. Older age group showed a significant change in number of nerve root compression.

Keywords: Weight-bearing, MRI, Lumbar spine, Back pain

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Low back pain is a common problem worldwide. It is a leading cause of activity limitation with work absence, causing huge burden on individuals, families, communities, industry, and governments[1-4]. However, only some cases have specific causes and most cases are non-specific[4].

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Nowadays, the physicians can evaluate low back pain with many diagnostic imaging methods, such as radiographs, computed tomography, magnetic resonance imaging (MRI), and even the ultrasonography[5,6]. However, according to The American College of Radiology, MRI is the most appropriate diagnostic imaging method to evaluate low back pain[5]. In the past, physicians performed the studies only in the supine position to evaluate low back pain, and in certain patients, were unable to demonstrate the cause. Since clinical symptoms can develop with sitting, standing, or dynamic maneuvers (including flexion and extension), the evaluation of low back pain may not be adequately assessed by supine MRI alone[7]. Axially loaded supine MRI has been performed to simulate the upright position. Although the results were interesting, the technique has not achieved a consensus. The studies with axial load, even when they allow better assessment in relation to the use of high-field machine, do not truly reflect spinal changes and muscle tone related to increase load in axial direction[8-11]. On the other hand, previous studies revealed the benefits of the evaluation of low back pain in real weight-bearing position with statistical significance[7,12-16].

Many demographic factors influence the onset and course of low back pain. These include age, body weight, educational status, psychosocial factors, and occupational factors[1,17,18]. These factors also can cause different degree of degenerative change in different populations. Since the first weight-bearing MR machine has just been established in Thailand in 2017, the present research project aimed to study the difference of MRI parameters of the lumbosacral spine between weight-bearing and supine positions, and evaluate additional value in patients with back pain.

Materials and Methods

Study subjects

Eighty-nine patients with back pain referred for weight-bearing MRI of the lumbosacral spine at Prachachuen Imaging Center between September 2017 and December 2018 were recruited for the present retrospective study. Signed informed consents were obtained from all patients for MR examination. The study was approved by the Institutional Review Board of Faculty of Medicine, Ramathibodi Hospital, Mahidol University (ID 02-61-64).

Inclusion criteria were patients with back pain that underwent MRI of the lumbosacral spine in both supine and upright positions. Exclusion criteria were patients who had previous lumbar spine surgery and spinal anomaly including pars defect, scoliosis, vertebral fracture, spinal tumor, and spinal infection.

Three patients were excluded due to previous spinal surgery. Eighty-six patients (40 men and 46 women) were enrolled in the present study.

MR examination

All MRI were performed on a dedicated 0.25-T low-field MR system (G-scan, Esaote, Genoa, Italy) using a lumbar distributed phase array coil. The MR system included a weight-bearing platform with a hydraulic tilting mechanism that allowed imaging of the lumbar spine in the supine (horizontal 0°) and standing (vertical 81° to 90°) positions. Sequences used were axial T1-weighted turbo spin echo (TE 16 ms, TR 620 ms, 4-mm thickness), axial T2-weighted turbo spin echo (TE 125 ms, TR 5,960 ms, 4-mm thickness), three-dimension hybrid contrast enhancement (3D HYCE; TE 4 ms, TR 8 ms, reconstructed slice thickness 0.6 mm in axial, coronal and sagittal planes), sagittal T1-weighted turbo spin echo (TE 20 ms, TR 530 ms, 4-mm thickness), sagittal T2-weighted turbo spin echo (TE 125 ms, TR 2,380 ms, 4-mm thickness), sagittal T2 STIR (TE 60 ms, TR 3,280 ms, 5-mm thickness) and coronal T1-weighted turbo spin echo (TE 20 ms, TR 470 ms, 3.5-mm thickness).

MR images were first obtained in the supine unloaded position. The patient was then tilted to a vertical standing position and identical lumbar spine images were obtained.

MR image analysis

Lumbar lordotic angle, lumbosacral angle, mid sagittal spinal canal diameter, intervertebral disk height, and presence of spondylolisthesis were evaluated in sagittal hybrid contrast enhancement (HYCE) images at the level of intervertebral disks of L2/L3 to L5/S1 in both supine and upright positions. The thickness of ligamentum flavum is evaluated in axial HYCE images. The presence of spinal nerve root compression was evaluated in all MRI planes. Images evaluation was performed by a second-year fellow in the Advanced Body Imaging and one musculoskeletal radiologist with 26-year experience by consensus agreement in presence or absence of nerve root compression without blinding to the clinical data to simulate the real routine clinical practice.

The following parameters were taken into account[12]:

1. Lumbosacral angle measured by using two tangent lines along anterior cortex of the L5 and S1 vertebral bodies (Figure 1A).
2. Lumbar lordotic angle measured by using two tangent lines along superior endplate of L1 and inferior endplate of L5 (Figure 1B).
3. Spinal canal diameter measured in mid sagittal image at each L2/L3 to L5/S1 disk levels, using horizontal distance from posterior surface of the disk to anterior surface the interspinous ligament (Figure 1C).
4. Ligamentum flavum thickness measured in axial HYCE image, using the line perpendicular to bony cortex of the lamina (Figure 1D).

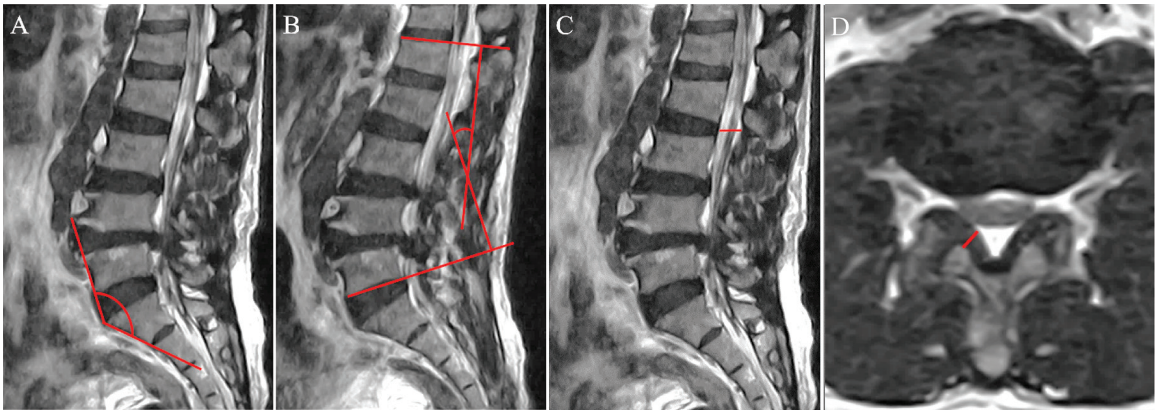

Figure 1. HYCE MRI in sagittal plane with measurement. (A) lumbosacral angle, (B) lumbar lordotic angle, (C) AP diameter of spinal canal, and (D) thickness of ligamentum flavum in axial plane.

Data and statistical analysis

The continuous variables were test for normal distribution with Shapiro and Wilk test. For normally distributed continuous data, mean and standard deviation were presented. For non-normally distributed data, median and range were documented. Categorical data were analyzed and elaborated as frequency and percentage.

For comparisons between supine MRI and weight-bearing MRI data, paired t-test and McNemar's chi-square test were performed for normally distributed continuous variables, and categorical data, respectively. For non-normally distributed data, the comparisons were performed using Wilcoxon sign-rank test.

All statistical analyses were performed using Stata, version 14.0 (StataCorp LP, College Station, TX, USA). Significant p-value was set as less than 0.05.

Sample size calculation

For alpha error 0.05, power of the study 0.8, mean spinal canal diameter of L5 level in supine position MRI from a pilot study is 11.2 mm, and standard deviation 2.2 mm, the clinical difference of spinal canal diameter of the same level in the weight-bearing MRI is 0.8 mm, the sample size was 62.

Results

Eighty-six patients were included in this study. The average age at investigation was 49.3±13.0. Forty-seven percent of the cases were male. The average body mass index (BMI) was 23.6 kg/m². About 77.4% had back pain radiating into leg, whereas 22.6% had back pain alone. The average upright angle performed was 82 degrees (Table 1).

Table 1. Baseline characteristics

Variables	n=86
Age (year); mean±SD	49.3±13.0
Male; n (%)	40 (46.5)
Height (cm); mean±SD	164.1±7.6
Body weight (kg); mean±SD	63.2±11.0
BMI (kg/m^2); mean±SD	23.6±2.9
Back pain with radiation into leg; n (%)	65 (75.6)
Upright angle (degree); mean±SD	82.5±2.1

SD=standard deviation; BMI=body mass index

Table 2. Comparison between supine and weight-bearing MRI parameters

Parameters	MRI; mean±SD		p-value
	Supine	Upright	
Lumbar lordotic angle (degree)	24.8±11.0	34.6±14.0	<0.001*
Lumbosacral angle (degree)	128.9±10.6	130.0±12.1	0.035*

SD=standard deviation; MRI=magnetic resonance imaging

* p<0.05 is statistically significant

The lumbar lordotic angle and lumbosacral angle were statistically significantly increased in weight-bearing position (Table 2).

When compared for baseline characteristics between unchanged and changed number of the nerve root compression with weight-bearing MRI (Table 3), the younger group, mean age 45.6 years, had a significant unchanged number of nerve root compression, whereas the older group, mean age 54.3 years, showed a significant changed number of nerve

Table 3. Comparison of baseline characteristics between unchanged and changed number of the nerve root compression after weight-bearing MRI

Baseline characteristics	Nerve root compression; mean±SD		p-value
	Unchanged (n=51)	Changed (n=35)	
Age (years)	45.6±12.3	54.3±12.4	0.022*
Male; n (%)	24 (47.1)	16 (45.7)	1.000
Height (cm)	165.6±7.9	161.4±6.8	0.178
Body weight (kg)	62.9±11.9	63.7±9.9	0.791
Body mass index (kg/m^2)	24.0±3.4	23.0±2.1	0.387
With radiating symptom**; n (%)	37 (72.5)	28 (80.0)	0.792
Without radiating symptom***; n (%)	14 (27.5)	7 (20.0)	0.792
Upright angle (degree)	82.4±1.8	82.6±2.5	0.574
Lumbar lordotic angle (degree)	25.0±22.1	24.7±12.4	0.905
Lumbosacral angle (degree)	128.8±9.7	129.0±12.0	0.936

SD=standard deviation

* p<0.05 is statistically significant, ** With radiating symptom (n=65), *** Without radiating symptom (n=21)

root compression (p=0.022). Forty-three percent (28 from 65) of the group with radiating symptom showed changed number of nerve root compression, whereas 33% (7 from 21) of the group without radiating symptom did, but without statistical significance. On the other hand, 80% of the patients who had changed nerve root compression with weight-bearing MRI had radiating symptom, also without statistical significance.

At L2/L3 intervertebral disk level

Two MRI parameters were significantly decreased in weight-bearing position, the spinal canal diameter and the intervertebral disk height (Table 4). One patient revealed spondylolisthesis at the L2/L3 level only in the weight-bearing position. However, there was no statistical difference in the presence and grading of spondylolisthesis.

At L3/L4 intervertebral disk level

The presence of spinal nerve root compression was significantly different, and the number of nerve root compression was significantly increased (Table 4). One patient revealed retrolisthesis at the L3/L4 level only in the weight-bearing position, but there was no statistical difference in the presence and grading of spondylolisthesis.

In L4/L5 intervertebral disk level

Spinal canal diameter and intervertebral disk height decreased, with increased number of nerve root compression. Those were significant. The presence of spondylolisthesis and its grading was also significant (Table 5). Three patients revealed (anterior) spondylolisthesis, and one patient revealed retrolisthesis, at the L4/L5 level only in the weight-bearing position. Two patients had their spondylolisthesis changed from grade 1 to grade 2 in the weight-bearing position.

At L5/S1 intervertebral disk level

Spinal canal diameter and intervertebral disk height decreased, with increased number of nerve root compression. All were significant. The presence of spondylolisthesis and its grading was not significant at this level (Table 5). However, three patients showed (anterior) spondylolisthesis only in the weight-bearing position. One patient had the spondylolisthesis changed from grade 1 to grade 2 in the weight-bearing position.

Multiple regression analysis was not performed due to the independent data of each parameter among various levels.

Discussion

The present study found a significant difference between age group with unchanged and changed number of nerve root compression with weight-bearing MRI (Table 3). Information that has not been mentioned before, to the authors' knowledge. The younger group, mean age 45.6 years, had significant unchanged number of nerve root compression, whereas the older group, mean age 54.3 years, showed significant changed number of nerve root

Table 4. Comparison between supine and weight-bearing MRI parameters at L2/L3 and L3/L4 levels

Parameters	MRI; mean±SD		p-value
	Supine	Upright	
L2/L3 level			
Flaval ligament thickness (mm)	2.6±0.7	2.5±0.6	0.164
Spinal canal diameter (mm)	15.9±2.8	15.2±3.2	0.018*
Root compression; n (%)	1 (1.3)	3 (3.6)	0.157
Number of root compression; median (range)	0 (0 to 2)	0 (0 to 4)	0.157
Intervertebral disk height (mm)	8.7±1.6	8.4±1.6	0.024*
Spondylolisthesis; n (%)	4 (4.7)	5 (5.8)	0.317
Spondylolisthesis type; n (%)			0.317
• None	82 (95.4)	81 (94.2)	
• Anterior	0 (0.0)	0 (0.0)	
• Posterior	4 (4.7)	5 (5.8)	
Spondylolisthesis grade; n (%)			0.317
• None	82 (95.2)	81 (94.2)	
• Grade 1	4 (4.7)	5 (5.8)	
• Grade 2	0 (0.0)	0 (0.0)	
L3/L4 level			
Flaval ligament thickness (mm)	2.8±1.0	2.8±1.0	0.490
Spinal canal diameter (mm)	14.5±2.9	13.9±3.2	0.050
Root compression; n (%)	7 (8.1)	13 (15.1)	0.014*
Number of root compression; median (range)	0 (0 to 2)	0 (0 to 4)	0.008*
Intervertebral disk height (mm)	9.9±2.2	9.9±2.1	0.663
Spondylolisthesis; n (%)	3 (3.5)	4 (4.7)	0.317
Spondylolisthesis type; n (%)			0.317
• None	83 (96.5)	82 (95.4)	
• Anterior	2 (2.3)	2 (2.3)	
• Posterior	1 (1.2)	2 (2.3)	
Spondylolisthesis grade; n (%)			0.317
• None	83 (96.5)	82 (95.4)	
• Grade 1	3 (3.5)	4 (4.6)	
• Grade 2	0 (0.0)	0 (0.0)	

SD=standard deviation; MRI=magnetic resonance imaging; L=lumbar

* p<0.05 is statistically significant

compression. This may be explained by advanced degree of degenerative change with increased instability of the lumbar spine in increasing age. This may imply that weight-bearing MRI should be beneficial in patients over 50 years of age, particularly, when the study in supine position did not explain the symptoms.

The present study also revealed that 43% (28 from 65) of the group with radiating symptom had changed number of nerve root compression with weight-bearing MRI. Although the result did not show statistical significance, it may help clinicians in the real practice not to miss existing problem (Figure 2).

Significant difference of multiple MRI parameters between weight-bearing and supine positions in patients with low back pain were also revealed. One of which was significantly increased lumbar lordotic angle in weight-bearing position. Splendiani et al[13] in their study of 4,305 patients using similar MR machine as in the present study, showed significantly higher lumbar lordotic angle in weight-bearing position. This finding may be the results of activation

Table 5. Comparison between supine and weight-bearing MRI parameters at L4/L5 and L5/S1 levels

Parameters	MRI; mean±SD		p-value
	Supine	Upright	
L4/L5 level			
Flaval ligament thickness (mm)	3.0±0.9	3.0±1.2	0.729
Spinal canal diameter (mm)	11.1±3.6	10.2±3.5	0.007*
Root compression; n (%)	28 (32.6)	40 (46.5)	0.001*
Number of root compression; median (range)	0 (0 to 4)	0 (0 to 4)	<0.001*
Intervertebral disk height (mm)	10.0±2.3	9.6±2.3	0.008*
Spondylolisthesis; n (%)	7 (8.1)	11 (12.8)	0.046*
Spondylolisthesis type; n (%)			
• None	79 (91.9)	75 (87.2)	0.046*
• Anterior	5 (5.8)	8 (9.3)	
• Posterior	2 (2.3)	3 (3.5)	
Spondylolisthesis grade (%)			
• None	79 (91.9)	75 (87.2)	0.046*
• Grade 1	7 (8.1)	9 (10.5)	
• Grade 2	0 (0.0)	2 (2.3)	
L5/S1 level			
Flaval ligament thickness (mm)	2.5±1.0	2.5±1.1	0.905
Spinal canal diameter (mm)	10.2±3.0	9.7±3.1	0.040*
Root compression; n (%)	19 (22.4)	27 (31.8)	0.0201*
Number of root compression; median (range)	0 (0 to 4)	0 (0 to 4)	0.001*
Intervertebral disk height (mm)	9.6±2.4	8.9±2.5	<0.001*
Spondylolisthesis; n (%)	10 (11.6)	13 (15.2)	0.180
Spondylolisthesis type; n (%)			0.180
• None	76 (88.4)	73 (84.9)	
• Anterior	4 (4.7)	7 (8.1)	
• Posterior	6 (7.0)	6 (7.0)	
Spondylolisthesis grade; n (%)			0.180
• None	76 (88.4)	73 (84.9)	
• Grade 1	10 (11.6)	12 (13.9)	
• Grade 2	0 (0.0)	1 (1.2)	

SD=standard deviation; MRI=magnetic resonance imaging; L=lumbar

* p<0.05 is statistically significant

of abdominal and paraspinal muscles from supine to weight-bearing position and osteoarthritic change of the facet joints, allowing hypermobility of the lumbosacral column[13,19,20].

Slightly increased lumbosacral angle is also observed in weight-bearing compared to supine position. Although the difference is minimal, it showed statistical significance.

Spinal canal diameter significantly decreased in weight-bearing position at all intervertebral disk levels, except at L3/L4 where there was no significance. Part of the reason relates to the supine patient positioned with hips and knees flexed, resulting in relative spinal flexion. This maximizes the dimensions of spinal canal and exit foramina, thus reducing the magnitude of any stenotic effect[7]. Lau et al[16] conducted a prospective study in 70 patients with similar MR machine as in the present study and revealed that findings in weight-bearing MRI correlated significantly and better than those in supine MRI, with claudication symptoms. Schmid et al[15] conducted a prospective study in 12 asymptomatic

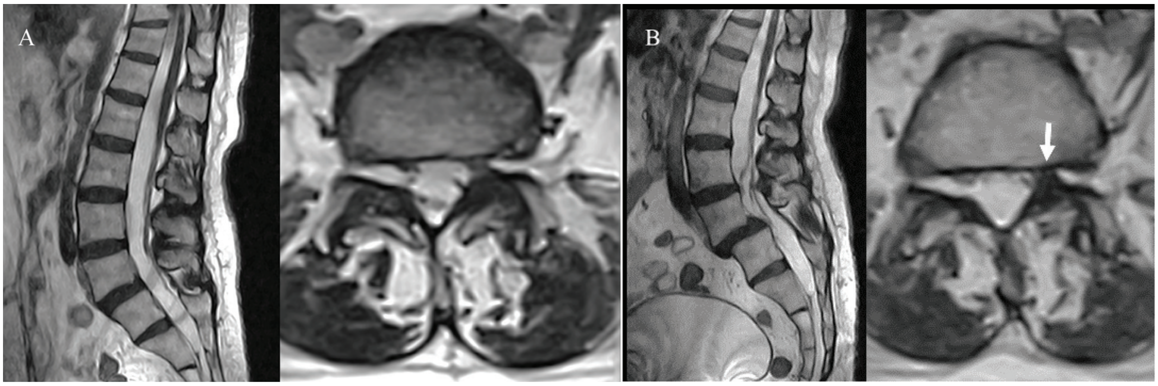

Figure 2. Sagittal and axial HYCE MRI in supine position (A) and weight-bearing position (B) of a 55-year-old female patient with back pain radiated to left leg. There is progression of spondylolisthesis at level of L5/S1 from grade 1 in supine position to grade 2 in weight-bearing position, with progressive left L5 traversing nerve root compression (white arrow in B).

volunteers and showed no statistical difference in anteroposterior (AP) diameter of spinal canal between weight-bearing and supine position. This may suggest that decreased AP diameter of the spinal canal is one factor contributing to the symptom.

Intervertebral disk height decreased in weight-bearing compared to supine position at all levels except L3/4 and showed significance in majority. This corresponds to the study of Tarantino et al[12] who used similar MR machine as in the present study and explained by physiologic axial loading on to the intervertebral disks.

Presence of spinal nerve root compression increased from L2/L3 downward. The weight-bearing position can detect nerve root compression undetectable in supine position in 28 patients (43% of patients with radiating symptom) (Figure 2). Number of spinal nerve root compression, due to non-symmetrical distribution, showed median value as zero in all levels, but significantly shown from L3/L4 downward. This finding can explain that some patients having symptom or more symptom in weight-bearing position and suggested additional benefits of weight-bearing scanning in patients with low back pain.

The authors found that nine of 86 (10.5%) patients showed new appearance of spondylolisthesis in weight-bearing position, with statistical significance at level of L4/L5. The present study result corresponded to Splendiani et al[13] who addressed that standing position can detect new appearance of spondylolisthesis in 9.5% of cases. Seven patients in 86 (8.1%) in the present study showed increased degree of spondylolisthesis in weight-bearing position, which may reflect patients' spinal instability. This is similar to Kubosch et al[14] who confirmed from their data that increased axial loading on the spinal column led to progressive listhesis of the vertebrae. Conversely, Hansen et al[21] reported no difference in number of spondylolisthesis between positions.

The present study included patients with and without sciatica, which may be different in the nature of the disease and treatment. The authors did not divide patients into two groups and did not match the level of nerve root compression detected in MRI to the clinically indicated level. One reason is because this was a routine-to-research study, the information in the request form was limited, such as back pain, or back pain radiated to right, left, or both legs. The request forms seldom indicated the suspicious level of nerve root compression. Another reason was due to the previous reports in the literature. Hancock et al[22] reported that they did not find evidence to support the accuracy of individual tests from the neurological examination in identifying the level of disk herniation on MRI. The outcome of multiple test findings was slightly more accurate but did not produce high sensitivity and specificity for level of disk herniation. The neurologists' overall impression was moderately accurate in identifying the level of disk herniation. Tawa et al[23] stated that MRI-visible nerve root compression does not necessarily mean radiculopathy, and vice-versa[24,25]. The clinicians should always correlate the findings on MRI with the patients' history and clinical presentation to achieve clinical decision making. Peterson et al[26] performed systematic review concerning clinical classification of low back pain to evaluate the best evidence diagnostic rules. They were able to construct promising clinical diagnostic rules but the accuracy of such findings in a primary care setting has yet to be confirmed.

Certain limitation in the present study should be acknowledged. The first limitation is the lack of inter- and intra-reader agreement. Hansen et al in 2017[21] studied 56 patients with degenerative spinal disease who underwent weight-bearing MRI and reported fair-to-substantial inter-reader and intra-reader reliability. The present study aimed to retrospectively evaluate the difference between MR findings in weight-bearing compared to supine position in overall by consensus agreement of two readers. Therefore, the inter- and intra-reader reading may be in the future research concerning more specific research question. The second limitation is that, currently, there is no evidence-based recommendation regarding the protocol and interpretation of MRI in weight-bearing position, even in common entity such as degenerative spinal diseases. Further studies are needed to standardize the protocol and to guide how to interpret these MRI parameters with positional changes.

Conclusion

With weight-bearing MRI, multiple significant position-dependent changes included lumbar lordotic angle, lumbosacral angle, thickness of the ligamentum flavum, spinal canal diameter, intervertebral disk height, presence of spinal nerve root compression, and presence of spondylolisthesis. Older age group (over 50 years of age) showed significant changed (increased) number of nerve root compression. Forty-three percent of patients with radiating symptom had changed number of nerve root compression, and 10% of all patients showed new appearance of spondylolisthesis. Although such results did not show statistical significance, it may help clinicians not to miss existing problem. The weight-bearing MRI has additional value in older age group and in patients with radiating back pain unexplained by MRI studies in supine position.

What is already known in this topic?

Weight-bearing MRI can demonstrate certain findings undetected in supine MRI, which may explain the patients' symptoms.

What this study adds?

Older age group (over 50 years of age) showed significant changed (increased) number of nerve root compression compared to younger group. To the authors' knowledge, this has not been described before. In addition, this present study was performed with the first weight-bearing MR machine established in Thailand.

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Conflicts of interest

The authors declare no conflict of interest.

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